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From Flower to Fork: How Fruit Science is Reshaping Agriculture and Diets?

Article ID: 74500

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Abstract

Fruits are far more than sweet snacks; they are biologically engineered packages that protect seeds, attract dispersers, and deliver nutrients to humans. This article explains the science behind fruit development, ripening, and quality, and shows how modern research is helping farmers reduce losses, improve flavor, and use fruit by-products more sustainably. By linking basic plant physiology with postharvest technology and nutrition, fruit science is becoming a key tool for building more resilient food systems and healthier diets in India and beyond.

Introduction

When you bite into a ripe mango or a crisp apple, you are experiencing the final act of a carefully timed biological program that begins in the flower and ends on your plate. After pollination, the ovary swells and cells divide while protective compounds guard the developing seeds; then, as the fruit matures, hormones, especially ethylene in climacteric fruits like banana, mango, and tomato trigger chlorophyll breakdown, pigment synthesis, starch-to-sugar conversion, and cell-wall softening (Singh *et al.*, 2015). Environmental signals such as water availability, temperature, and salinity further shape color, sweetness, acidity, aroma, and texture by influencing hormone pathways and gene expression (Zhang *et al.*, 2026), while postharvest innovations in packaging, controlled atmospheres, and low-cost cooling help reduce water loss and decay (Kumar and Rao, 2024). At the same time, fruit by-products once treated as waste are now valued as sources of fiber, antioxidants, and natural colorants (Patel and Sharma, 2023), and higher fruit intake is consistently linked with lower risk of heart disease, some cancers, and metabolic disorders (Singh and Mishra, 2015). Looking ahead, genomics, gene editing, sensors, and AI are enabling smarter breeding, real-time quality monitoring, and compact plant architectures (Lee *et al.*, 2025; Science Daily, 2026), aiming to deliver fruit that tastes better, lasts longer, requires fewer inputs, and generates less waste from farm to fork.

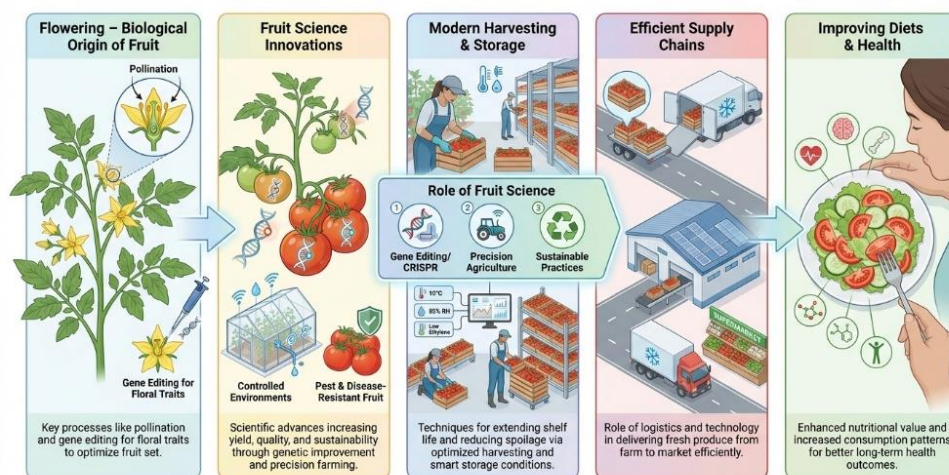
The Journey from Flower to Fruit

Fruit development starts with pollination and fertilization in the flower. The fertilized ovule becomes the seed, while the surrounding ovary tissue transforms into the fruit. This transformation involves three overlapping phases:

1. **Cell division phase** - Rapid formation of new cells determines the final size and shape of the fruit.
2. **Cell expansion phase** - Cells enlarge, accumulating water, sugars, acids, and storage compounds.
3. **Maturation and ripening phase** - Biochemical changes produce color, flavor, aroma, and soft texture.

During early development, fruits often contain high levels of organic acids and bitter compounds, which discourage animals from eating them before the seeds are mature. As ripening begins, these defenses are reduced, and attractive traits—sweetness, color, and aroma—are enhanced to encourage seed dispersal.

From Flower to Fork: How Fruit Science Is Reshaping Agriculture and Diets



The Science of Ripening: Nature's Perfect Timing

Ripening is controlled by a network of hormones and genes. In climacteric fruits (banana, mango, tomato, papaya), a burst of ethylene acts as the main ripening signal. Ethylene triggers:

1. Breakdown of chlorophyll and synthesis of pigments (carotenoids, anthocyanins)
2. Conversion of starch to soluble sugars (increased sweetness)
3. Degradation of pectin and other cell wall components (softening)
4. Production of volatile compounds (aroma)

In non-climacteric fruits (grapes, citrus, strawberries), ripening is less dependent on ethylene and more influenced by abscisic acid (ABA) and other signals. For postharvest management, controlling ethylene is key. Techniques such as low-temperature storage, modified atmosphere packaging, and ethylene scrubbers slow down ripening and extend shelf life. However, if ripening is delayed too much, flavor and aroma may not fully develop, leading to bland fruit. The challenge is to find the right balance between longevity and quality.

Production Technologies

Fruit quality is not determined by genetics alone. Water availability, salinity, heat, and cold can all reshape fruit color, sweetness, acidity, aroma, texture, and antioxidant activity (Zhang *et al.*, 2026). For example:

1. Mild water stress can increase sugar concentration and color intensity in grapes and tomatoes.
2. High temperatures can accelerate ripening but reduce acidity and aroma complexity.
3. Salinity stress may boost certain antioxidants but reduce fruit size and yield.

Understanding these responses helps farmers adjust irrigation, mulching, shading, and nutrient management to optimize both yield and quality. It also guides breeders in selecting varieties that maintain good quality under changing climate conditions.

Postharvest Innovations: Reducing Loss, Adding Value

A significant portion of fruit produced in India is lost after harvest due to poor handling, inadequate cold chains, and limited processing capacity. Postharvest research focuses on:

1. **Improved packaging:** Using liners, wraps, and boxes that reduce water loss and physical damage.
2. **Controlled and modified atmosphere storage:** Adjusting oxygen and carbon dioxide levels to slow respiration and ripening.
3. **Low-cost cooling:** Evaporative coolers and small cold rooms for smallholder farmers.
4. **Minimal processing:** Cutting, peeling, and packaging fresh-cut fruit for urban markets.

From Waste to Wealth: Using Fruit By-Products

Fruit processing generates large amounts of by-products: peels, seeds, cores, and pomace. Traditionally, these were discarded or used as low-value animal feed. Today, they are recognized as rich sources of:

1. **Dietary fiber** - for bakery products, snacks, and functional foods.
2. **Antioxidants and polyphenols** - for beverages, supplements, and natural preservatives.
3. **Pectin and starch** - for gelling agents, thickeners, and biodegradable materials.
4. **Natural colorants and flavors** - for the food and cosmetic industries.

Extracting and stabilizing these compounds requires careful processing to maintain their activity and safety. Still, the potential is huge: turning waste into income while reducing environmental impact. This approach aligns with broader efforts to valorize agro-wastes, such as banana pseudostem fiber for textiles and composites.

Nutrition and Health: Why Fruit Matters

Fruit is a cornerstone of a healthy diet. Regular consumption is associated with:

1. Lower risk of cardiovascular disease and hypertension
2. Better weight management and glycemic control
3. Reduced risk of certain cancers and chronic inflammation

These benefits come from the synergy of fiber, vitamins, minerals, and bioactive compounds. For example, citrus fruits provide vitamin C and flavonoids; berries offer anthocyanins; mangoes and papayas supply carotenoids and digestive enzymes. Public health messages encouraging “five servings of fruits and vegetables a day” are backed by strong evidence. Fruit science supports this by improving the availability, affordability, and quality of fruit in the diet.

The Future of Fruit: Genes, Sensors, and Data

New technologies are accelerating progress in fruit science:

1. **Genomics and gene editing** help identify and modify genes controlling ripening, flavor, and stress tolerance. Recent work has even created compact plant architectures suitable for high-density farming (Lee *et al.*, 2025).
2. **Sensors and IoT** monitor temperature, humidity, and ethylene in storage and transport, enabling real-time adjustments.
3. **AI and imaging** detect early signs of disease, bruising, or over-ripening before humans can see them, improving sorting and grading.

These tools are not just for large companies; low-cost sensors and mobile apps are increasingly accessible to smallholders and cooperatives. The goal is smarter, more precise fruit production and handling that reduces losses and improves quality.

Conclusion

Fruit science sits at the intersection of plant biology, postharvest technology, nutrition, and sustainability. By decoding how fruits develop, ripen, and respond to their environment, researchers are helping to reduce losses, improve flavor and nutrition, and make better use of fruit by-products. For agriculture and food systems in India, this means more resilient supply chains, higher farmer incomes, and healthier diets. The next wave of progress will come from combining traditional knowledge with modern tools—genetics, sensors, and data—to ensure that the fruit reaching our plates is not only abundant, but also tasty, nutritious, and sustainably produced.

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From Peel to Profit: Turning Fruit Waste into Food, Feed, and Future Materials

Article ID: 74501

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Abstract

India is among the top producers of banana, mango, citrus, papaya, and guava. However, 30-50% of fruit biomass often ends up as waste during harvest, processing, and household use. Peels, seeds, cores, and pomace are frequently discarded, causing odor, pest, and water-pollution problems. At the same time, these materials are rich in dietary fiber, polyphenols, carotenoids, pectin, and minerals. Treating fruit waste as a resource can reduce pollution, create rural jobs, and support a circular, low-waste food system.

Introduction

Fruit waste arises on-farm (rejected fruits), during processing (peels, seeds, pomace), and at household/market levels (trimmings, spoiled fruits). In banana, up to 80% of plant biomass (pseudostem, leaves, peels) may be underused. In citrus, around one-quarter of fruit weight can become peel and pomace.

Proper valorization can:

- Reduce disposal costs and environmental hazards
- Provide low-cost raw materials for food and non-food industries
- Generate extra income for farmers and small enterprises
- Improve nutrition by adding fiber and bioactives to everyday foods

Key Pathways to Valorization

1. Direct Use as Food and Feed:

- Banana peel powder in biscuits, cakes, and breads increases fiber and minerals.
- Mango peel and pomace improve texture and antioxidant content in bakery products.
- Citrus peel is used as candied peel, dried spice, or flavoring agent.
- Fresh or ensiled peels and pomace serve as animal feed after safety checks.

These options need basic equipment (washers, dryers, grinders) and suit small-scale units.

2. Extraction of Bioactive Compounds: Fruit wastes are rich in polyphenols, flavonoids, carotenoids, and pectin. Green extraction methods (water, ethanol, ultrasound, microwave) are preferred for food-grade products. Extracts can be used in functional foods, nutraceuticals, natural preservatives, and cosmetics.

Biodegradable Packaging and Films

Pectin- and fiber-based films from citrus pomace act as edible coatings or biodegradable wraps with antioxidant and antibacterial properties. Composite films with fruit peel extracts show potential for active packaging that extends shelf life and reduces dependence on petroleum-based plastics.

Biofertilizers, Biochar, and Soil Amendments

- Compost and vermicompost from fruit peels supply organic matter and nutrients.
- Liquid extracts and biofertilizers from banana peels provide potassium, calcium, and growth-promoting compounds.
- Biochar from fruit waste improves soil water retention and carbon sequestration.

For horticulture farmers, converting local fruit waste into soil amendments can lower input costs and improve soil health.

Advanced Applications

Adsorbent materials from banana peel can remove dyes and heavy metals from wastewater. Biopolymers and hydrogels from pectin and cellulose are being tested for drug delivery and wound dressings. Many of these are at research or pilot stage but show broad potential.

Case Examples

1. Banana: Up to 80% of banana plant biomass may be underused. Uses include peel powder for bakery, pectin and fiber for food and packaging, biofertilizers and biochar for soil, and adsorbents for wastewater treatment. Small-scale peel powder or biofertilizer units linked to farmer groups can have significant impact.

2. Citrus: Citrus peel and pomace are rich in essential oils, pectin, and flavonoids. Applications include essential oils and flavors for food and cosmetics, pectin and fiber concentrates for jams and bakery, active packaging films, and animal feed.

3. Mango: Mango peels and seed kernels contain polyphenols, carotenoids, and starch. Uses include antioxidant-enriched flours for baked goods, natural colorants and flavors, and starch from seed kernels for food and industry.

Benefits and Challenges

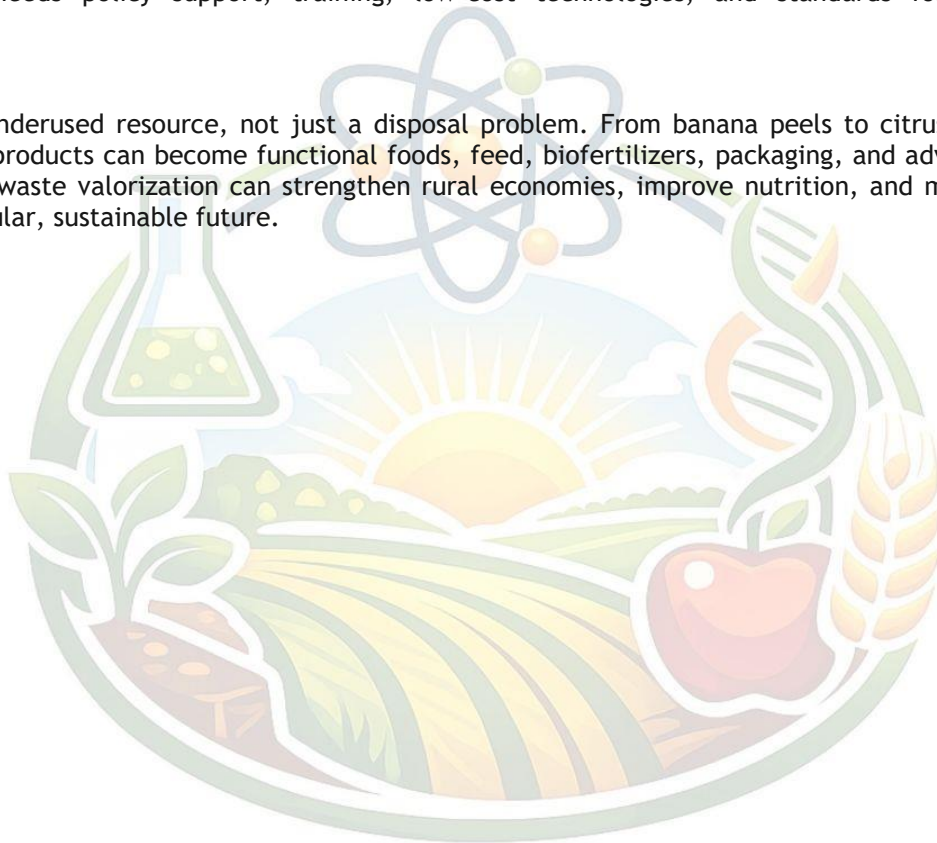
1. Benefits: New revenue from sale of powders, extracts, compost, or biochar; rural employment in collection, processing, and marketing; improved nutrition through fortified foods; less waste in landfills and water bodies; lower greenhouse gas emissions.

2. Challenges: Collection and logistics for scattered, perishable waste; quality and safety (pesticide residues, microbial load); access to appropriate technology and skills; stable market linkages and fair pricing.

Addressing these needs policy support, training, low-cost technologies, and standards for fruit-waste-derived ingredients.

Conclusion

Fruit waste is an underused resource, not just a disposal problem. From banana peels to citrus pomace and mango residues, these by-products can become functional foods, feed, biofertilizers, packaging, and advanced materials. For India, scaling fruit waste valorization can strengthen rural economies, improve nutrition, and move the food system toward a more circular, sustainable future.



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From Agricultural Residues to Regenerative Agriculture: An FPO-Based Model for Farmer Income, Climate Resilience and Sustainable Rural Economy

Article ID: 74502

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Abstract

Agricultural residues are often considered waste after harvesting; however, with scientific management, organized value chains, and proper market linkages, these residues can become valuable resources for sustainable development.

This article presents an FPO-based model where farmers, Farmer Producer Organisations (FPOs), and industries collaborate to convert suitable non-feeding agricultural waste into an economic opportunity. The model demonstrates how agricultural residue aggregation, biomass utilization, and industrial linkages can support regenerative agriculture, circular economy principles, climate resilience, and additional income generation for farmers.

The case study of Jaitaran Farmer Producer Company Limited, Rajasthan, highlights how an organized FPO approach can connect farmers with industrial demand and create sustainable rural business opportunities.

Keywords: Regenerative Agriculture, Agricultural Residue Management, Farmer Producer Organisation, Circular Economy, Climate Resilience, Sustainable Supply Chain, Farmer Income.

Introduction

Agriculture plays a vital role in India's economy and rural livelihoods. Along with crop production, agriculture also generates significant quantities of crop residues such as stalks, straw, husks, and other biomass materials.

Traditionally, many agricultural residues have been considered waste and are often burned or disposed of without recognizing their economic potential. This creates environmental challenges and results in the loss of valuable resources.

Regenerative agriculture provides an opportunity to transform this approach by promoting sustainable resource management, improving ecosystem health, and creating additional income opportunities for farmers.

Agricultural Residues: From Waste to Resource

Agricultural residues should not always be viewed as waste. A scientific approach is required to identify:

- Which residues should remain in the field for soil health?
- Which surplus residues can be collected and utilized?
- How these residues can create economic value?

Suitable agricultural residues can be utilized for:

- Biomass applications
- Renewable energy
- Industrial purposes
- Bio-based products
- Circular economy initiatives

This approach converts agricultural waste management into a value creation opportunity.

Non-Feeding Agricultural Waste Management

Not all agricultural residues are suitable for animal feeding. Some residues can generate higher value through alternative applications.

Non-Feeding Agricultural Waste Management focuses on:

- Identification of suitable residues
- Scientific collection systems
- Aggregation and quality management
- Market linkage development

Through proper systems, agricultural residues can become valuable raw materials for industries.

Role of Farmer Producer Organisations (FPOs)

Individual farmers often face challenges in collecting, storing, transporting, and marketing agricultural residues.

Farmer Producer Organisations provide an effective solution by organizing farmers and developing collective value chains.

The FPO-based model works as:

Farmers



Collection



Aggregation



Quality Management



Industry Linkage



Farmer Income:

- a. FPOs support farmers through:
- b. Farmer mobilization
- c. Organized aggregation
- d. Transparent measurement systems
- e. Market connectivity
- f. Business coordination.

Agriculture and Industry Partnership

Agriculture and industry partnerships can create new opportunities for rural development.

Industries require reliable biomass resources, while farmers generate agricultural residues. FPOs act as a bridge between these two sectors.

This partnership supports:

- a. Reduction in residue burning
- b. Sustainable resource utilization
- c. Rural employment generation
- d. Additional farmer income
- e. Circular supply chains

Real World Case Study: Jaitaran Farmer Producer Company Limited, Rajasthan

Jaitaran Farmer Producer Company Limited, Rajasthan, represents a practical example of an FPO-based agricultural residue value chain model.

The FPO has developed a system to connect farmers with industrial demand through organized agricultural residue collection, aggregation, and supply management.

The value chain model:

Farmers



Agricultural Residues



Jaitaran FPO



Collection & Aggregation



Industrial Buyer (Cement Sector)



Biomass Utilization



Additional Farmer Income

According to available FPO business information, this initiative has achieved approximately INR 18 crore business activity.

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The model has created additional income opportunities for farmers by converting agricultural residues into a commercially valuable resource.

Impact of the FPO Model

Farmers:

- Additional income opportunities
- Better market access
- Improved resource utilization

FPO:

- New business opportunities
- Stronger farmer engagement
- Sustainable value chain development

Industry:

- Organized biomass supply
- Efficient resource utilization

This creates a shared value model: Farmer + FPO + Industry = Sustainable Rural Development

Climate Resilience and Regenerative Agriculture

Agricultural residue management contributes to climate-resilient agriculture by improving resource efficiency and reducing environmental pressure.

The approach supports:

- Sustainable farming systems
- Reduced residue burning
- Circular economy practices
- Climate action

However, soil health must remain a priority. Not all residues should be removed from farms because some contribute to soil organic matter and nutrient cycling.

The principle should be:

“Keep what the soil needs; utilize what is surplus and suitable.”

Future Scope

The agricultural residue-based FPO model can be replicated in different regions by developing:

1. Residue mapping
2. Farmer awareness
3. Collection infrastructure
4. Quality management systems
5. Industry partnerships
6. Long-term market linkages

This can create a “Residue to Revenue” model across agricultural regions.

Conclusion

Agricultural residues are not only waste materials. With the right institutional support, technology, and market linkage, they can become a pathway for farmer prosperity, climate resilience, and sustainable rural development.

The Jaitaran Farmer Producer Company Limited case demonstrates how FPOs can play a key role in developing regenerative and circular agricultural systems by connecting farmers with industries.

Agricultural residue is not the end of a crop cycle; it can become the beginning of a new economic opportunity for farmers.

AGRICULTURE & FOOD

Field Implementation Photos



Figure: Agricultural residue aggregation, loading and biomass value chain activity.



Figure: Agricultural residue aggregation, loading and biomass value chain activity.



Figure: Agricultural residue aggregation, loading and biomass value chain activity.



Figure: Agricultural residue aggregation, loading and biomass value chain activity.



Figure: Agricultural residue aggregation, loading and biomass value chain activity.



Figure: Agricultural residue aggregation, loading and biomass value chain activity.

A Living Soil Needs More Than a Fertilizer: A Popular Article on Conservation Agriculture

Article ID: 74503

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Abstract

This article addresses how conventional farming's heavy reliance on synthetic chemical fertilizers degrades soil health, leading to widespread compaction, acidification, and disrupted microbial life. To break this unsustainable cycle and prevent environmental nutrient losses, I outline the implementation of Conservation Agriculture through three core practices: minimal soil tillage, permanent organic ground cover, and crop diversification. By combining these ecological habits with the 4R Nutrient Stewardship approach, I demonstrate how farmers can gradually restore subterranean biodiversity, improve water retention, and build a resilient, long-term productive farming system despite initial transition challenges.

Every season, millions of farmers look at their fields, shake their heads, and worry that their soil has "gone weak." To fix it, they do what conventional farming has taught them for decades, they pour a little more synthetic chemical fertilizer into the dirt. Yet, even after adding more fertilizer, the harvest often refuses to improve and sometimes gets worse.



Figure 1: Crops struggling against degraded, heavily compacted soil that has lost its biological strength.

The strange part is that while we keep feeding our crops, the soil beneath them is slowly losing its strength.

We often think of soil as nothing more than the ground that holds our crops at a place where we add fertilizer and expect plants to grow. But soil is much more than that. Beneath every field is a living world that works quietly to keep the soil fertile and productive. A single handful of healthy soil can contain billions of microorganisms, with earthworms,

burrowing animals and other tiny creatures. Together, they form a busy community beneath our feet, breaking down dead plant material, helping the soil hold water, and releasing nutrients that plants need to grow (Figure 2). We may not see this life, but much of what happens above the ground depends on what is happening below it.



Figure 2: Visual breakdown of soil biodiversity, illustrating the relationship between soil flora and soil fauna.

Chemical fertilizers are important for supplying crops with nutrients, but they cannot do the work of the living organisms in the soil. When we depend too heavily on fertilizer alone, we may overlook the organic matter, microbes and natural processes that keep soil healthy. Over time, this can change the soil's chemical and biological balance and leave farmers caught in a cycle where more fertilizer is needed just to maintain the same level of production.

Global research shows that over 60% of agricultural soils now suffer from declining health, and 35% are severely compacted and hard. When we rely too heavily on synthetic inputs, several problems can arise. Heavy and repeated use of chemical fertilizers can make the soil more acidic, disturbing soil microorganisms and affecting the soil's natural balance. At the same time, not all the fertilizer we put into the soil reaches the crop. A significant amount of nitrogen can be lost from the field, either washed away with water or released into the air. In the end, farmers may be paying for fertilizer that never reaches their plants. Some of this lost nitrogen can also be released as nitrous oxide, a powerful greenhouse gas that contributes to climate change.

The problem is not only about what we put into the soil, but also about how much pressure we place on the land. In the hills of Northeast India, for example, Jhum cultivation was traditionally practiced with long fallow periods that gave the soil enough time to recover. Today, with growing populations and less available land, shorter fallow periods can leave the soil with little time to regain its strength.



Figure 3; A recently cleared and burned Jhum field in the hills of Northeast India.

The solution is not to stop feeding crops, but to take care of the soil while feeding the crop. Adding organic materials such as animal manure and compost can improve soil health by increasing microbial activity, adding organic matter, and helping nutrients move naturally through the soil.

Three Habits of a Living Soil

So how do we bring this underground workforce back to life? Conservation Agriculture offers three simple practices that work together to protect the soil. The first is to disturb the soil as little as possible. Every time a plough turns the soil over, it disturbs soil aggregates and the burrow systems created by earthworms and other organisms. Minimal tillage helps preserve this underground architecture and can reduce the rapid breakdown of protected soil organic matter. The second is to keep the soil covered. Leaving soil bare exposes it to the scorching sun, which rapidly drains its moisture and leaves it completely defenseless against heavy rain and erosion. Crop residues or living cover crops act like a blanket, helping keep the soil surface cooler and moist while protecting it from erosion. Finally, farmers can rotate what they grow and increase the plant diversity by mixing two or more crops. Planting the same crop season after season can allow the same pests and diseases to build up and repeatedly draw on the same nutrients. Crop Diversification helps break these cycles and brings a wider variety of roots and residues into the soil.

When Soil Comes Back to Life

When farmers adopt these practices, the changes are not always visible from above, but beneath the surface, life begins to return. With less disturbance and more organic material left on the soil, earthworms, springtails and other soil organisms find better conditions to live and multiply. Earthworms create channels through the soil that improve aeration and water movement, while smaller organisms help break down crop residues and return nutrients to the soil. A healthier soil also provides a better home for beneficial insects and natural predators that can help keep crop pests under control. In this way, protecting the soil does not just protect the crop, but it helps rebuild the whole community living beneath and around it.



Figure 4: The practical workflow of no-till agriculture, showing how seeds are successfully planted and germinated directly through thick, protective surface residue without disturbing the underlying soil structure.

Switching to these practices is not always easy. Farmers may need specialized equipment to sow seeds through crop residues, and controlling weeds can be challenging during the first few seasons. The soil also needs time to respond as its physical structure and biological activity gradually recover. But with proper management, Conservation Agriculture can help build soils that hold more water, resist erosion, support more biological activity and remain productive for longer.

Good soil management also means using fertilizers wisely. The 4R Nutrient Stewardship approach using the Right Source, at the Right Rate, at the Right Time and in the Right Place helps farmers provide crops with the nutrients they need while reducing unnecessary losses.

Synthetic fertilizer has an important place in modern agriculture, but it cannot fix a struggling soil on its own. Chemistry can feed a crop, but it cannot replace the living processes that keep soil healthy. If we want our fields to keep giving season after season, we need to stop treating soil like something we can simply refill, and start treating it as what it truly is: a living system that needs to be cared for.

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AI at the Farm Gate: Digital Innovations for Sustainable and Profitable Agriculture

Article ID: 74504

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Introduction

Agriculture plays a vital role in ensuring food security, generating employment, and supporting economic growth. However, the agricultural sector is increasingly affected by challenges such as climate variability, shortage of farm labour, deterioration of soil health, frequent occurrence of pests and diseases, limited water availability, and increasing costs of agricultural inputs. Addressing these constraints requires the adoption of innovative technologies and improved management practices to enhance farm productivity and sustainability.

Artificial Intelligence (AI) has emerged as an important technology in the development of smart and modern agriculture. It supports farmers in making timely and informed decisions by enabling efficient crop monitoring, input management, weather forecasting, and early identification of pests and diseases. The adoption of AI-driven agricultural technologies can contribute to higher productivity, efficient resource utilization, improved farm profitability, and greater resilience of farming systems to changing climatic conditions.

Role of AI in Agriculture

Artificial Intelligence (AI) plays an important role in enhancing agricultural efficiency by supporting data-driven decision-making and enabling farmers to identify potential problems at an early stage. AI-based systems collect and analyse data from various sources, including agricultural fields, weather stations, satellites, sensors, drones, and mobile applications, to provide timely and reliable recommendations.

AI can be used for crop monitoring and growth assessment, early detection and identification of pests and diseases, soil and nutrient management, efficient irrigation scheduling, weather forecasting, and precision application of fertilizers and pesticides. It also supports yield prediction and market price forecasting, helping farmers make better production and marketing decisions. In addition, AI-based technologies are increasingly being used for livestock monitoring and overall farm resource management. By integrating these applications, AI can improve the efficiency of farm operations, optimize the use of agricultural inputs, reduce unnecessary costs, and contribute to sustainable and profitable farming.

Important AI Tools and Technologies in Agriculture

1. Agricultural Drones: Agricultural drones are unmanned aerial systems designed to support crop monitoring and various farm operations. Equipped with cameras, GPS, sensors, and spraying units, they collect field-level data and assist in timely decision-making. Their use enables efficient crop assessment and precise management of agricultural activities.

Advantages of Drones in Agriculture

Application	Purpose	Benefits
Crop Health Monitoring	Captures high-resolution images to identify unhealthy plants, nutrient deficiencies, water stress, and disease symptoms.	Helps farmers detect problems early and take timely corrective measures.
Spraying of Fertilizers and Pesticides	Sprays pesticides, fertilizers, and micronutrients uniformly across fields.	Reduces labour requirement, saves operational time, minimizes chemical wastage, and supports precision farming.
Seed Broadcasting	Used for direct seed broadcasting in large or inaccessible agricultural fields.	Saves time and improves efficiency in seed sowing operations.
Field Mapping and Surveying	Prepares digital maps of agricultural fields for better field analysis.	Helps farmers understand field conditions, crop distribution, and soil variability.
Weed Detection	Identifies weed-infested areas using imaging technology.	Enables targeted herbicide application and reduces unnecessary chemical use.

AI-Based Mobile Applications

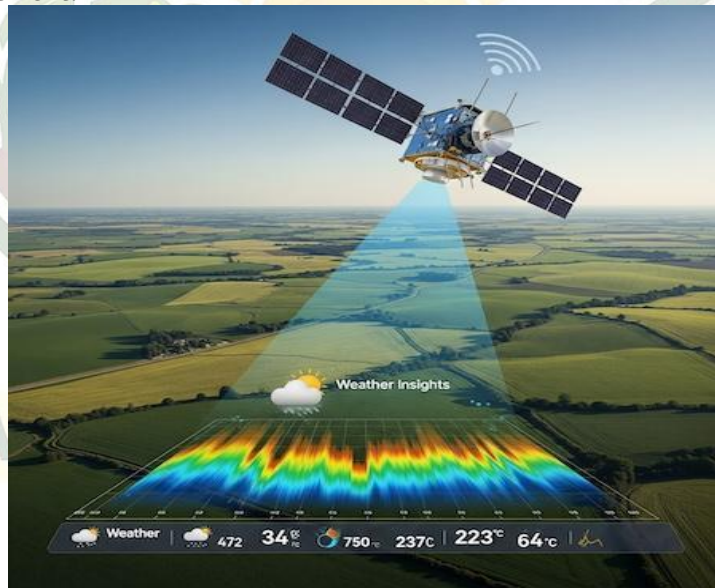
AI-enabled mobile applications provide farmers with quick access to crop-related information and decision-support services. By using image analysis and data-driven technologies, these apps can assist in identifying pests and diseases

from crop photographs. They also offer weather updates that help farmers plan sowing, irrigation, fertilizer application, and harvesting activities. Real-time market information enables farmers to make informed decisions about when and where to sell their produce. Some applications provide irrigation and crop management recommendations based on soil moisture and prevailing weather conditions. Examples of agricultural mobile applications include Plantix, AgriApp, Kisan Suvidha, IFFCO Kisan, and Pusa Krishi.



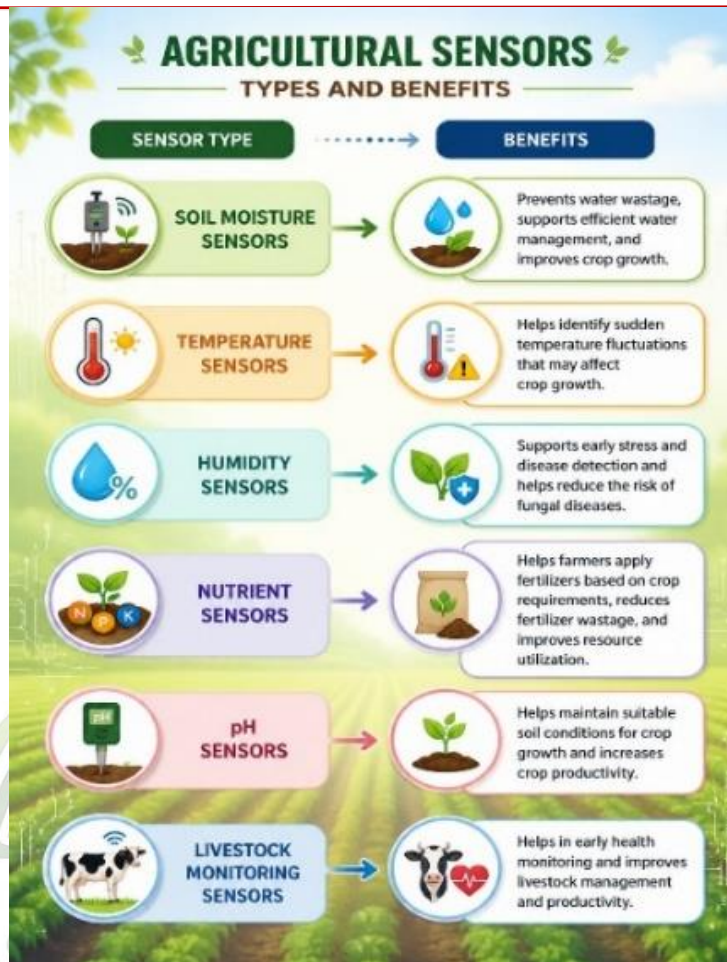
Satellite Technology and Remote Sensing

Satellite-based remote sensing has become an important technology for monitoring and managing agricultural resources. Satellite imagery provides information on crop growth, field conditions, soil characteristics, and climatic variations over large areas. It helps identify crop stress caused by inadequate moisture, nutrient deficiencies, pests, and diseases at an early stage. Satellite data is also useful for drought monitoring, soil mapping, and assessing areas affected by natural disasters such as floods and cyclones. When combined with Artificial Intelligence, satellite information can support crop yield estimation before harvest. These technologies enable farmers and agricultural agencies to plan timely interventions and improve resource management.



Precision Farming Technology

Precision farming is an advanced agricultural approach that uses field-specific information to apply inputs such as water, fertilizers, and pesticides in the right quantity and at the appropriate location. Technologies such as GPS, GIS, drones, sensors, satellite imagery, and AI-based data analytics support precise farm management. Variable-rate fertilizer application helps match nutrient supply with the requirements of different parts of a field. Site-specific irrigation delivers water according to soil moisture conditions, reducing water wastage. Precision weed management enables targeted herbicide application, while yield mapping identifies variations in crop productivity across the field. Together, these technologies improve input-use efficiency, reduce production costs, and promote sustainable farming.



Smart Irrigation Systems

Water scarcity is a serious constraint in agriculture, making efficient irrigation management essential for sustainable crop production. Smart irrigation systems integrate soil moisture sensors, weather information, automated valves and pumps, and mobile-based control systems to manage irrigation effectively. These systems continuously monitor soil moisture and climatic conditions to determine the water requirement of crops. Irrigation can be initiated automatically when the soil moisture falls below the required level. By supplying water according to actual crop needs, the system reduces over-irrigation and water losses. It can also lower energy and labour requirements while improving crop growth and irrigation efficiency. Thus, smart irrigation technology contributes to cost-effective and sustainable water management in agriculture.



Benefits and Challenges of AI in Agriculture

Benefits of AI	Challenges of AI Adoption
1. Improved Crop Management: Enables early detection of pests, diseases, crop stress, and nutrient problems through drones, sensors, and satellite data.	1. High Investment: AI tools, drones, sensors, and precision equipment involve high initial costs and maintenance expenses.
2. Efficient Resource Use: Helps optimize water, fertilizers, pesticides, labour, and energy, reducing wastage and production costs.	2. Technical Requirements: Effective use requires technical knowledge, training, reliable electricity, internet connectivity, and regular maintenance.
3. Better Decision-Making: Provides weather forecasts, yield estimates, and market information, supporting timely farm and marketing decisions.	3. Limited Accessibility: Poor digital infrastructure, low digital literacy, language barriers, and limited access to smartphones can restrict adoption.

4. **Higher Productivity & Sustainability:** Supports improved yields, farm profitability, and conservation of natural resources through precision-based farming.

4. **Small Farmer Constraints:** High technology costs may limit adoption among small and marginal farmers, requiring subsidies, demonstrations, and institutional support.

Future Scope of AI in Agriculture

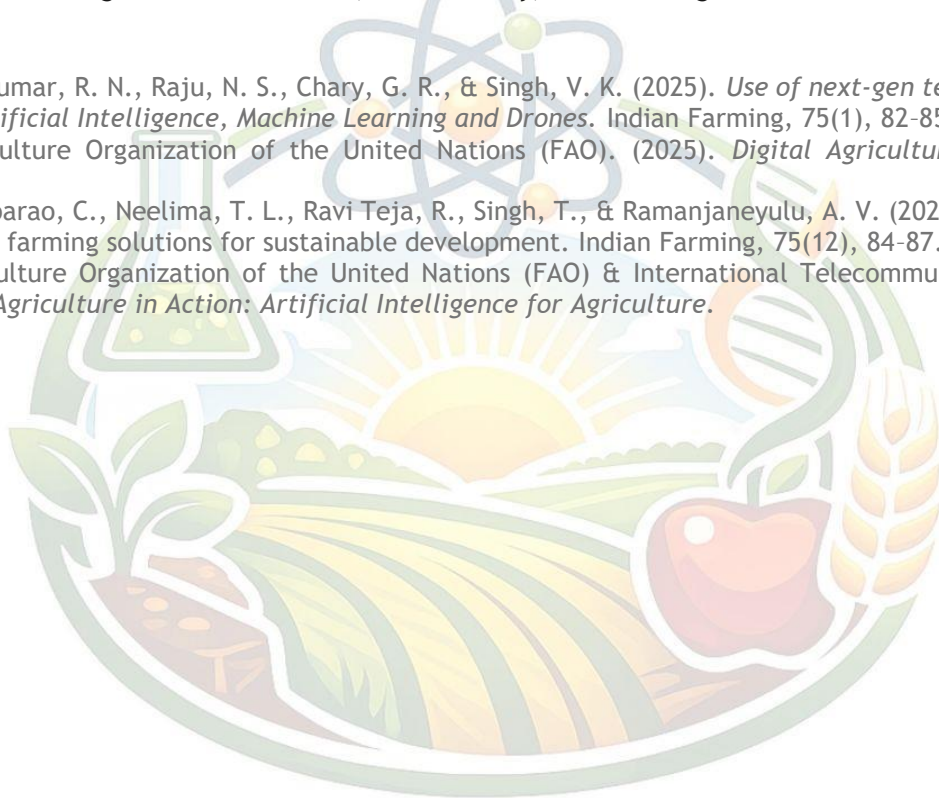
The future of agriculture will increasingly integrate AI with IoT, big data, cloud computing, and smart machinery to enhance productivity and resource efficiency. Advanced systems such as automated irrigation, AI-based crop advisory, climate monitoring, real-time disease detection, and digital farm management are expected to become more accessible. These innovations can strengthen sustainable farming, improve food security, and support better farmer incomes.

Conclusion

Artificial Intelligence is driving the transition from conventional agriculture towards smarter and more efficient farming systems. The use of drones, sensors, satellite data, mobile applications, precision technologies, and smart irrigation can improve productivity, optimize inputs, and conserve natural resources. With adequate training, infrastructure, and farmer support, AI can strengthen farm resilience, sustainability, and income generation for future agriculture.

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From Earth Observation to Agricultural Decision-Making

Article ID: 74505

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Introduction

Remote sensing provides repetitive, nondestructive information on crop status throughout the growing season at different spatial scales, supporting applications from field-level precision farming to global food security monitoring. The technology spans satellite, aerial, UAV, and ground-based platforms carrying multispectral, hyperspectral, thermal, radar, and LiDAR sensors to estimate agronomic variables and plant traits across visible, near-infrared, shortwave-infrared, and microwave wavelengths.

Satellite remote sensing in agriculture began with the Landsat Multispectral Scanner System in 1972, and the field has since expanded exponentially, with a sharp increase in publications since 2013 driven by new satellite constellations, UAVs, and cloud computing. UAVs have emerged as a transformative platform, offering centimeter-scale spatial resolution and on-demand imaging that overcomes satellite limitations from cloud cover and revisit periods. Synthetic aperture radar (SAR) provides a weather-independent complement to optical sensing. Data fusion techniques integrating multispectral, hyperspectral, LiDAR, and thermal sources further enhance monitoring of individual plant components.

Why it matters: Agriculture is spatially variable. Two neighbouring parts of the same field can differ in crop vigour, water status, nutrient condition or pest pressure. Remote sensing turns these differences into spatial information that can support more targeted management rather than treating an entire field as uniform.

Applications of Earth Observation System

Remote sensing and Geographic Information Systems (GIS) are becoming powerful tools for understanding the complex and changing nature of agricultural landscapes. This combination allows agriculture to move beyond isolated field observations towards a more comprehensive understanding of where agricultural resources are located, how conditions vary across space, and how these variations change over time. The resulting geospatial information can strengthen agricultural research, resource assessment and planning by providing a common platform for interpreting the relationships between crops, land, water and the surrounding environment. The detailed applications of remote sensing and GIS in agriculture was shown in Fig. 1.

1. Crop Intelligence:

a. Crop and Crop-Area Mapping: Remote sensing enables rapid identification and mapping of different crop types and their spatial distribution. Multi-temporal satellite observations are particularly useful because crops exhibit different spectral responses as they progress through their growth stages. Vegetation indices such as NDVI, EVI and LSWI can contribute to crop discrimination and crop-area mapping. Optical satellite data can also be combined with SAR observations to improve crop identification.

b. Crop Health Monitoring: Changes in crop reflectance can provide information about crop condition and plant stress. Spectral vegetation indices derived from visible, near-infrared and shortwave-infrared wavelengths can be used to monitor vegetation vigour, water stress, nutrient status and other crop conditions.

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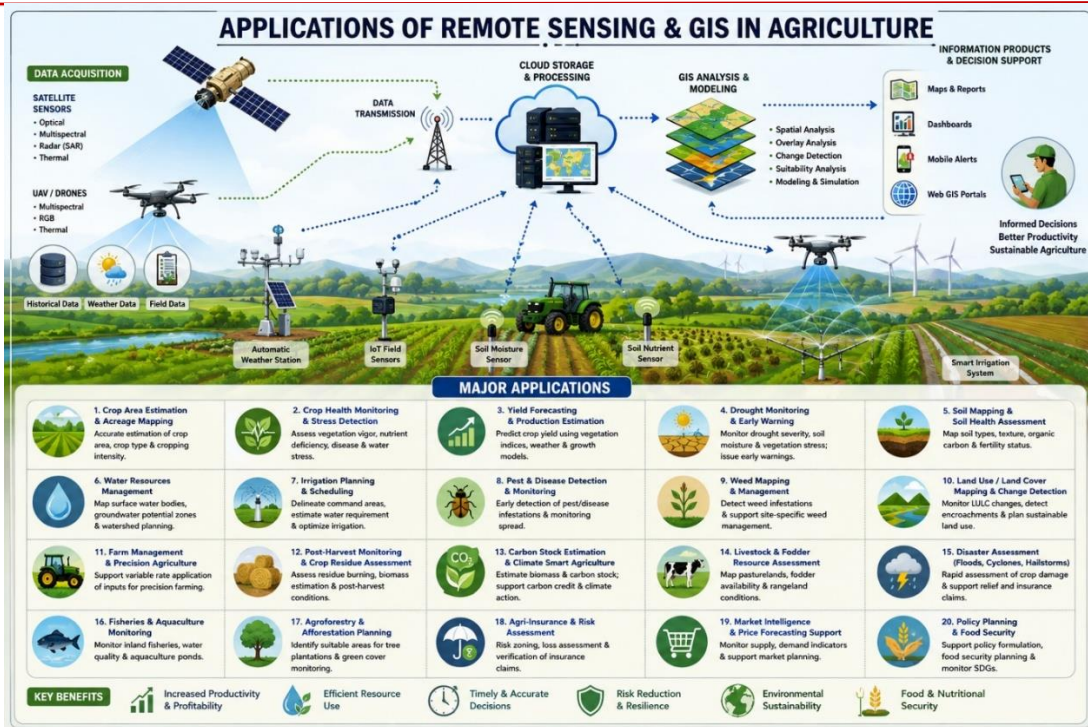


Fig. 1 Applications of Remote Sensing and GIS Agriculture

c. Crop Growth Assessment / Phenology Monitoring: Remote sensing provides a non-destructive method for monitoring crop development throughout the growing season. UAV imagery can provide detailed information on canopy characteristics, while satellite imagery can provide repeated observations over larger areas. Parameters such as canopy cover, plant height and leaf area index can be extracted from remotely sensed data to characterize crop growth.

d. Yield Forecasting: Remote sensing can support yield prediction by combining vegetation indices with crop characteristics such as plant height, biomass, LAI, chlorophyll content and growing-season information. Spatial yield maps can identify differences in crop productivity within fields and provide valuable information for site-specific crop management.

e. Biomass Estimation: Crop biomass can be estimated using spectral, structural and textural information derived from UAV and satellite imagery. Combining plant height with colour or vegetation-index information has been shown to improve biomass estimation, particularly when observations are collected at important crop growth stages.

2. Resource Intelligence:

a. Soil Resource Mapping / Water-Resource Assessment: Remote sensing and GIS can be used to map soil resources and investigate spatial variability in soil properties. Integrating soil information with other spatial layers provides a stronger basis for agricultural resource assessment and land-management planning. Also provides spatial information on hydrological features and agricultural water conditions.

b. Soil Moisture Assessment: Spectral information, particularly from relevant visible, near-infrared and shortwave-infrared wavelengths, can provide indicators associated with moisture conditions. Water-related indices such as NDWI and LSWI are useful for assessing water conditions and identifying areas experiencing moisture-related stress.

c. Irrigation Mapping: Remote sensing can distinguish irrigated and rainfed agricultural areas by analysing differences in vegetation response over time. Such mapping provides information on irrigation patterns, agricultural water demand and the spatial distribution of irrigated production.

d. Land-Use/Land-Cover Mapping / Land Suitability Assessment: Land-use and land-cover mapping provides a fundamental spatial framework for agricultural planning. Remote sensing can distinguish agricultural land from other land-cover categories and monitor changes in land use over time. GIS allows these maps to be integrated with soil, terrain and other resource information.

3. Risk & Stress Intelligence:

a. Drought Monitoring: Drought is one of the major environmental stresses affecting agricultural productivity. Remote sensing-based indicators such as NDVI, VCI and TCI can be used to monitor vegetation and temperature-related stress. Combining VCI and TCI produces the Vegetation Health Index (VHI), which has been used as an indicator of drought conditions. Satellite-based drought monitoring also provides information on the spatial variation of drought severity, helping agricultural agencies prioritize areas requiring attention.

b. Flood and Disaster Assessment: Remote sensing can provide large-area information on land, hydrological conditions and areas vulnerable to natural disasters. Its ability to provide synoptic and repeated observations makes it useful for assessing agricultural landscapes affected by environmental hazards.

c. Pest and Disease Detection / Weed Mapping: Changes in vegetation condition can provide signals associated with biotic stresses. Remote sensing and GIS approaches have been applied to map weed, pest and disease incidence, allowing affected areas to be spatially identified and monitored. High-resolution UAV imagery adds further value because it can capture detailed information at field and plot scales. High-resolution UAV imagery is particularly useful for vegetation mapping in mixed and small-farming environments and can support precision activities such as targeted pesticide application.

d. Abiotic Stress Monitoring: Crops are affected by stresses such as water limitation and temperature extremes. Multispectral, thermal and other sensor technologies can capture different aspects of crop condition and support the identification of abiotic pressures. Sentinel-2 observations, for example, have been highlighted for monitoring abiotic and biotic pressures, crop water demand and nutrient status.

4. Decision & Precision Agriculture:

a. Precision Farming / Site-Specific Farming: Remote sensing provides spatial information that can help move agricultural management from a uniform approach toward site-specific management. Variations in crop condition, soil characteristics, water status and productivity can be mapped and used to identify areas requiring different management strategies.

b. Farm-Scale Decision Support: The integration of remote sensing with machine learning can provide farm-specific information for agricultural decision-making. Instead of treating an entire field as homogeneous, spatial information can help identify zones with different crop and resource conditions.

c. Machine-Learning-Based Prediction: Machine learning can extract relationships from large volumes of remotely sensed and field data. Its integration with satellite and UAV observations has been explored for crop monitoring, LAI estimation, biomass prediction and yield forecasting. Combining satellite spectral information with UAV-derived structural characteristics can improve predictive performance.

Challenges and Limitations

Despite technological advances, full adoption of remote sensing in commercial agriculture remains limited by knowledge gaps on sensor appropriateness, techno-economic feasibility, and the complexity of image processing workflows. Satellite imagery adoption is constrained by limited on-demand imaging flexibility, high costs, cloud cover restrictions, and lack of automated analysis frameworks. Most studies on cropping practices remain exploratory case studies at local scales with high dependence on ground data and single-sensor approaches, limiting scalability. Key unresolved needs include soil moisture inversion under high vegetation cover, whole-phenological-period monitoring, and integration of remote sensing retrievals with crop growth and hydrological models. Overcoming these barriers will require interdisciplinary collaboration, improved data processing techniques, and user-friendly systems that bridge the gap between research and operational deployment.

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From Cultivation to Consumption: Nutritional Kitchen Gardening for Household Food and Nutrition Security

Article ID: 74506

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Introduction

Food and nutrition security have become major global concerns due to rapid urbanization, climate change, shrinking cultivable land, and changing food consumption patterns. Although agricultural production has increased considerably, micronutrient deficiencies—often referred to as hidden hunger—continue to affect people of all age groups. Deficiencies of iron, vitamin A, zinc, calcium, and other essential nutrients can impair growth, immunity, and overall health. Therefore, ensuring access to fresh, safe, and nutrient-rich food at the household level has become increasingly important.

A Nutritional Kitchen Garden (NKG) is an innovative household food production system that combines traditional kitchen gardening with modern agricultural technologies to produce diverse vegetables, fruits, herbs, and medicinal plants throughout the year. By integrating climate-smart practices such as raised-bed cultivation, drip irrigation, mulching, protected cultivation, vertical gardening, composting, rainwater harvesting, and precision nutrient management, NKG enhances productivity while conserving natural resources.

Beyond improving household nutrition, NKG promotes sustainable lifestyles by reducing dependence on market-purchased vegetables, minimizing pesticide exposure, and encouraging the consumption of freshly harvested produce. It also supports environmental conservation through efficient water use, organic waste recycling, and biodiversity enhancement. Thus, a High-Tech Nutritional Kitchen Garden serves as a practical and sustainable solution for achieving household nutritional security, environmental sustainability, and improved quality of life.

Need for and Importance of Nutritional Kitchen Garden

The increasing prevalence of malnutrition, micronutrient deficiencies, lifestyle diseases, and food safety concerns has highlighted the need for sustainable household food production systems. Although vegetables and fruits are readily available in markets, their quality, freshness, nutritional value, and pesticide residues remain major concerns. In addition, rapid urbanization, shrinking landholdings, rising food prices, and climate variability have reduced the ability of many families to access fresh and nutritious produce regularly. These challenges necessitate innovative approaches that ensure year-round availability of safe and healthy foods at the household level.

A Nutritional Kitchen Garden addresses these challenges by enabling families to cultivate a wide range of nutrient-rich crops within limited spaces using modern, resource-efficient technologies. Freshly harvested vegetables retain higher levels of vitamins, minerals, antioxidants, and natural flavours than produce transported over long distances or stored for extended periods. The integration of climate-smart practices such as drip irrigation, mulching, rainwater harvesting, composting, and protected cultivation improves productivity while conserving water, maintaining soil fertility, and reducing environmental impacts.

Furthermore, NKG encourages healthy eating habits, promotes dietary diversity, reduces household expenditure on vegetables, and minimizes dependence on external food sources. It also provides practical learning opportunities for children, empowers women through household food production, and strengthens community resilience against food insecurity and climate-related challenges, making it an essential component of sustainable living.

KEY PRINCIPLES

- Sunlight**
6-8 hours of direct sunlight daily
- Water Source**
Easy access to clean and reliable water
- Well Drained Soil**
Good drainage and fertile soil with compost
- Raised Beds**
Improve aeration, root growth and easy management
- Compost Unit**
Recycle kitchen and garden waste into organic manure
- Rainwater Harvesting**
Ensure water availability during dry periods
- Drip Irrigation**
Water efficient, saves time and resources



BENEFITS

- Fresh, safe and nutritious food for the family
- Reduces household expenditure
- Better health and nutrition
- Efficient use of water and resources
- Encourages family participation and healthy lifestyle
- Environment friendly and sustainable

DIVERSIFIED CROP PLANNING

Leafy Vegetables	Fruit Vegetables	Root Crops	Legumes	Herbs	Spices	Medicinal Plants
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Vertical Gardening

Trellis for Climbers

Hanging Baskets

Mulching

Shade Net

Insect-Proof Net

Protected Cultivation

“ A scientifically planned kitchen garden ensures higher productivity, better resource conservation and a continuous supply of fresh, safe and nutritious food for the entire family. ”

Planning and Design of a Nutritional Kitchen Garden

The success of a Nutritional Kitchen Garden (NKG) depends on proper planning and scientific design. The garden should be established in an open area receiving 6-8 hours of sunlight daily, with easy access to a reliable water source and good drainage. A well-planned layout improves space utilization, facilitates crop management, and ensures a continuous supply of fresh produce throughout the year. Raised beds of convenient width are recommended as they improve soil aeration, root development, drainage, and ease of intercultural operations.

Crop selection should be based on family nutritional requirements, seasonal suitability, and local climatic conditions. Leafy vegetables, fruit vegetables, root crops, legumes, herbs, spices, and medicinal plants should be arranged systematically to optimize sunlight and simplify management. Vertical structures such as trellises, hanging baskets, and wall-mounted planters can be used to grow climbers like bitter melon, cucumber, and beans, making efficient use of limited space. Provision for a compost pit or vermicompost unit enables recycling of kitchen and garden waste into nutrient-rich organic manure, while rainwater harvesting systems enhance water availability during dry periods.

Incorporating drip irrigation, mulching, shade nets, insect-proof structures, and protected cultivation further improves water-use efficiency, reduces pest incidence, and supports year-round production. A scientifically planned HTNKG therefore ensures higher productivity, better resource conservation, and a diversified supply of fresh, safe, and nutritious food for the entire family.

Modern Technologies in Nutritional Kitchen Gardens

The distinguishing feature of a Nutritional Kitchen Garden (NKG) is the integration of advanced agricultural technologies that enhance productivity, improve resource-use efficiency, and ensure year-round cultivation. Among these, drip irrigation is one of the most effective techniques, delivering water directly to the root zone, thereby reducing water wastage by 40-60% and improving crop growth. When combined with fertigation, water-soluble fertilizers can be applied precisely through the irrigation system, enhancing nutrient-use efficiency and minimizing losses.

Mulching using organic residues or biodegradable plastic films conserves soil moisture, suppresses weed growth, regulates soil temperature, and improves soil health. Protected cultivation through shade nets, insect-proof net houses, or polyhouses safeguards crops from adverse weather conditions, insect pests, and diseases while enabling off-season production. In areas with limited land, vertical gardening, rooftop gardening, and container cultivation maximize space utilization and increase crop diversity.

Emerging technologies such as hydroponics, aquaponics, and sensor-based smart irrigation systems further improve production efficiency by optimizing water and nutrient management. Internet of Things (IoT)-enabled devices can monitor soil moisture, temperature, humidity, and irrigation schedules in real time, allowing timely interventions. The adoption of these modern technologies transforms traditional kitchen gardens into climate-resilient, resource-efficient, and sustainable production systems capable of supplying fresh, nutritious, and safe food throughout the year.

A High-Tech Nutritional Kitchen Garden (HTNKG) ensures a continuous supply of fresh, safe and nutritious vegetables, herbs and other food crops for the family throughout the year. Scientific planning and design improve space utilization, resource conservation and overall productivity.

KEY PLANNING PRINCIPLES

- Select an open area receiving 6–8 hours of sunlight daily.
- Ensure easy access to a reliable water source.
- Provide good drainage to avoid waterlogging.
- Use raised beds for better soil aeration, root development and ease of operations.
- Choose crops based on family nutritional needs, seasonal suitability and local climate.



DIVERSIFIED CROP SELECTION



Arrange crops systematically to optimize sunlight, ensure easy management and provide a balanced, nutritious diet for the family.

VERTICAL GARDENING

Use trellises, hanging baskets and wall-mounted planters to grow climbers like bitter melon, cucumber and beans. This saves space and increases yield.

ORGANIC WASTE RECYCLING

Provide a compost pit or vermicompost unit to convert kitchen and garden waste into nutrient-rich organic manure.

RAINWATER HARVESTING

Harvest rainwater to enhance water availability during dry periods and reduce dependence on external sources.

MODERN TECHNOLOGIES

Drip irrigation, mulching, shade nets, insect-proof nets and protected cultivation ensure efficient use of water and nutrients.

BENEFITS OF A HIGH-TECH NUTRITIONAL KITCHEN GARDEN



INTEGRATE SMART PRACTICES



Nutritional Significance and Health Benefits of Nutritional Kitchen Gardens

A Nutritional Kitchen Garden (NKG) plays a vital role in improving household nutrition by ensuring a regular supply of fresh, diverse, and nutrient-dense foods. A well-planned garden can provide green leafy vegetables, fruit vegetables, root and tuber crops, legumes, fruits, herbs, and medicinal plants, thereby supporting a balanced diet throughout the year. Regular consumption of freshly harvested produce enhances dietary diversity and helps meet the recommended intake of essential vitamins, minerals, dietary fibre, antioxidants, and phytonutrients required for optimal growth, immunity, and overall well-being.

Leafy vegetables such as spinach, amaranthus, and moringa leaves are excellent sources of iron, folate, calcium, and vitamin A, while tomatoes, capsicum, and citrus fruits are rich in vitamin C and antioxidants that strengthen the immune system. Orange- and yellow-coloured vegetables, including carrot and pumpkin, provide β-carotene, a precursor of vitamin A that supports healthy vision and immune function. Leguminous crops such as cowpea and French bean contribute plant-based proteins, whereas herbs like mint, coriander, and curry leaves enhance flavour and provide valuable bioactive compounds.

By promoting the consumption of freshly harvested, pesticide-safe produce, NKG helps reduce the risk of micronutrient deficiencies, obesity, diabetes, hypertension, and other diet-related non-communicable diseases. Thus, it serves as an effective household strategy for achieving nutritional security, promoting healthy eating habits, and improving the quality of life across all age groups.

Economic Benefits, Future Prospects

A Nutritional Kitchen Garden (NKG) is not only a means of producing fresh and nutritious food but also a valuable investment in household health, economic well-being, and environmental sustainability. By growing vegetables, fruits, herbs, and spices at home, families can substantially reduce their expenditure on food while ensuring a continuous supply of safe, high-quality produce. Surplus harvests can be marketed locally or processed into value-added products, creating additional income opportunities for women, rural youth, and Self-Help Groups (SHGs). The garden also serves as a practical learning platform for school children and farm families, promoting awareness of balanced nutrition, sustainable agriculture, and responsible resource management.

The future of NKG lies in the adoption of smart agriculture technologies, including Internet of Things (IoT)-based irrigation systems, Artificial Intelligence (AI)-assisted crop monitoring, automated fertigation, hydroponics, rooftop farming, and solar-powered irrigation. These innovations can further enhance productivity, resource-use efficiency, and climate resilience, making household food production more sustainable and accessible.

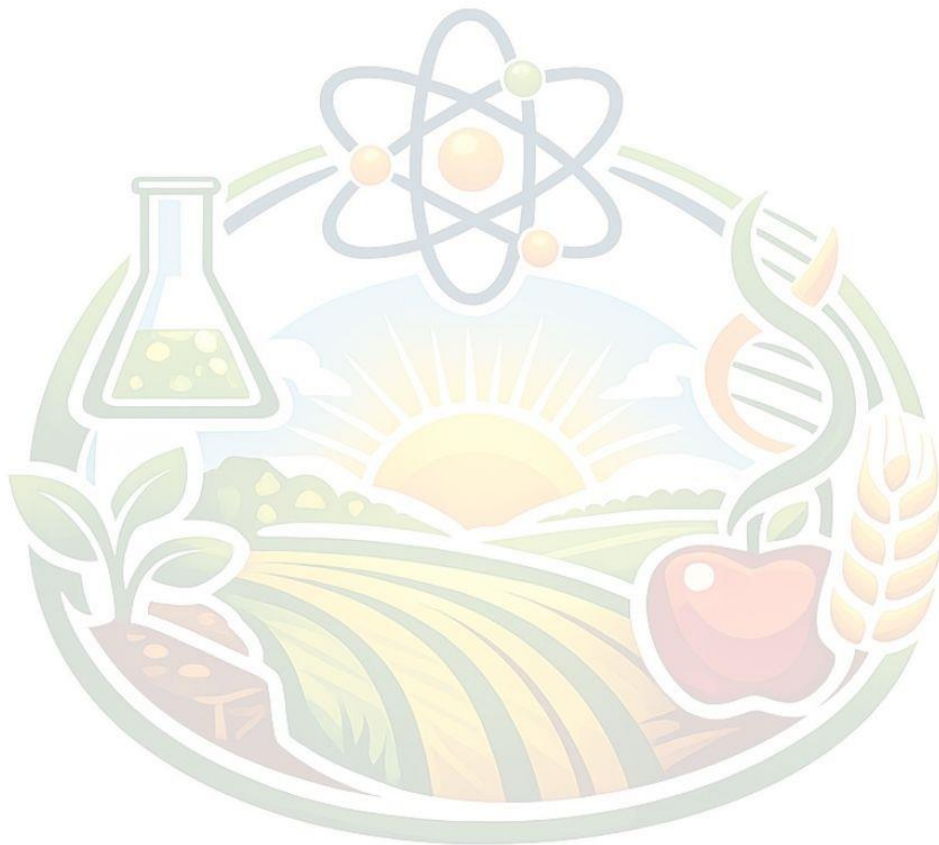
Conclusion

Nutritional Kitchen Garden is a simple yet transformative approach to achieving household nutritional security and environmental stewardship. By integrating modern technologies with eco-friendly cultivation practices, every household

can produce fresh, diverse, and safe food throughout the year while contributing to healthier families, resilient communities, and a sustainable future. Widespread adoption of HTNKG will support national efforts towards food security, nutrition enhancement, climate resilience, and sustainable agricultural development.

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Advancing Agricultural Engineering Through Computer Science and ICT

Article ID: 74507

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Agricultural engineering integrates engineering principles with agricultural practices, focusing on areas such as the development and usage of farming machinery, design of rural infrastructure, soil and water conservation, irrigation systems, renewable energy utilization, and post-harvest processing. Computer science plays a pivotal role in enhancing these areas by offering modern solutions to complex agricultural challenges. This article highlights how computer science contributes to agricultural engineering through various means, including system modeling, simulation, process optimization, machine design, and artificial intelligence (AI). Journals such as Computers and Electronics in Agriculture provide a global platform for showcasing advancements in computer-based and electronic solutions in agriculture, spanning disciplines like agronomy, horticulture, forestry, aquaculture, and livestock management. Its companion journal, Smart Agricultural Technology, focuses on intelligent technologies that optimize agricultural productivity.

Role of IT in Addressing Agricultural Challenges

Agriculture in developing regions faces numerous obstacles, including the need to increase productivity, ensure food security, and generate employment, especially in rural areas. The rapid transformation of the agricultural landscape due to global trends makes it essential to adopt information technology (IT) for enhancing productivity and market access. However, the agricultural sector lags in IT adoption compared to other industries, primarily due to infrastructural and educational barriers. This paper explores the transformative potential of IT in agriculture and agribusiness. Economic analysis and literature suggest that IT can significantly boost efficiency, productivity, and decision-making for farmers and agricultural stakeholders. Despite this potential, challenges remain in widespread IT implementation due to a lack of resources, training, and connectivity.

Information as a Catalyst for Agricultural Development

Reliable and timely information is critical for the improvement of agricultural operations, especially in countries undergoing economic transitions or market integration, such as those entering the European Union. As agricultural sectors become deregulated, access to accurate information becomes essential for stakeholders, from producers to input suppliers and buyers. The use of ICT (Information and Communication Technology) can greatly contribute to the socio-economic development of rural populations. Unfortunately, farmers often struggle to access relevant information in a format they can understand. ICT tools can support evidence-based farming through data collection, cost analysis, and advanced marketing strategies, empowering farmers to make informed decisions and improve profitability.

Key Information Needs in Agriculture

Crop Data: Information such as crop types, land use, sowing/harvesting timelines, and yield estimates can be collected and analyzed. Farmers can access this data online to plan their activities efficiently. Production Techniques: Techniques developed by agricultural research institutions can be disseminated via digital platforms to aid farmers in adopting best practices.

Input and Equipment Information: Data about seeds, fertilizers, and machinery offered by suppliers can be made accessible to farmers for better decision-making. **Market Intelligence:** Real-time market prices, export/import trends, and seasonal forecasts can guide farmers on when and where to sell their produce for maximum profit.

Additional Support: Weather updates, access to credit, pest and disease management tips, and expert guidance are also vital. However, collecting and disseminating this information requires significant effort and investment. ICT reduces the cost and increases the reach of information dissemination. Mobile phones and internet-based applications have become essential tools for farmers, especially in remote areas, allowing them to access crucial information in real time.

Enhancing Productivity Through ICT

ICT benefits agricultural production in two main ways:

1. Direct Contributions: Technologies such as precision farming rely on ICT to optimize agricultural inputs and increase yields. Techniques include the use of satellite imagery, GIS (Geographic Information Systems), and meteorological data collected from field-based sensors. These systems monitor parameters like temperature, rainfall, soil moisture, and wind speed, providing data-driven insights for farm management. While highly effective, these solutions often require significant capital investment, making them more suitable for large-scale or corporate farms.

2. Indirect Contributions: ICT empowers farmers by improving access to critical information, thus enabling better decision-making. Traditional information sources often lack timeliness and accuracy. With reliable ICT tools, farmers can stay competitive in the global market by making informed choices on crops, marketing, and investments. However, digital literacy is essential for these tools to be effective. When farmers are trained in basic computing, they can utilize the internet to gather information, seek advice, and connect with peers and experts globally.

ICT Use in the European Union and Serbia

Precision farming (PF) serves as an indicator of agricultural automation. Although it has not been widely adopted across the EU, some countries are advancing. For instance, the Czech Republic has made notable progress in this field. Agricultural equipment manufacturers in Germany, Denmark, the Netherlands, and Finland are promoting PF technologies, which include data collection and geospatial analysis. In many regions, PF remains in the research or pilot stage but holds promise for improving farm efficiency. Computers and their applications changed the face of most traditional occupations including agriculture. From computerized milk collection and seed estimators to weather predictions and automated farmland assessment, computers have revolutionized farming practices. Technological advances have brought about drastic changes in farming and animal husbandry resulting in a tremendous increase in production capacity. The most common use of computers has been in replacing human effort and intervention in traditional farming machinery and other equipment. In addition, even the support functions for farming such as delivery of machinery, fertilizers and production of raw products have been successfully automated. But all these are just the labour-saving, basic uses that have been around even before the turn of the century. If computers have changed the ways of farming, then the Internet has only doubled that pace of change. Applications of Computing Technologies in Agriculture In today's times, agriculture is not just about crop production or livestock farming and associated activities. The challenges brought forth by ecological factors affecting the environment need to be a major consideration for any kind of farming activity. Farmers need to pre-empt environmental impact due to climate change and this is where modern technology comes to the rescue. In a nutshell, the uses of computers in agriculture include: There are softwares which help in the prediction of weather conditions and estimation of agricultural production. Computers are used for record-keeping of information related to costs involved in production, transport, agricultural processes, and in the estimation and calculation of profit and/or loss. The Internet aids communication among farmers and between farmers and agriculture experts. This leads to an exchange of knowledge and serves as guidance for farmers to improve production and earn profits.

Farmland Assessment

Geographic Information Systems (GIS): GIS are being used for developing ranking systems that evaluate land and provide a site assessment to aid what is now known as precision agriculture. These hi-tech, interactive systems provide information based on a variety of factors such as soil conditions, drainage and slope conditions, soil pH and nutrient status, etc. Prior to the use of these systems, farmers were often in the dark about soil output, and unpredictable weather conditions affecting crop quality and profitability. Precision agriculture provides farmers with control by predicting vital information including fertilizer application and problems with drainage, insects, and weeds. Most government websites provide this kind of information free of cost, covering agricultural land masses across the United States. Global Positioning System (GPS) based technologies also help to monitor irrigation, field mapping, soil sampling, tractor guidance and crop scouting. This kind of technology equips farmers with enough information to increase crop yield in a manner that is consistent with the best environmental practices for sustainable agriculture.

Autonomous Farm Equipment and Tractors: Automated farm equipment, needless to say, scores over human controlled equipment in terms of consistency and reliability. Engine and machine functions such as transmission and hydraulic power output are controlled using microchips built into the equipment. Guidance technology is already being widely used in self-propelled equipment to aid crop seeding and fertilizer application. Automated feeding systems, computerized milk collection and milking machines have been around since the late 20th century, resulting in better economic yield for the dairy industry as well as livestock production. Automated tractors are probably not far away.

Farm Software: With regard to livestock farming, ready-made computer applications are available to track animals, storing and evaluating information such as age, health records, milk production, offspring productivity, and reproductive cycle status. This is often called herd recording. Similarly, most farm accounting software and other computer applications in agriculture provide services for record keeping, simulation of prediction-based models using that data, and revenue and productivity estimation. Most farm software vendors provide you with an option to customize their applications to the specific needs of your farm or ranch.

Internet Forums, Social Networking and Online Knowledge Bases: Any business in the world that you can think of, has benefited from the advent and global reach of the Internet and related communication technologies (mobile computing, ecommerce, etc.). Agriculture is no different. Imagine using the power of the Internet to connect with farmers, agriculturists and agricultural scientists and other experts spread across the globe. There are several forums and social networking sites on the Internet where farmers can connect with other farmers and farming experts and exchange know-how. In addition, there are several learning repositories that provide information on a wide variety of agricultural topics.

These avenues serve to reduce the rural digital divide, influence public policies, foster partnerships and connect all stakeholders across the agricultural value chain. For instance, a farmer can easily seek out and connect with an agricultural entrepreneur and begin the exchange of ideas or business proposals. Information such as price review for grain and livestock, pest information, real-time weather information (precipitation, temperature, humidity, solar radiation, wind speed, soil moisture and soil temperature) in any part of the world is literally available at one's fingertips.

E-agriculture: An emerging field of agricultural practices, e-agriculture focuses on coming up with innovative ways and best practices to use the existing information and communication technologies (ICTs) for sustainable agricultural development and food safety standards, particularly in rural areas. E-agriculture encompasses other related technological fields such as agricultural informatics, agricultural development and business. It aims to deploy all available technologies (computers, mobile computing, satellite systems, smart cards) for the empowerment of farmers and strengthening of partnerships across the food value chain.

The uses of computers in agriculture do have some real constraints such as, the lack of hardware and software infrastructure, training and skills, and research priorities. However, once these are overcome, the use of computers goes past automation and software application. In fact, it could be instrumental in bridging the digital divide and bringing prosperity to agriculturists not only in the United States, but also in other developing and emerging economies around the world.

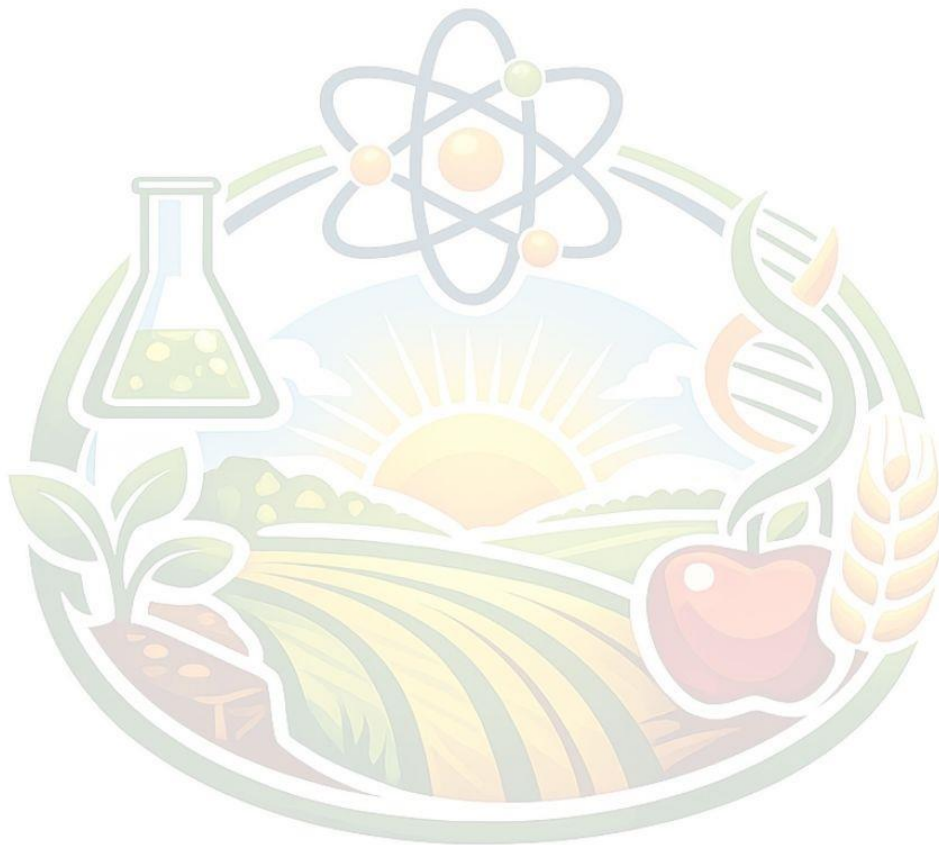
Digital transformation is acting as a game-changer for Indian agriculture. This has led to the rise and development of mobile apps which are helping existing government schemes and other agriculture-based information to reach farmers in rural India. Now, with a click of a button, farmers can access all the necessary information he needs.

List of 25 Mobile Apps That Can Significantly Improve the Lives of Farmers - App Names and Download Links

1. **My Agri Guru** <https://play.google.com/store/apps/details?id=com.myagrigruru&hl=en>
2. **IffcoKisan** <https://play.google.com/store/apps/details?id=com.IFFCOKisan>
3. **Agriplex** <https://play.google.com/store/apps/details?id=com.agriplexindia.agriplexconsumer>
4. **Market yard** <https://play.google.com/store/apps/details?id=com.globalfarm.marketyard>
5. **Indian Satellite Weather** <https://play.google.com/store/apps/details?id=com.shahul3d.indiasatelliteweather>
6. **Zero Budget Natural Farming** <https://play.google.com/store/apps/details?id=com.oyepages.zbnf>
7. **Kisan Space** <https://play.google.com/store/apps/details?id=com.kisan>
8. **Crop Insurance** <https://play.google.com/store/apps/details?id=in.farmguide.farmerapp.central&hl=en>
9. **Mandi Central** <https://play.google.com/store/apps/details?id=com.tradeforsure>
10. **Machinery guide** <https://play.google.com/store/apps/details?id=hu.zbertok.machineryguide&hl=en>
11. **Kisan Suvidha** <https://play.google.com/store/apps/details?id=in.cdac.bharatd.agriapp>
12. **Kisan Yojana** <https://play.google.com/store/apps/details?id=com.purplechai.admin.kissan.yojnaapp>
13. **Krishi Network** <https://play.google.com/store/apps/details?id=com.krishi.krishi>
14. **MSAMB** <https://play.google.com/store/apps/details?id=com.msamb>
15. **e-Gram** <https://play.google.com/store/apps/details?id=com.reformist.krushiking001>
16. **Fasal Salah** <https://play.google.com/store/apps/details?id=com.weathersys.agro>
17. **Farm Bee** <https://play.google.com/store/apps/details?id=com.rml.Activities>
18. **KVSMT** <https://play.google.com/store/apps/details?id=com.kvsmt.mobile>
19. **CCMobile** <https://play.google.com/store/apps/details?id=com.root.ccmobile&hl=en>
20. **Bijak** <https://play.google.com/store/apps/details?id=com.bedwal.bijak.mvp&hl=en>
21. **Agromedix** <https://play.google.com/store/apps/details?id=com.iqra.agromedix>
22. **BajarBhav** <https://play.google.com/store/apps/details?id=com.bajarbhav>
23. **Agriculture Business** <https://play.google.com/store/apps/details?id=com.AgriculturalBusiness3ds>
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Conclusion

The integration of computer science into agricultural engineering is transforming traditional farming into a more precise, efficient, and sustainable practice. Through the use of advanced technologies such as artificial intelligence, geographic information systems (GIS), remote sensing, and mobile applications, farmers now have access to timely data and expert insights that enhance decision-making and productivity. Despite certain challenges—especially in rural and developing areas—the potential of information and communication technologies (ICT) to revolutionize agriculture is undeniable. As access to digital tools continues to expand, and awareness of their benefits grows, the agricultural sector stands to gain significantly in terms of yield improvement, market access, and sustainable resource management. Embracing these digital advancements is not only a step toward modernization but also a critical move toward global food security and rural development.

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Importance of National Nutrition Month (Rashtriya Poshan Maah)

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Highlights of National Nutrition Month (Rashtriya Poshan Maah 2026)

The celebration of National Nutrition Month (Rashtriya Poshan Maah) in India started in the year 2018. Prime Minister Narendra Modi launched the POSHAN Abhiyaan (Prime Minister's Overarching Scheme for Holistic Nourishment) on March 8, 2018, from Jhunjhunu, Rajasthan. As a part of this mission, the entire month of September was designated to be celebrated annually as 'Poshan Maah' to drive community mobilization and awareness. First Poshan Maah: Observed in September 2018.

Primary Objective Poshan Maah: To combat malnutrition among children, pregnant women, and lactating mothers across India. Organizing Ministry: Led by the Ministry of Women and Child Development as a month-long *Jan Andolan* (people's movement).

For India's 9th Rashtriya Poshan Maah (September 2026), the Ministry of Women and Child Development has organized the nationwide campaign under the overarching theme of "Swasth Nari, Sashakt Parivar" (Healthy Woman, Empowered Family).

The initiative actively combats malnutrition across India by driving community participation (*Jan Andolan*) through five core focus pillars.

Major Focus Areas & Pillars for 2026

Undernutrition: Stunting, wasting, and underweight issues, particularly among vulnerable young demographics.

Micronutrient Deficiencies: Often termed "hidden hunger," involving shortages of essential vitamins and minerals.

Overweight and Obesity: Rising due to sedentary routines and calorie-dense, nutrient-poor diets.

Dietary Diversity & Overnutrition Prevention: Promoting the consumption of traditional, localized, and protein-rich foods. This pillar places a strong emphasis on Addressing Obesity by educating families to dramatically reduce sugar and oil consumption.

Early Childhood Care and Education (ECCE): Aligning with the *Poshan Bhi Padhai Bhi* (PBPB) framework to upgrade Anganwadi Centres into high-quality preschool learning environments. It prioritizes nutrition combined with early stimulation for rapid brain development in a child's first six years.

Infant and Young Child Feeding (IYCF) Practices: Educating communities on critical health milestones, including the importance of exclusive breastfeeding for the first six months and introducing proper complementary feeding for children under two years old.

Men's Involvement in Caregiving: Actively "men-streaming" or integrating men into everyday health conversations to break the stereotype that nutrition and child upbringing are solely a woman's responsibility.

Environmental & Maternal Support: Linking environmental sustainability with nutrition through the "Ek Ped Maa Ke Naam" tree-plantation drive. This coincides with celebrating 10 years of maternal support through the Pradhan Mantri Matru Vandana Yojana (PMMVY).

Benefishery group: Pregnant women, lactating mothers, parents of children aged 0-6 years, and adolescent girls (14-18 years).

Take-Home Ration (THR): Monthly distributions of fortified grains, pulses, and nutrition mixes for pregnant/lactating women and children under 3 years.

Hot Cooked Meals: Provided daily at the Anganwadi centre for children aged 3-6 years to fulfill their foundational macro and micronutrient goals.

Medicinal Supplements: Free distribution of Iron and Folic Acid (IFA) tablets and Vitamin A supplements to prevent anaemia

Village Health Sanitation Nutrition Days (VHSND): Attend these localized monthly health drives for free check-ups, early pregnancy registration, and essential immunizations

Participate in Community Workshops

Recipe & Millet Demonstrations: Free village workshops that teach affordable, healthy cooking techniques using local produce like millets to combat obesity and reduce sugar/oil intake.

Husband-Orientation Events (Suposan Diwas): Community programs designed to help male family members understand caregiving, breaking old taboos.

Monitor Progress: If you are registered, you can track your family's dynamic health, immunization status, and ration history online by visiting the official portal or logging into the Poshan Tracker with your registered mobile number and an OTP.

Share Local Recipes: Participate directly in the nationwide campaign by sharing your traditional healthy recipes on the MyGov Portal using the hashtag #Local for Poshan.

Supports Healthy Growth in Children

Growth and Development: Adequate macro- and micronutrients fuel skeletal growth and tissue development.

Brain Development: The early years require dense nutrients to support rapid neurological wiring.

Immunity: Well-nourished children fight off infections and communicable diseases far more effectively.

School Performance: Steady energy and proper micronutrient status directly correlate with attention span, cognitive processing, and academic success.

Helps Prevent Nutritional Deficiencies

Targeted nutrient intake keeps common deficiencies at bay, protecting against:

Iron: Prevents fatigue and nutritional anaemia.

Vitamin D: Essential for bone mineralization and immune function.

Calcium: Supports structural density in bones and teeth.

Vitamin B12 and Essential Nutrients: Crucial for nerve integrity and cellular replication.

Supports Maternal Health

Nutrition Before and During Pregnancy: Lays the foundation for both maternal well-being and fetal development (Haugen *et al.* 2008).

Folic Acid, Iron, and Calcium Needs: Vital for preventing neural tube defects, ensuring healthy blood volume, and protecting maternal bone density.

Healthy Weight Gain: Supports uncomplicated deliveries and healthy birth weights.

Professional Dietary Advice: Tailors eating plans to manage gestational requirements safely.

Helps Reduce the Risk of Lifestyle Diseases

Chronic poor dietary patterns heavily accelerate the onset of non-communicable diseases (NCDs), closely tying into risks for: Hypertension, Obesity, Diabetes, Cardiovascular diseases.

Supports Healthy Ageing

Maintaining Muscle Mass: Combats age-related muscle wasting (sarcopenia) through adequate protein intake.

Bone Health: Preserves bone density to lower fracture risks.

Adequate Protein and Micronutrients: Sustains metabolic function and physical independence.

Hydration: Prevents common electrolyte imbalances and dehydration issues in older adults.

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From Field to Fiber: The Multidimensional Role of Cotton in Industry and Livelihoods

Article ID: 74509

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Abstract

Cotton (*Gossypium* spp.) is a premier non-food cash crop cultivated across approximately 84 countries. Globally, India holds the largest area under cotton cultivation, while China leads in total production and Australia achieves the highest productivity. Within India, the states of Maharashtra, Gujarat, and Rajasthan rank highest in cultivated area, total production, and yield productivity, respectively. The primary driver behind cotton domestication was the harvesting of its lint fiber, which finds extensive commercial applications ranging from everyday apparel to technical products and cellulose derivatives. Beyond fiber, cottonseed is processed for edible oil used in culinary, personal care, industrial, and biofuel applications. The leftover extraction residue, known as cottonseed meal or cake, serves as nutrient-dense livestock feed and organic soil fertilizer. Socioeconomically, cotton cultivation sustains the livelihoods of approximately 100 million households across 75 countries, 90% of which belong to low-income economies.

Keywords: cotton fiber, cotton seeds, cottonseed cake, employment generation.

Introduction

Cotton, *Gossypium* spp. belongs to the Malvaceae family. Approximately 50 species are included in the *Gossypium* genus (Viot and Wendel, 2023). Among these, four species, viz., *Gossypium arboreum*, *G. herbaceum*, *G. hirsutum*, and *G. barbadense*, are cultivated worldwide. *G. arboreum* and *G. herbaceum* are diploid ($2n=26$), indigenous to India and Pakistan (*G. arboreum*) and southern Africa and the Arabian Peninsula (*G. herbaceum*), and *G. hirsutum* and *G. barbadense* are tetraploid ($2n=52$), having a Central America and tropical South America origin. The crop is known as a profitable, non-food and cash crop around the world. Cotton is the source of a natural fibre used as the main raw material in the textile and apparel industries.

Globally, cotton is grown in 84 countries (Jumanov et al., 2025), with an area of 318.78 lakh hectares, production of 1429.84 lakh bales (one bale equals 170 kg of compressed raw cotton fibres), and productivity of 763 kg/ha (ICAR et al., 2024). It is cultivated in 31 countries across Africa, 28 countries in Asia and Oceania, 20 countries in North and South America, and 3 countries in Europe (Jumanov et al., 2025). Globally, India holds the first position in terms of area under cotton cultivation, with approximately 124.69 lakh hectares. In terms of production, China occupies the first position with 56.00 lakh tonnes (equivalent to 329 lakh bales of 170 kg). In productivity, Australia is first with 2239 kg/ha. Across the world, 80% of raw cotton production and 75% of consumption are from China, India, Pakistan, Bangladesh, and Vietnam. In the world scenario, China is the major importer, and the USA is a major exporter of cotton. During 2023 and 2024, India imported 16.40 lakh bales of 170 kgs and exported 28.00 lakh bales of 170 kgs (Cotton Association of India, 2024).

Globally, India contributes 39% to the cotton area and 22% to the production, respectively. In India, cotton is primarily grown in 11 states, covering an area of 125 lakh hectares, with a production of 323.11 lakh bales at a productivity of 170 kg/ha, resulting in 441 kg of lint/ha. In India, the northern zones of Rajasthan, Haryana, and Punjab, the central zones of Madhya Pradesh, Gujarat, and Maharashtra, and the southern zones of Tamil Nadu, Karnataka, Andhra Pradesh, and Telangana, as well as the eastern zone of Odisha, mainly grow cotton. In overall cotton cultivation, the north zone accounts for 12.18%, the central zone for 60.53%, and the south zone for 24.31% of the area. In production, the north, central, south, and eastern zones account for 14.49%, 58.82%, 24.32%, and 2.30%, respectively. Throughout India, 70.05% of the area and 68.15% of the production is from Maharashtra, Gujarat, and Madhya Pradesh. Among the cotton-growing states of India, Maharashtra has the largest area, at 42.34 lakh ha, Gujarat has the highest production, at 89.65 lakh bales of 170 kg, and Rajasthan has the highest productivity, at 590 kg/ha (ICAR et al., 2024).

Cotton Fiber

The main driver behind the domestication of the cotton crop was the harvesting of its fiber. Morphologically, it is an epidermal outgrowth of the seed coat known as a seed trichome (hair). In its raw, unbleached form (on a dry-weight basis), it primarily consists of cellulose (88-96%), accompanied by minor non-cellulosic constituents including protein (1.1-1.9%), pectic substances (0.7-1.2%), minerals (0.7-1.6%), wax (0.4-1.0%), total sugars (0.3%), and organic acids (0.5-0.8%). The evolutionary production of fiber serves as an adaptive mechanism for seed survival and dispersal, facilitating both anemochory (wind dispersal) and epizoochory (animal dispersal). Furthermore, its hydrophilicity enables it to retain

moisture and provides soil anchoring to prevent seed displacement during germination. Chemically, cotton seeds are rich in proteins and lipids, which many animals prefer to consume. However, the interwoven fibers protect them by acting as mechanical defence structures and inhibit mastication and ingestion by granivores. Additionally, this dense matrix around seeds protects the internal embryo from thermal fluctuations.



Figure 1. Cotton fiber

Cotton fiber has several useful properties including high hydrophilicity, absorbency, tensile strength, thermal conductivity, breathability, softness, skin-friendliness, alkali resistance, dye affinity, and acid sensitivity. Additionally, it has unique characteristics such as increased strength when wet and high spin cohesion. As a result, cotton fiber has numerous applications in commercial and industrial sectors. It is used in the apparel and textile industry (everyday garments, heavy-duty apparel, knitted and woven fabrics), in home textiles and furnishings (bedding, bath linens, and upholstery), in medical, sanitary, and personal care (surgical supplies, personal hygiene), in industrial and technical applications (cordage and tarps, industrial belting, filtration systems), in specialty papers and security printing (currency and banknotes, archival paper), and in cellulose derivatives and chemical products (cellulosic plastics and films, explosives and propellants, viscose/rayon production).

Cotton Seeds

After lint is extracted from seed cotton, the remaining seeds are called cotton seeds. On average, whole cottonseed contains 45% meal, 27% hull, 16% crude oil, 8% linters, and 4% wastes. If we consider only the kernel, it contains 41% protein and 37% crude oil (He et al., 2023). Cottonseeds are used to produce oil. Cottonseed oil contains unsaturated fatty acids, linoleic (51-58%) and oleic (18-23%), and saturated fatty acids, palmitic (21-24%) and stearic acids (1.8-2.2%), tocopherols, sterols (beta-sitosterol), phosphatides (lecithin and cephalins), and gossypol (Ye et al., 2022).



Figure 2. cotton seeds

Cottonseed oil is used as a cooking oil in the preparation of edible food materials. In cosmetics and personal Care, it is used in the preparation of skin creams, lotions, moisturizers, shampoos, conditioners, in industries, used in soaps, detergents, lubricants, paints, varnishes, and biodiesels (Gutierrez and Komarnytsky, 2025) and in explosives, gasoline, and toothpaste (Simair and Simair, 2020). During refining, toxic elements such as gossypol and other pigment glands, colloids, and waxes are removed, and oil is used for cooking.

Leftover Residues

During cottonseed oil preparation, the leftover residues are used as cottonseed meal or cottonseed cake. It is rich in proteins, fibres and retains some oil compounds. Cottonseed cake is used as feed for cattle and as an organic fertilizer for the soil. After the completion of the primary ginning process, the short, fuzzy, short-fibered residues left on cottonseeds are known as cotton linters. These are the purest form of cellulose with 90% cellulosic content. Cotton linters are utilized in industries related to paper, oil biosorbents, cellulose derivatives, and the automotive sector. After

harvesting the cotton crop, cotton stalks, such as the main stem, branches, and burrs (after extraction of lint and seeds from seedcotton, the leftover dried shell), are used in the preparation of particle boards, hardboard, corrugated boxes, composting, biooil, biochar, briquetting, pulp for paper, and bioethanol production.



Figure 3. Leftover residues

Employment Generation

Additionally, the entire journey of cotton, starting from the fields where it's grown by farmers to its processing in factories and final sale in stores, provides jobs for a vast number of people. It was estimated that, in 2021, the global retail market value for cotton raw products processing was about USD 18 billion, and the economic value of the worldwide textile market, which largely depends on cotton raw materials, was USD 1 trillion. Approximately, in 75 countries, cotton cultivation supports the livelihoods of around 100 million households, with 90% of them belonging to low-income economies. Additionally, 350 million people are globally associated with cotton-related processes, including labour, transport, ginning, baling, and storage, and about 25 million people are employed in the textile industry (Voora et al., 2023). Hence, though the cotton crop does not directly provide food for human beings, it serves humankind in many ways.



Figure 4. Cotton uses (A.I assisted)

Conclusion

Even though cotton is not a food crop, it touches almost every part of our daily lives. From the soft clothes we wear and the sheets we sleep on, to cooking oil, animal feed, banknote paper, and clean energy, every single part of the cotton plant is useful. On top of that, it provides jobs and income for millions of families around the world. Truly, cotton is much more than just a plant. It is a miracle crop that clothes, protects, and supports humankind.

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Climate-Smart Breeding for Improved Sesame

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Abstract

Sesame production is increasingly threatened by drought, heat, irregular rainfall, waterlogging, salinity, pests, and diseases. Climate-smart breeding integrates conventional breeding, physiological phenotyping, molecular markers, QTL mapping, GWAS, genomic selection, and genome editing to develop high-yielding, stress-tolerant, stable, non-shattering, and quality-rich cultivars. Such integrated approaches can strengthen sesame resilience, reduce production risks, and support sustainable oilseed production.

Introduction

Sesame (*Sesamum indicum* L.) is one of the oldest cultivated oilseed crops and is popularly known as the “Queen of Oilseeds.” It belongs to the family Pedaliaceae and is mainly cultivated in tropical and subtropical regions of Asia and Africa. Sesame seeds are an important source of edible oil, protein, minerals and natural antioxidants such as sesamin and sesamol. Sesame oil is used not only for cooking but also in pharmaceutical, cosmetic and industrial products. In India, sesame is an important kharif oilseed crop, and a large area is cultivated under rainfed conditions. Although sesame has comparatively good drought tolerance, its production can be seriously affected by climate-related stresses such as drought, high temperature, irregular rainfall, waterlogging, salinity, pests and diseases. These stresses can reduce both seed yield and oil quality. Therefore, modern sesame improvement should not focus only on increasing yield; it should also aim to develop varieties that can maintain good and stable production under changing climatic conditions. This approach is known as climate-smart breeding (Dossa et. al., 2017).

Keywords: Oilseed, Breeding, Physiological, Stress, Production.

Climate-Smart Breeding

Climate-smart breeding is a modern crop improvement approach aimed at developing varieties that can perform well and maintain stable productivity under climate variability and diverse environmental stresses. In sesame, it primarily focuses on achieving high and stable seed yield, improving tolerance to major abiotic and biotic stresses, and enhancing seed and oil quality. Although conventional breeding remains an important component of crop improvement, complex traits such as drought tolerance, heat tolerance, and yield stability are controlled by multiple genes and are strongly influenced by environmental conditions. Therefore, integrating conventional breeding with molecular markers, genomics, physiological screening, and other advanced breeding technologies can improve the accuracy and efficiency of selection and accelerate the development of climate-resilient sesame varieties (Zhang et. al., 2013).

Need for Climate-Smart Breeding in Sesame

Sesame is predominantly cultivated in rainfed and marginal environments, making its productivity highly vulnerable to climate variability and environmental stresses. Drought, particularly during the reproductive stage, can severely reduce plant growth, flowering, capsule development, and seed filling. Similarly, excessively high temperatures can negatively affect flowering, pollen viability, fertilization, and seed development, ultimately leading to yield losses, despite sesame being naturally adapted to warm climates. Irregular rainfall patterns, including delayed monsoons, uneven precipitation, and sudden heavy rainfall, may expose the crop to alternating periods of drought and excess moisture. Waterlogging is especially damaging because sesame is highly sensitive to excess soil moisture, which can impair root function, photosynthesis, and overall plant growth.

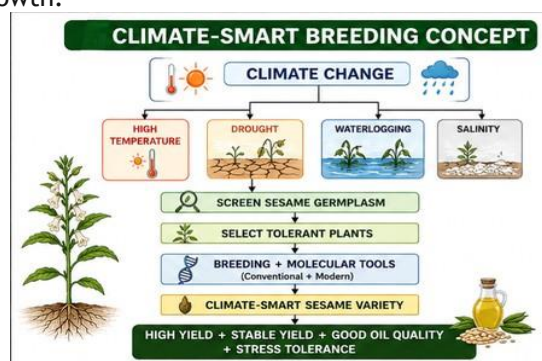


Figure 1: Climate-smart breeding concept for sesame

Salinity further limits crop productivity by disrupting water absorption and nutrient uptake. In addition, climate change can alter the occurrence and severity of insect pests and diseases, as changing temperature and humidity conditions may favor specific pathogens and insect populations (Raj et. al., 2025). Therefore, the development of climate-smart sesame varieties should focus on combining tolerance to multiple environmental stresses with resistance to major biotic stresses to ensure stable and sustainable production under changing climatic conditions (Fig 1).

Major Breeding Objectives

The major goal of climate-smart sesame breeding is to develop high-yielding, stable, stress-tolerant, and farmer-friendly varieties. Key objectives include drought and heat tolerance, waterlogging and salinity tolerance, resistance to pests and diseases, and improved water-use efficiency. Non-shattering capsules, uniform maturity, good seed retention, and suitable plant architecture are also important for reducing harvest losses and supporting mechanization (Wei et al., 2015).

Conventional Breeding Approaches

Traditional breeding remains the foundation of climate-smart sesame improvement. It begins with germplasm evaluation, where landraces, released varieties, breeding lines, and wild *Sesamum* species are screened for useful traits such as stress tolerance, disease resistance, high yield, oil content, early maturity, and capsule-shattering resistance. Selection under both normal and stress conditions helps identify stable and superior genotypes. Hybridization combines desirable traits from different parents, such as high yield with drought tolerance or high oil content with non-shattering capsules. Mutation breeding can further generate new genetic variation for traits such as early maturity, improved plant architecture, and disease resistance (Zhou et. al., 2022).

Molecular and Genomics-Assisted Breeding

Modern molecular technologies can improve the precision and efficiency of sesame breeding. Marker-Assisted Selection (MAS) enables early selection of plants carrying markers linked to desirable traits such as drought tolerance. QTL mapping helps identify genomic regions controlling complex traits, including yield, stress tolerance, oil content, and capsule shattering. Genome-Wide Association Studies (GWAS) reveal genetic regions associated with important agronomic and stress-related traits across diverse germplasm. Genomic selection uses genome-wide marker information to predict breeding values and is useful for complex traits such as yield, stability, and stress tolerance (Qian et. al., 2023). Genome editing, particularly CRISPR-based approaches, offers the potential to precisely modify genes associated with capsule shattering, stress tolerance, disease resistance, plant architecture, and oil quality, although extensive validation, biosafety assessment, and regulatory approval are required before commercial application (Fig 2).

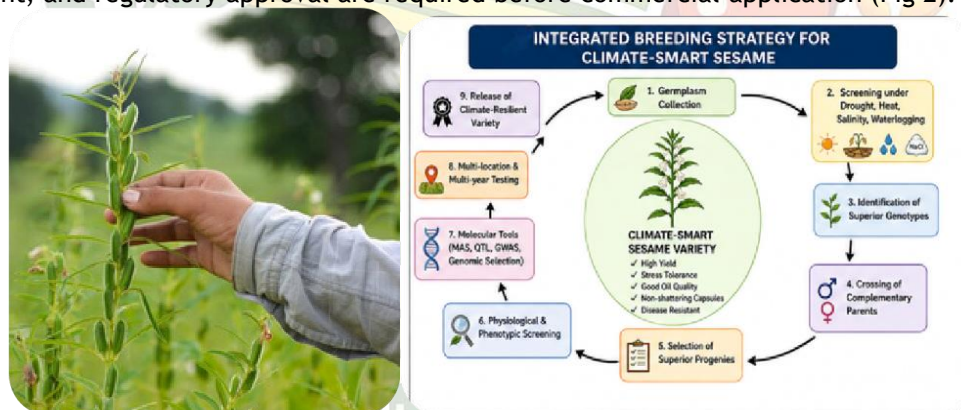


Figure 2: Integrated climate-smart breeding strategy for sesame

Physiological Screening and Phenotyping

Climate-smart sesame breeding should consider physiological traits in addition to seed yield to identify genotypes that perform better under stress. Important traits include root growth, leaf water content, canopy temperature, chlorophyll content, photosynthetic activity, water-use efficiency, flowering time, and seed-filling ability. Genotypes should be evaluated under both stress and non-stress conditions through multi-location and multi-year trials to identify stable performers. An ideal climate-smart sesame variety should combine tolerance to drought, heat, excess moisture, and salinity with high and stable yield, suitable maturity, efficient water and nutrient use, and desirable plant architecture. Non-shattering capsules, uniform maturity, and good seed retention are important for reducing harvest losses and facilitating mechanization. The variety should also possess high oil content, desirable fatty acid composition, good nutritional quality, antioxidant properties, and resistance to major pests and diseases. Overall, climate-smart breeding aims to develop productive, stable, high-quality, and farmer-friendly sesame varieties adapted to changing climatic conditions (Teklu et. al., 2025).

Benefits and Challenges

Climate-smart breeding can help sesame achieve stable yields under variable climates, improve drought and heat tolerance, reduce environmental losses and dependence on irrigation and chemical inputs, enhance oil quality, broaden adaptation across agro-climatic regions, and improve suitability for mechanized harvesting. It can also reduce production risks and support sustainable agriculture, particularly for small and marginal farmers. However, challenges include the complex genetic control of drought tolerance and yield stability, strong environmental effects on genotype performance, and comparatively limited genomic research in sesame. Combining multiple traits such as high yield, stress tolerance, disease resistance, superior oil quality, and capsule non-shattering in a single variety is also difficult. Moreover, useful genes from wild *Sesamum* species may be challenging to transfer due to crossing barriers and undesirable linked traits. Effective breeding therefore requires advanced phenotyping, reliable stress screening, controlled experiments, and multi-location and multi-year evaluation.

Conclusion

Climate change poses major challenges to sesame production through drought, high temperatures, irregular rainfall, waterlogging, salinity, pests, and diseases. Although sesame is relatively resilient, severe and combined stresses can reduce yield and quality. Climate-smart breeding provides a long-term solution by integrating germplasm resources and conventional breeding with physiological screening, molecular markers, QTL mapping, GWAS, genomic selection, and genome-editing technologies. The ultimate goal is to develop high-yielding, stress-tolerant, disease-resistant, non-shattering, oil-rich, and stable sesame varieties. Therefore, integrating genetic diversity, conventional breeding, modern genomics, and reliable field testing is essential for developing climate-resilient sesame varieties that can reduce production risks, improve farmer income, and support sustainable oilseed production.

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Problematic Soils in Anantapur Region: Challenges and Management

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Introduction

Anantapur district, located in the Rayalaseema region of Andhra Pradesh, is one of the most drought-prone areas in India. The district experiences a semi-arid climate characterized by low and erratic rainfall, high temperatures, and frequent droughts.

Agriculture is the primary livelihood, but productivity is constrained by poor soil conditions and water scarcity. Among the various agricultural challenges, **problematic soils**, particularly saline and alkaline (sodic) soils, adversely affect crop growth and soil productivity. These soils occupy a relatively small area but have a significant impact on agricultural sustainability and farm income.

What are Problematic Soils?

Problematic soils are soils with physical or chemical properties that restrict plant growth and reduce agricultural productivity. The major problematic soils in Anantapur are saline soils and alkaline (sodic) soils.

Saline Soils

Saline soils contain excessive concentrations of soluble salts such as:

- Sodium chloride (NaCl)
- Calcium chloride (CaCl₂)
- Magnesium sulphate (MgSO₄)
- Sodium sulphate (Na₂SO₄)

Generally, saline soils have:

- Electrical Conductivity (EC) > 4 dS/m
- pH less than 8.5
- Exchangeable Sodium Percentage (ESP) less than 15

Characteristics

- White salt crust on the soil surface
- Poor seed germination
- Stunted crop growth
- Reduced water absorption by roots
- Wilting even when soil appears moist.

Causes of Salinity

Low Rainfall: Insufficient rainfall fails to wash salts below the root zone.

High Evaporation: Intense summer temperatures draw water upward through capillary action, leaving salts behind.

Saline Groundwater Irrigation: Continuous use of poor-quality groundwater contributes to salt accumulation.

Poor Drainage: Improper drainage prevents removal of excess salts.

Alkaline (Sodic) Soils

Sodic soils contain excessive exchangeable sodium ions on soil colloids.

Generally, sodic soils have:

- pH greater than 8.5
- ESP greater than 15
- Poor soil structure

Characteristics:

- Hard and compact soil
- Surface crust formation
- Poor infiltration rate
- Poor aeration

e. Reduced nutrient availability.

Causes:

Sodium Accumulation: Excess sodium replaces calcium and magnesium on soil particles.

Inadequate Drainage: Poor drainage encourages sodium build-up.

Semi-Arid Climate: High evaporation and low rainfall accelerate sodicity development.

Factors Responsible for Problematic Soils

Low and Erratic Rainfall: Anantapur receives one of the lowest rainfalls in Andhra Pradesh. Due to inadequate rainfall:

- a. Salts are not leached from the root zone.
- b. Salt concentration gradually increases.
- c. Soil moisture remains low.

High Temperature and Evaporation

Summer temperatures often exceed 40°C.

Effects include:

- a. Increased evaporation losses
- b. Upward movement of dissolved salts
- c. Salt deposition near the surface

Soil Characteristics

The district's red soils have:

- a. Low clay content
- b. Low cation exchange capacity
- c. Poor moisture retention

These conditions make the soils more vulnerable to degradation.

Irrigation Water Quality

Many farmers depend on groundwater irrigation.

Problems include:

- a. High salinity levels in groundwater
- b. Excess sodium content
- c. Long-term deterioration of soil structure.

Effects of Problematic Soils on Agriculture

Crop Production Losses: Problematic soils reduce agricultural productivity through:

Poor Germination: High salt concentration inhibits seed emergence.

Reduced Water Uptake: Plants experience physiological drought even when water is available.

Nutrient Imbalance: Availability of essential nutrients decreases:

- a. Nitrogen
- b. Phosphorus
- c. Zinc
- d. Iron.

Root Growth Restriction: Compacted soils limit root penetration and nutrient absorption.

Yield Reduction: Farmers often experience significant yield losses in sensitive crops.

Management Practices

1. Leaching of salts
2. Application of gypsum
3. Addition of organic matter
4. Proper drainage management
5. Rainwater harvesting
6. Cultivation of salt-tolerant crops such as sorghum, pearl millet, cotton, barley, and sunflower.

Problematic Soils in Anantapur Region: Challenges and Management



WHAT ARE PROBLEMATIC SOILS?
Problematic soils are soils with physical or chemical properties that restrict plant growth and reduce agricultural productivity.
The major problematic soils in Anantapur are saline soils and alkaline (sodic) soils.

EFFECTS ON AGRICULTURE

- Reduced crop yields
- Poor germination
- Nutrient imbalance
- Restricted root growth
- Soil degradation

INTRODUCTION
Anantapur district, located in the Rayalaseema region of Andhra Pradesh, is one of the most drought-prone areas in India. The district experiences a semi-arid climate characterized by low and erratic rainfall, high temperatures, and frequent droughts. Agriculture is the primary livelihood, but productivity is constrained by poor soil conditions and water scarcity. Among the various agricultural challenges, problematic soils, particularly saline and alkaline (sodic) soils, adversely affect crop growth and soil productivity. These soils occupy a relatively small area but have a significant impact on agricultural sustainability and farm income.

TYPES OF PROBLEMATIC SOILS IN ANANTAPUR

1. SALINE SOILS
Saline soils contain excessive soluble salts such as chlorides and sulphates.
Characteristics:
• White salt crust on the soil surface
• Poor germination and stunted growth
• Reduced water uptake
Causes:
• Low rainfall
• High evaporation
• Saline irrigation water
• Poor drainage



Fig 1: Saline soil showing white salt deposits

2. ALKALINE (SODIC) SOILS
Sodic soils contain excessive exchangeable sodium and usually have a pH greater than 8.5.
Characteristics:
• Hard and compact soil structure
• Surface crusting
• Poor infiltration and aeration
• Nutrient deficiencies
Causes:
• Sodium accumulation
• Inadequate drainage
• Semi-arid climatic conditions



Fig 2: Sodic soil showing surface crusting

MANAGEMENT IN ACTION - GYPSUM APPLICATION IN SODIC SOIL RECLAMATION



Application of gypsum → Gypsum mixes with the soil → Improved soil structure and better infiltration → Healthier crops and higher productivity



FACTORS RESPONSIBLE FOR PROBLEMATIC SOILS

1. Low and erratic rainfall
2. High temperature and evaporation
3. Poor soil characteristics
4. Use of poor-quality groundwater

MANAGEMENT PRACTICES

1. Leaching of salts
2. Application of gypsum
3. Addition of organic matter
4. Proper drainage management
5. Rainwater harvesting
6. Cultivation of salt-tolerant crops (sorghum, pearl millet, cotton, barley, and sunflower)

CONCLUSION
Problematic soils, particularly saline and sodic soils, pose a major challenge to sustainable agriculture in Anantapur district. Scientific soil reclamation practices such as gypsum application, organic matter incorporation, efficient drainage, and cultivation of salt-tolerant crops can significantly improve soil productivity and sustainability.

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Characteristics and Agronomic Potential of Biochar Derived from Different Feedstocks

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Abstract

Biochar is a carbon-rich, environmentally stable material produced from biomass through thermochemical conversion. It is widely used as a renewable energy source, soil amendment, and adsorbent for wastewater treatment. Compared with open burning of agricultural residues, biochar production reduces air pollution and greenhouse gas emissions. Its properties depend on feedstock type, reactor design, and pyrolysis conditions, which determine its chemical composition, porosity, surface area, and functional groups. Owing to its high carbon content, large specific surface area, porous structure, and high cation/anion exchange capacity, biochar effectively adsorbs heavy metals, nutrients, organic pollutants, and pathogens. These characteristics make biochar a sustainable material for environmental remediation, soil improvement, and pollution control.

Keywords: Biochar, Feedstock, Pyrolysis, Pollution.

Introduction

Biochar contains about 65 to 90 per cent carbon, with the balance being volatile matter and mineral matter. With increasing temperature, the recovery of biochar commonly decreases, whereas the carbon content increases. Biochar from wood has very low ash content, typically less than 2 per cent, whereas the ash content of tyre-derived char is often over 10 per cent. The proportion of biochar comprised of ash increased from 0.67 to 1.26 per cent between 300° C and 800° C.

Biochar is a carbon-rich material produced by the pyrolysis of biomass under oxygen-limited conditions. It has gained significant attention as a sustainable soil amendment due to its ability to improve soil fertility, enhance crop productivity, sequester carbon, and mitigate environmental pollution. The growing availability of agricultural, forestry, and municipal organic wastes has further promoted biochar production as a value-added strategy supporting sustainable waste management and the circular economy. Biochar physicochemical properties are mainly determined by feedstock type and pyrolysis conditions, which influence nutrient composition, carbon stability, porosity, pH, CEC, and specific surface area (SSA). Biochar properties vary with biomass source. Wood-based biochars are rich in stable carbon and improve soil physical properties; crop residue biochars support nutrient cycling; while manure- and biosolid-derived biochars provide abundant nutrients but may contain heavy metals. Overall, biochar enhances soil fertility, water retention, nutrient retention, microbial activity, and carbon sequestration, while reducing nutrient losses and greenhouse gas emissions. Its performance depends on feedstock, pyrolysis conditions, and soil type; therefore, selecting appropriate biomass and ensuring a sustainable, low-cost feedstock supply are essential for producing application-specific biochars.

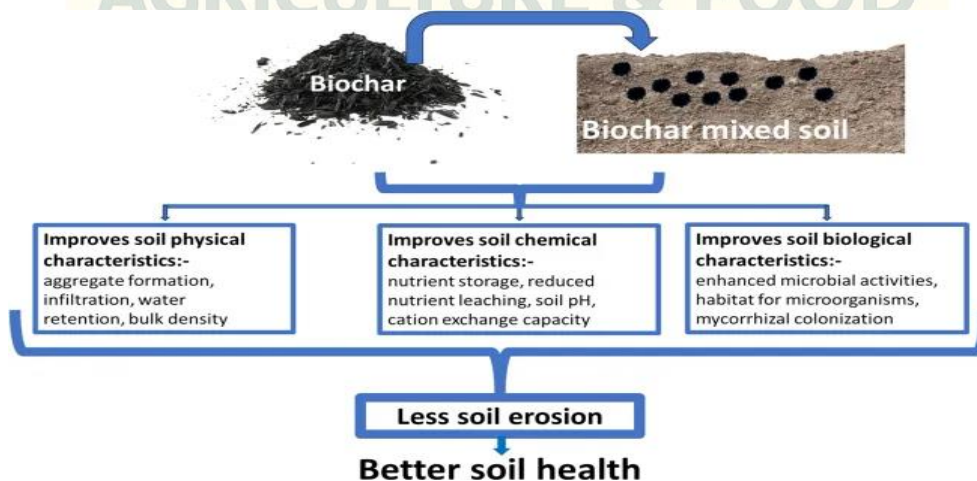


Figure 1: Multifaceted mechanisms affecting soil properties and processes due to the interaction between biochar and soil

History of Biochar

The use of biochar dates back more than 2,000 years and is closely associated with the indigenous communities of the Amazon Basin. They developed the highly fertile **Terra preta** ("Amazonian dark earth") by incorporating charcoal with organic materials such as compost, manure, plant residues, and bones. These soils are exceptionally rich in nutrients, particularly nitrogen (N), phosphorus (P), and potassium (K), and remain highly productive despite prolonged leaching under tropical conditions. Although Terra preta and biochar are related, they differ in composition and carbon structure. The remarkable fertility of Terra preta inspired modern interest in biochar as a sustainable soil amendment. In addition to human-made biochar, natural biochar is also formed through forest and grassland fires and contributes to soil fertility in many regions worldwide.

Biochar Production Process

Biochar is produced by heating biomass such as sugarcane bagasse, wood bark, crop residues, and manure under limited oxygen conditions (pyrolysis). Before pyrolysis, the feedstocks are cleaned, dried, and prepared to ensure uniform heating. The production temperature strongly influences biochar quality, with higher temperatures generally yielding more stable, carbon-rich biochar. Biochars made from crop residues and manure usually have higher ash and nutrient contents due to their greater mineral content, whereas wood-derived biochars have lower ash and higher stable carbon, making them suitable for long-term soil improvement.

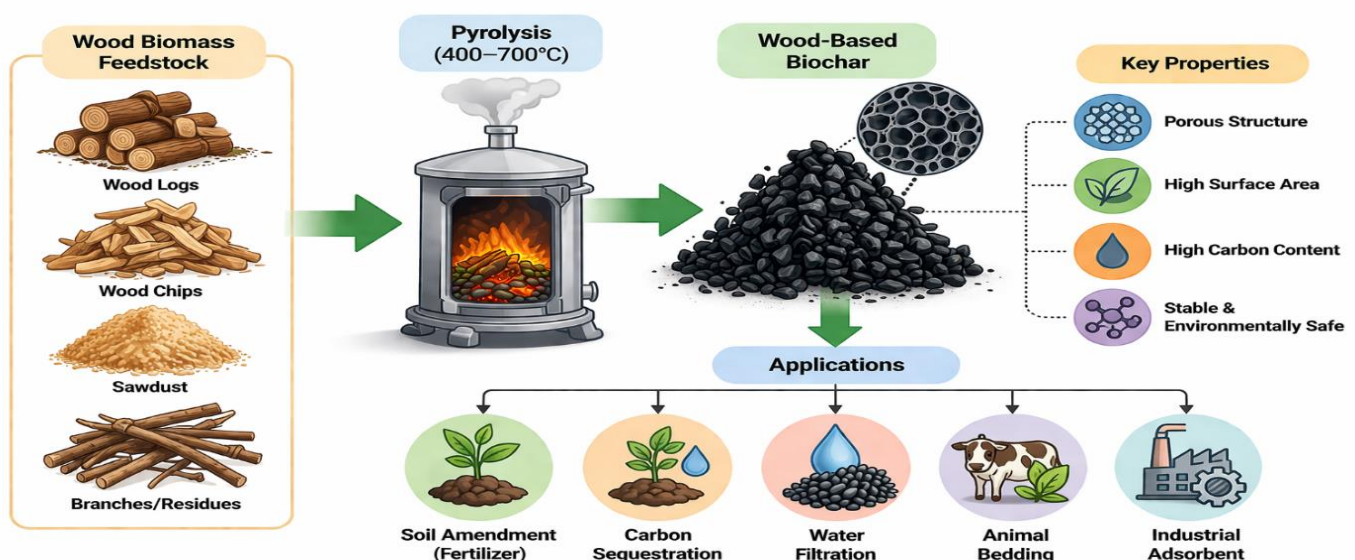
Characterization of Biochar

The properties of biochar vary substantially depending on the source of biomass, the rate at which it is heated, the maximum temperature of heating, and the extent to which volatiles produced during pyrolysis are separated from the biochar before cooling. The level of aromaticity directly influences the stability of biochar in soil environments. Other properties of biochar that influence soil quality are particle size, porosity, surface area, the density and types of surface functional groups, concentrations of biologically available and biologically active compounds in the biochar, and concentrations and forms of inorganic bases that are admixed with the biochar.

Wood-Based Feedstocks

Wood-based biochar, produced from hardwood and softwood under oxygen-limited pyrolysis, is valued for its favorable physical, chemical, and biological properties. It has high porosity, large surface area, and low bulk density, improving soil aeration, water retention, and structure. Rich in stable carbon (60-90%), it promotes long-term carbon sequestration and is typically alkaline, helping to ameliorate acidic soils. Although lower in nitrogen and phosphorus than manure-derived biochar, it can supply potassium and develop moderate to high cation exchange capacity (CEC), enhancing nutrient retention. Surface functional groups and a porous structure support nutrient adsorption and provide habitats for beneficial soil microorganisms. These properties are strongly influenced by pyrolysis temperature, with higher temperatures increasing carbon stability, alkalinity, and porosity while reducing surface functional groups. Overall, wood-based biochar is an effective soil amendment for improving soil fertility, nutrient retention, and sustainable agricultural productivity.

Wood-Based Biochar Production & Applications



Crop Waste Feedstocks

Agricultural crop residues, particularly corn, wheat, and rice, are widely used as biochar feedstocks due to their abundance and contribution to sustainable waste management. They decompose at relatively low pyrolysis temperatures, producing higher biochar yields but lower carbon stability than wood-derived biochar. Among these feedstocks, wheat straw biochar is an excellent potassium source, with available K concentrations (~6,000–30,000 mg kg⁻¹), making it suitable for meeting crop K requirements. Phosphorus availability can be predicted to a limited extent, whereas nitrogen availability from crop residue biochars remains generally low and difficult to predict. Their use also helps reduce crop residue burning and promotes resource recycling, although high ash content and seasonal availability remain challenges.

Manures/Biosolids Feedstocks

Manures and biosolids are nutrient-rich feedstocks for biochar production, characterized by higher bulk density, ash, moisture, and nutrient (N, P, K) contents than woody biomass. Their biochars are generally more alkaline, possess liming potential, and enhance soil fertility, although potential heavy metal contamination requires careful management. Pyrolysis effectively eliminates pathogens, making these feedstocks safe for agricultural use. Among manure-derived biochars, pig manure biochar showed the greatest potential to supply plant-available nitrogen, whereas cattle manure biochar provided insufficient N due to its lower total N content. Despite higher initial N, poultry manure and biosolids biochars exhibited low N availability because of the formation of stable N compounds during pyrolysis. Phosphorus and potassium availability from these biochars was less predictable. Co-pyrolyzing pig manure with crop residues or woody biomass may produce balanced biochars with improved availability of N, P, and K.

Conclusion

1. Recently, a lot of studies have also looked into the use of biochar made from agricultural waste as an environmentally friendly, locally accessible adsorbent for the removal of organic compounds, metals, nutrients, and pathogens. Since biochar has a higher calorific value than raw biomass, it is also now utilised to make briquettes as an alternative fuel in rural areas. Numerous functional groups, such as -CHO (aldehyde), -COOH (carboxyl group), and -OH are frequently found in modified biochar (alcohol or phenol). It achieves remarkable outcomes in the removal of organic pollutants and toxic metals from the environment. Modified biochar operates through both physical and chemical adsorption during the adsorption process.
2. Wood biochar is suitable for carbon sequestration and improving soil structure.
3. Crop residue biochar provides balanced nutrient availability.
4. Manure-derived biochar is nutrient-rich but requires monitoring of heavy metals.
5. Future research should focus on engineered and blended biochars for sustainable agriculture.

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Understanding Farmer's Knowledge, Attitude, and Practices (KAP) towards Drought and Salinity Management in Sugarcane Cultivation

Article ID: 74513

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Introduction

Sugarcane is one of the most important commercial crops in India, playing a vital role in the agricultural economy and rural livelihoods. However, its productivity is increasingly threatened by abiotic stresses such as drought and soil salinity, particularly in semi-arid and irrigated regions. Erratic rainfall patterns, declining groundwater levels, and poor-quality irrigation water have intensified these challenges, leading to reduced cane yield and sugar recovery. Addressing these issues requires not only technological interventions but also a clear understanding of farmers' awareness, perceptions, and on-field management practices. In this context, Knowledge, Attitude, and Practices (KAP) studies provide a comprehensive framework to assess farmers' preparedness in dealing with such stresses. A KAP approach helps identify existing knowledge gaps, behavioural tendencies, and the extent of adoption of recommended practices. This information is crucial for designing effective extension strategies, policy interventions, and capacity-building programs aimed at promoting sustainable sugarcane cultivation under stress conditions.

KAP Study Design and Methodology

The present KAP study was conducted using a structured and pre-tested questionnaire specifically designed for sugarcane farmers. Before final implementation, the questionnaire was pilot tested with a small group of farmers to evaluate its clarity, relevance, and practicality. Based on their feedback, necessary modifications were incorporated. The questionnaire consisted of two major sections. The first section captured socio-demographic and farm-related information of the respondents, including age, gender, education level, caste category, family size, farming experience, income from sugarcane, landholding, sugarcane variety grown, yield levels, and cost of cultivation. These variables are essential for understanding the background characteristics that influence farmers' decision-making and adoption behaviour. The second section focused on the KAP components related to drought and salinity management in sugarcane.

The knowledge (K) section comprised questions with binary responses (Yes/No). It assessed farmers' awareness of critical issues such as the impact of drought stress and soil salinity on sugarcane productivity, knowledge of soil health indicators (pH and electrical conductivity), awareness of tolerant varieties, and understanding of critical growth stages sensitive to water stress. It also included awareness of government schemes for micro-irrigation, use of soil amendments like gypsum, crop insurance provisions, and the effects of poor-quality irrigation water. This section reflects the extent to which farmers are informed about scientific and management aspects of stress mitigation. The attitude (A) component measured farmers' perceptions and beliefs using a five-point Likert scale ranging from "strongly agree" to "strongly disagree". It included statements related to the effectiveness of drip irrigation, importance of soil health improvement, adequacy of government support, and perceived impact of climate change on drought frequency. It also assessed farmers' views on economic benefits of water-saving technologies, manageability of salinity at the farm level, usefulness of crop insurance, and the role of crop diversification in risk reduction. This section provides insights into farmers' willingness and readiness to adopt improved practices. The practice (P) section evaluated the actual adoption of management strategies at the farm level. Farmers responded using three categories: regularly, sometimes, and never. The practices included use of drip or sprinkler irrigation, application of gypsum or other soil amendments, mulching and conservation tillage, soil and water testing, and adjustment of irrigation schedules during drought conditions. It also covered adoption of stress-tolerant varieties, crop insurance, and maintenance of proper drainage systems. This section highlights the gap between knowledge and real-world implementation. To maintain data quality, respondents were briefed about the purpose of the study, and all questions were made mandatory to avoid incomplete responses.

Statistical Techniques for KAP Survey Data Analysis

Appropriate statistical tools have been employed to analyse the collected data and derive meaningful conclusions. The association between socio-demographic characteristics (such as age, education, income, and farming experience) and knowledge or practice variables has been examined using the Chi-square (χ^2) test of independence (Agresti, 2013). This helps identify whether differences in awareness and adoption are influenced by farmers' background characteristics. The relationship among knowledge, attitude, and practice scores has been analysed using the Spearman rank correlation test, a non-parametric method that measures the strength and direction of association between these variables (Spearman, 1987). This analysis helped to assess the extent to which increased knowledge translates into positive attitudes and better management practices. Since attitude data are ordinal in nature, the Kruskal-Wallis's rank-sum test can be used to compare median attitude scores across different socio-demographic groups (Kruskal & Wallis, 1952). This

helps determine whether perceptions vary significantly among different categories of farmers. In addition, the reliability and internal consistency of the KAP questionnaire have been assessed using Cronbach's alpha coefficient (Cronbach, 1951). Values exceeding 0.70 reflect acceptable reliability, indicating that the questionnaire items reliably measure the intended constructs. Figure 1 shows the salinity-affected sugarcane field with visible signs of crop stress and soil salt accumulation.



Figure 1. Salinity-affected sugarcane field showing salt accumulation on the soil surface, leading to reduced productivity.

Conclusion

The KAP study approach provides a holistic understanding of farmers' awareness, perceptions, and adaptation strategies in sugarcane cultivation under drought and salinity stress conditions. By identifying knowledge gaps, attitudinal misconceptions, and constraints in existing practices, it generates valuable insights for policymakers, researchers, and extension agencies. Strengthening farmers' knowledge through targeted training, promoting climate-resilient technologies, and improving access to government schemes can significantly enhance adoption of sustainable practices. Ultimately, such efforts contribute to improving productivity, resilience, and long-term sustainability of sugarcane-based farming systems in stress-prone regions.

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Exploring the Medicinal Value of *Cassia Tora*

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Introduction

There are more than 12,000 species of plants that are edible to mankind. The World Health Organization reports about 80% of people in developing countries rely almost exclusively on traditional medicines available from wild for their primary health care needs. Ethno-botanical investigations show that more than 7,000 species WEPs (Wild Edible Plants) have been used as food in human history directly or indirectly. There are 600 WEP species in India that has contributed to survival of indigenous people.

Cassia tora (*Cassia obtusifolia* / *Senna obtusifolia*) is a small shrub which grows up in warm moist soil throughout the tropical parts of Asian and African countries abundantly in waste places and uncultivated fields up to an altitude of 1000-1400 meters. It is commonly known as *Charota* or *Chakod*, *Tarota*, *Tovora* in India and usually found in different states namely Uttar Pradesh and Madhya Pradesh. The plant is probably native to the Americas but has also spread to a pan-tropical distribution and has become widely naturalized in northern Australia and considered as a weed. This plant is problematic, infesting approximately 600,000 ha in coastal north and far north Queensland.

Medicinal Value of *Cassia Tora*

According to Ayurveda the leaves and seeds are acrid, laxative, antiperiodic, anthelmintic, ophthalmic, liver tonic, cardiogenic and expectorant. *Cassia tora* constitutes an Ayurvedic preparation “*Dadhughnavati*” which is one of the successful antifungal formulations. In Many countries like Japan and Korea the plant is commercially cultivated for medicinal purposes. *Cassia tora* seed has been used in Chinese medicine as aperients and also improve the visual activity. Medicinally active compounds extracted from the seed include the anthraquinones chrysophanic acid, emodin, physcion and obtusin.

In many countries such as Thailand and China ‘*Cassia tora* tea’ has created a new term “Coffee-Tea” which is made of 100% *Cassia tora* with no artificial coloring and no caffeine. It could be a great substitute for coffee and other sodas and in China under it is sold under the name ‘*Juemingzi*’. Besides this, the seed contain high protein and hence can be used in supplement of other food particularly in feeds and additive. The seed is exported from India to Japan where an extract is used in the production of tonic drinks as ‘*Mitsui Japon*’. In addition to being used as medicinal herbs, the seeds are also used as a mordant in dyeing. The methanolic extract of *Cassia tora* seed possessed mosquito larvicidal activity against *Aedes aegypti*, and it is often used as anti-oxidant.

Processed *Cassia tora* meal also contains 30-32% protein and can be used either in conjunction with other feed stuffs or by itself, as it is a complete nutritional feed. The leaves extract are used as laxatives and in the treatment of fungal skin disorders. The leaves are also used as a tea in some parts of India [8]. The paste of the ground, dried root is used in Ayurveda as a treatment for ringworm and snakebite. The gum extracted from *Cassia tora* is Galactomannans nature and contain Mannose to Galactose as 5:1 (JECFA (2009), published in FAO JECFA Monographs 7 (2009). The composition of saccharides is: mannose (77.2-78.9%), Galactose (15.7-14.7%) and Glucose (7.1-6.3%). This gum is used as a flocculants in paper and textiles manufacturing.

Conclusion

Although *Cassia tora* is widely used in different areas, the application for its gum is limited. It could be suggested that Hydroxy-propyl derivative of *Cassia* gum can offer option when the gum are intended to be used in high temperature with high solubility. The application this gum in the field of nutraceutical industries through microencapsulation is not yet reported. Besides this the gum can be explored for manufacturing water resistant biomaterial biocide film as the structure of gum is similar to guar gum. Sodiumcarboxymethyl hydroxypropyl derivative of *Cassia* can be synthesized where normal gum fails in certain situation.

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Fig.1. a) Cassia tora plant b) Cassia tora seed and c) cassia tora gum powder.

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Indigenous Knowledge as Potential Weapon in Post-harvest Pests Management

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In response to environmental and health concerns about widespread use of pesticides, ITK can also be exploited for pests management as alternative approaches. The indigenous traditional methods of Post harvest Pests of North-East India is still practising in the hills districts of Manipur. Tribal people are known for rich indigenous knowledge for controlling the insect-pests which got evolved over generations. Indigenous tribes practice traditional methods used locally available plants resources such as dried leaves/ branch of *A. vulgaris* for repelling insects as well as rodents. The smoke of the *Chullah* (kitchen) is allowed to exposed any post harvest grains to protects from the attack of insects and fungus which also enhance to increases the shelf life. Thus Indigenous traditional knowledge (ITK) can ensure food security and be incorporated as an integral component of IPM for sustaining crop protection in post-harvest pests management.

Traditional Farming System in North-East India

Traditional farming system in north-east India is complex and unique of its own as the land use system in this regions is dominated by slash and burn agriculture(Jhums cultivation) where management of crops and pests are carried out by integrating indigenous knowledge and traditional ecological knowledge of the communities. The knowledge's of indigenous and ecological have been recognized as worldwide by scientific communities and scientists are showing keen interest in traditional agriculture practices because indigenous farmers and their system may be of great importance of pest management in modern agriculture. Therefore, indigenous knowledge should be encouraged as an integral component of IPM. So, that it can also contribute in sustaining the agricultural production using of eco-friendly products in Post harvest Pests management through ITK.

ITK as Weapons of Decision Making

Indigenous knowledge is the knowledge of the indigenous people who inhabited in different geographical regions of the world with their own language, culture, tradition, belief, folklore, rites and rituals. While managing the land and environmental resources for theirs survival; they encounter complex problems in their day to day life which make them to developed a certain decisions to solve their solutions. They are closely interactions to nature and natural resources. Based on their necessities, curiosity and observations knowledge is developed to mitigate with the situations. Hence, indigenous knowledge can exploited in the decision making process as to how, when and where to act depending on the situations. There is considerable public pressure and pressure from environmental scientists to decrease emphasis on chemical control and use biological methods for controlling plant pests and diseases Therefore under this scenario, ITK can also be adopted this knowledge's in managing the menace of emerging post-harvest pests in present days agriculture viz. in grains protection practices to resilient any situations under Global climatic changes (GCC) as biosafety measures.

Present Scenario of ITK over Modern Pests Management

Present methods for post-harvest protection, is mainly based on used of synthetic chemical grain protectant which has been become more popular practice applied so far, in the farming communities because of their getting quick solution facing by them. In other hand majority of the farmers lack awareness that indiscriminate use of pesticides results residual effect in food chain and cause negative impact in health while consumptions of such chemical grain protectant. However, considering with regards to human health implications and non sustainability nature of chemical grain protectant, there is considerable interest in finding alternative control approaches. Researchers and policy planners have been given kin attention, using of eco-friendly products over chemical pesticides in pests management. The advantage of traditional post-harvest pest management methods in taking account of storage loss is being increasingly appreciated. Adopting of traditional practices is their efficacy in controlling one or more types of insect pests, especially at the small farm level as well as for the relative safety in the form in which they are used. Further, some of these methods can even be applied in large scale storage. The most advantageous of adopting indigenous knowledge is cheap, effective practices, environmentally safe and efficient utilization of available natural resources.

Exploitation of Locally Available Plants Resources

Plant based locally available resources is used by the tribal people for repelling post harvest insects as well as rats, such as dried leaves / branches of *A. vulgaris* which are put in and around granaries. This showed that we are blessed by

abundantly resources to take care of the nature. In animal based protection, Pulses are rubbed / coated with pork oil and dried before storing as a post-harvest protection measure. The usage of vegetable oils in stored grain protection is well known but application of oils of animal origin is very rare to see and needs special attention. Traditional post-harvest pest management methods of the ethnic tribes follows such as used of fused electric bulbs are ground and mixed with ground rice and the mixture is used as rodenticide. Ultimately the rats die after consuming the mixture. Some of the plants like *E. blanda* are used to repel insect pests while others such as *D. sinuata* and *E. purseatha* are used as rodenticide. Further, few plants like *C. tomentosa* and *S. parasitica* are used for trapping rats. In addition to use of plants, different types of indigenously designed traps are also used for catching rats. Storing grains in the kitchen is one of the most common methods of post-harvest protection among the indigenous tribes, be it for their own consumption or maintaining seeds for next year sowing.

Promising Traditional Kitchen Designed in Pests and Fungal attacks

It is well known that in majority North-East tribal kitchen is designed in such a way, the smoke of the *Chullah* (cooking place) 2- 3 m above from the ground is allowed to exposed any post harvest grains to protects the grains from the attack of insects and fungus and also enhanced the shelf life of preserved grains. Further, most of the tribes' in the North- East store the grains in traditional granaries, usually built in an open place a little away from the house. This is to ensure proper aeration and different materials like tins, wooden sheets are also put in the poles as rat barriers. It revealed that 40% of the traditional methods against post- harvest pests are found to be based on the principle of repellency.

Potential Utilization of ITK Methods in Post Harvest Pests

Traditional post-harvest pest management methods of the ethnic tribes				
Plant based	Local name	Methodology	Mode of action	District
<i>Artemisia vulgaris</i> L	Maharna (Tn)	Fresh or dried branches/leaves are put in and around granaries, for repelling insects and Rats,	Aroma of the shrub is intolerable	Ukhrul & Senapati
<i>Azadirachta indica</i>	Juss.	Crush and put fresh or dried leaves in around granaries to repel insects	Leaves posses an aroma	Ukhrul
<i>Scorulla parasitica</i> L.	Chithi thou (Mo)	Gum is prepared from the fruits, fix in sticks and put in possible rat runways for trapping	Rats get stuck to the gum	Senapati
<i>Entada pursaetha</i> DC	Kah (Pu),	Equal proportion of ground seed kernel and ground rice is mixed and put in possible rat runways as rodenticide	The seeds are toxic to rats	Senapati
Animal based				
Not available	Pork oil	Rub pulses with pork oil before storing Rub with pork oil before storing	Protects pulses from post-harvest damage	Ukhrul
Miscellaneous				
Not available	Electric bulbs	Mix crushed electric bulbs and ground rice in equal proportion and put in possible rat runways as rodenticide	Rats die after consuming the mixture	Senapati
Not available	Kitchen storage	Pulse, maize, onion etc. are kept in kitchen around 2-3 m above the ground at an angle of 45° from the <i>chullah</i> (cooking place)	Kitchen smoke drives away insects and reduces fungal attack	All tribes

It is also evidence that the indigenous people are aware of the different post-harvest damage namely, insects, rodents and fungi. But in case of fungi idea is explicit in the practices of storing grains in the kitchen and traditional granaries. Grains stored in the kitchen are reported to have less fungal attack because of the heat treatment exposed from kitchen smoking.

Identification and Preservation of Indigenous Plants Possessing Insecticidal

Properties to enhance Food Security: Traditional methods for post-harvest pests caused by pests and disease in the storage impacts on food security. Using of indigenous plants which possess insecticidal properties are being found to offer a safe, low cost, and more dependable method of storage protection, technically feasible, compatible with internal resources of the household and widely used as acceptable methods in other parts of the world as well. Thus one has to identify and preserve the indigenous plants possessing insecticidal properties and which can preserve for long-term period. However this indigenous plants fulfilled both the characters in all, they can be used both in fresh and dried form. Utilization of plants products in dried form is preferentially utilizable and is of great advantages. This traditional practice would be useful in developing low-cost post-harvest management methods, which are eco-friendly with the producer as well as at consumer's level.

To enhance food grain production, which can feed the ever increasing world population, the goals to achieve and to meet of the food demand appears to be through the proper handling of reduction of losses in the storage and the cost of preventing post-harvest loss is relatively less than the cost for producing the same amount of food. About 90% of the potential yield harvested farmers like in North-East store approximately for consumption purpose as well as for seed purpose which is preserved for next season sowing, out of which around 10-40% is lost due to pests and diseases attack. Therefore reduction of this storage loss can mitigate through adopting of improved eco-friendly storage methods and practices are prime importance which would help in enhancing food security. Traditional post-harvest pest management methods indicate that the prevalence of ITK in the areas of Northeast India.

Conclusion

Therefore, due recognition and importance of ITK must be given. Indigenous traditional knowledge (ITK) system is being a need based on locally available resources without any external inputs, they are eco-friendly in nature, have a high cost-benefit ratio and do not pose the risk of the pathogen developing pathogens resistance. Therefore traditional ecological knowledge should be protected, preserved and documented. ITK should incorporate as an integral component of IPM concept in post-harvest pest's management for enhancing the food security.

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AI-Based Disease Detection System: A Smart Guardian for Crop Health

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Abstract

Plant diseases are among the leading causes of yield reduction and economic losses in agriculture, making their timely and accurate detection essential for sustainable crop production. Conventional disease identification methods rely on visual inspection by farmers or experts, which can be time-consuming, subjective, and often unavailable in remote areas. Recent advancements in Artificial Intelligence (AI), Machine Learning (ML), Computer Vision, and deep learning have enabled the development of intelligent disease detection systems that can identify crop diseases rapidly and accurately using images captured by smartphones, drones, or field cameras. These systems analyze visual symptoms such as leaf discoloration, lesions, spots, and texture changes to diagnose diseases and provide instant recommendations for appropriate management practices. AI-powered disease detection not only facilitates early intervention but also minimizes unnecessary pesticide application, reduces production costs, and enhances crop productivity while promoting environmentally sustainable agriculture. With the integration of Internet of Things (IoT), cloud computing, and precision agriculture technologies, these systems are becoming valuable decision-support tools for farmers, extension workers, and researchers. This article highlights the principles, working mechanism, applications, advantages, challenges, and future prospects of AI-based disease detection systems, emphasizing their role in improving crop health monitoring and supporting the transition towards smart and digital agriculture.

Keywords: Artificial Intelligence, Plant Disease Detection, Deep Learning, Computer Vision, Precision Agriculture, Smart Farming, Crop Health Monitoring, Machine Learning.

Introduction

Plant diseases are one of the major challenges affecting agricultural productivity worldwide. Every year, diseases caused by fungi, bacteria, viruses, and pests result in significant crop losses, reducing both yield and quality. According to the Food and Agriculture Organization (FAO), 20-40% of global crop production is lost annually due to plant pests and diseases. In India, where agriculture supports the livelihood of millions of farmers, timely disease detection is essential to ensure food security and improve farm profitability.

Traditionally, disease diagnosis relies on visual inspection by experienced farmers or agricultural experts. However, symptoms of different diseases often appear similar, making accurate identification difficult. Moreover, expert assistance is not always available in remote villages, and delays in diagnosis can allow diseases to spread rapidly.

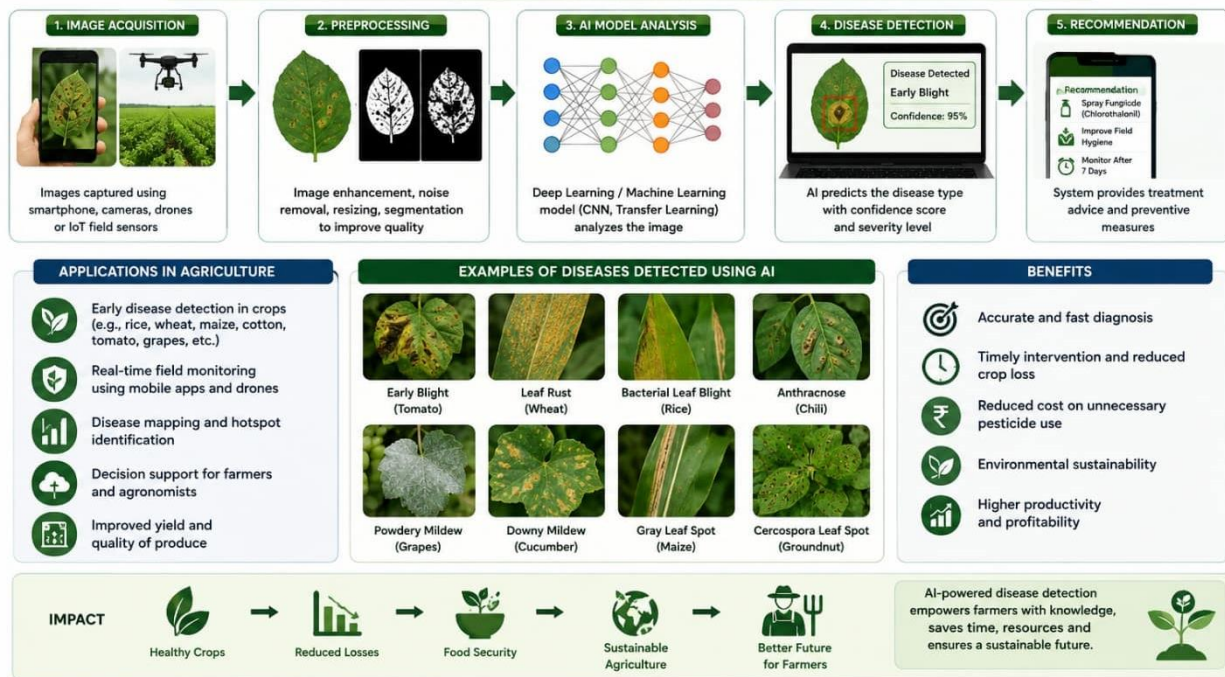
Recent advances in Artificial Intelligence (AI), Machine Learning (ML), Computer Vision, and smartphone technology have led to the development of AI-based disease detection systems. These systems can identify diseases from images of plant leaves, stems, fruits, or flowers within seconds, enabling farmers to take timely corrective measures.

Purpose

Early diagnosis offers several advantages:

1. Prevents disease spread to healthy plants.
2. Reduces crop losses and improves productivity.
3. Minimizes unnecessary pesticide applications.
4. Lowers production costs.
5. Improves crop quality and market value.
6. Promotes environmentally sustainable farming.

Timely intervention can often save an entire crop that might otherwise be severely affected.



AI-Based Disease Detection System

An AI-based disease detection system is a computer application that automatically identifies plant diseases using digital images. Farmers simply capture a photograph of the affected plant using a smartphone or drone. The image is analyzed by an AI model trained on thousands of disease images. Within a few seconds, the system predicts the disease and provides recommendations for management. Such systems are increasingly being developed for crops like wheat, rice, maize, cotton, soybean, tomato, potato, citrus, mango, grapes, and many others. The disease detection process generally involves the following steps:

1. Image Acquisition: Images were taken at controlled lighting conditions to reduce shadows and glare on each leaf. Multiple images are taken at different angles and zoom levels for each leaf to collect the range of leaf disease displays. Metadata tagged includes plant species, disease (if applicable), location latitude and longitude, temperature, humidity, and condition of the soil present at the time. These images were taken in different seasons and regions, as well as agricultural practices, for diversity. Public Agriculture Image Repositories - Datasets like PlantVillage, PlantDoc, and PlantCLEF contain annotated images of many crop species and diseases. Agricultural Research Institutes also partnered with agricultural universities for verified images under experimental conditions.

2. Image Processing: Raw images undergo various pre-processing methods to enhance input quality for the model. Images are resized to a consistent resolution (e.g., 224 × 224 pixels) to satisfy the deep learning architectures. Statistical colour normalization is performed to normalize the illumination. Noise is minimized through Gaussian filtering. Methods of data augmentation, such as rotation and flipping, zooming, and controlled brightness adjustments that artificially expanded the dataset and counteracted overfitting. Background segmentation is applied to remove leaves from other surrounding irrelevant environmental factors.

3. Feature Extraction: The process of feature extraction is critical to plant disease patterning, typically conducted on leaf images because it serves the purpose of converting raw pixel data into structured numerical representations that maximize relevant symptoms. Placing built-in descriptors into an image analysis framework brings together both traditional image processing and deeplearning- based approaches for greater accuracy and robustness. In the traditional method, descriptors (textures) such as the Gray Level Co-occurrence Matrix (GLCM) are calculated to examine the surface patterns of plant leaves by calculating the spatial co-occurrence/relationship (i.e., repeating pixel intensity values) of pixel intensity values so that we identify abnormalities, lesions, or fungal spots. Color histograms are also produced to characterize colors and their distributions, important for identifying lesions that cause discoloration (yellowing, browning, etc.). For deep learned-based methods of feature extraction, we fine-tune pre-trained convolutional neural networks (CNNs) such as VGG16, ResNet50, Efficient-Net to automatically extract systems will be automatically learned hierarchical abstractions from the images. Any model trained on ImageNet, a large-scale image data set, provides the system with the potential to identify more complex relationships between images based on the dominant pattern of IPM-related symptoms of disease and the speed of the training opportunity by its deemed transfer learning. The ability to make use of both a domain-derived descriptor designed by an expert and hierarchically-generated descriptions of disease will allow the model to distinguish between healthy and diseased leaves in a myriad of settings.

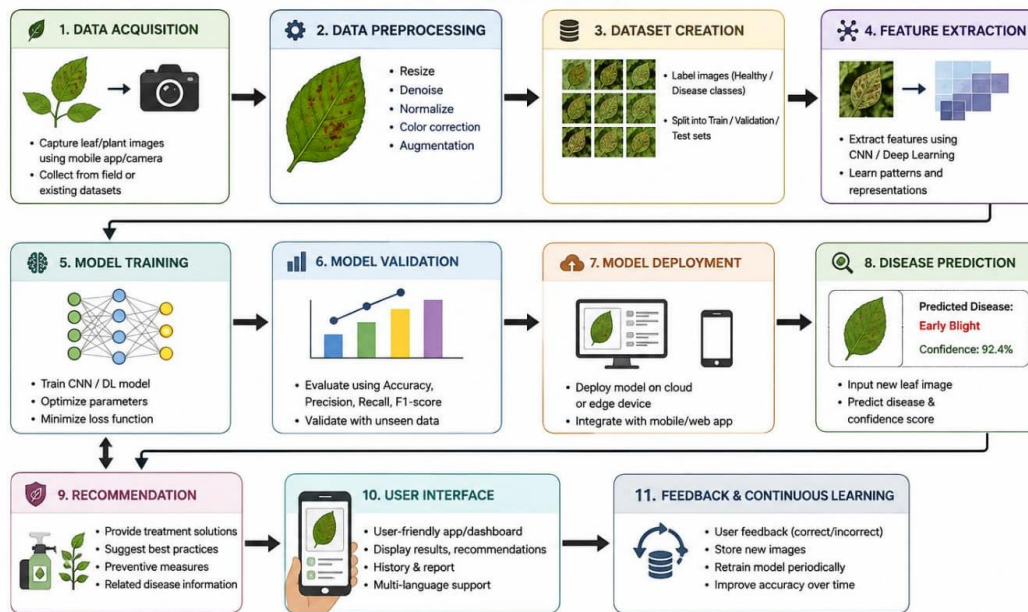
4. Model Selection and Training: Multiple machine learning algorithms are tested to determine the optimal classification model. Traditional classifiers such as Support Vector Machines (SVM), Random Forest (RF), and k-Nearest Neighbors (k-NN) are evaluated alongside deep learning models like CNNs. The dataset is split into training (70%), validation (15%), and testing (15%) subsets. Hyperparameter tuning is performed using grid search and Bayesian optimization to find the best learning rate, number of layers, batch size, and dropout rates. Cross-validation ensures model robustness and prevents overfitting. Thereafter, Model performance is assessed by the metrics accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve (AUCROC).

5. Model Deployment: The best performing model is chosen and "lightweight" models will be optimized for deployment (e.g., TensorFlow Lite, ONNX). Finally, the models will be embedded in a mobile (or web) application, with cloud-processing for extensive computations and with offline prediction capacities, for areas with low internet connectivity. Based on the algorithm and available data base model perform analysis and as a result the disease is detected.



6. Advisory Generation: A diagnosis alone isn't much use to a farmer without a clear next step, which is why the final stage of the system focuses on generating practical, actionable advice. This is often the most valuable part of the whole experience, translating a technical AI output into plain-language farming guidance. A well-designed advisory typically includes cultural and preventive practices, such as removing and destroying infected plant debris, adjusting irrigation timing to reduce leaf wetness, or improving field spacing for better air circulation often the first line of defence against disease spread. It includes biological control options, like beneficial microorganisms or biopesticides that can suppress the pathogen with minimal environmental impact, particularly favoured in organic or sustainable farming systems. It includes chemical treatment recommendations, naming specific, locally approved fungicides, bactericides, or pesticides suited to the diagnosed disease. And critically, it includes dosage and safety guidance, specifying application rates, timing (such as avoiding spraying right before rainfall or during flowering when pollinators are active), and safety precautions like protective equipment and pre-harvest intervals to ensure food safety.

PROCESS FLOW CHART



Advantages for Farmers

AI-powered disease detection offers several practical benefits:

1. Instant disease diagnosis.
2. Easy operation through mobile applications.
3. Reduced dependence on experts.
4. Timely disease management.
5. Lower pesticide consumption.
6. Increased crop productivity.
7. Reduced production costs.
8. Better crop quality.
9. Improved farm profitability.



Challenges

Despite significant progress, several challenges remain:

1. Similar symptoms caused by different diseases.
2. Variations in lighting conditions.
3. Background interference in field images.
4. Limited disease datasets for some crops.
5. Continuous emergence of new disease variants.
6. Limited internet connectivity in rural areas.
7. Requirement for multilingual user interfaces.

Addressing these challenges requires robust datasets, improved AI models, and farmer-friendly applications.

Future Prospects

The future of AI-based disease detection is promising. Emerging developments include:

1. Real-time disease monitoring using drones.
2. AI-powered wearable devices for field scouts.
3. Integration with weather forecasting for disease prediction.
4. IoT-based smart crop monitoring systems.

5. Automatic disease severity estimation.
6. Multilingual advisory services.
7. Offline mobile applications for remote areas.
8. Integration with precision spraying equipment.

These innovations will make disease management more proactive rather than reactive.

Conclusion

Artificial Intelligence is transforming the way plant diseases are detected and managed. AI-based disease detection systems enable farmers to diagnose crop diseases quickly, accurately, and economically using smartphones or drones. By facilitating early intervention, these technologies help reduce crop losses, optimize pesticide use, improve productivity, and support sustainable agriculture. As digital technologies become more accessible and affordable, AI-powered disease detection is expected to become an integral component of modern farming. Continued collaboration among researchers, extension agencies, technology developers, and farmers will be essential to ensure that these innovations reach the field and contribute to resilient and profitable agriculture.

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Genomic Assisted Crop Improvement: A Review

Article ID: 74517

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Abstract

Crop improvement has moved beyond conventional phenotypic selection into an era where the genome itself guides breeding decisions. Genomics-assisted breeding combines molecular markers, high-throughput sequencing, and computational tools to identify genes and quantitative trait loci (QTLs) controlling yield, quality, and stress tolerance. Techniques such as marker-assisted selection, genomic selection, and genome editing allow breeders to shorten breeding cycles, improve selection accuracy, and stack multiple desirable traits with far greater precision than traditional methods. This review outlines the principal genomic tools used in modern plant breeding, their applications across major crops, and the challenges that remain in translating genomic knowledge into farmer-ready varieties. A balanced understanding of these technologies is essential for building climate-resilient and nutritionally secure agriculture.

Keywords: Genomics, Crop improvement, Genomic selection, QTL mapping, Genome editing, CRISPR-Cas9, Plant breeding.

Introduction

Global agriculture faces the combined pressure of a growing population, shrinking arable land, and increasingly erratic climate patterns. Conventional plant breeding, which relies on phenotypic selection across successive generations, is often slow and imprecise because many important traits are governed by multiple genes with small individual effects. The completion of genome sequencing projects for rice, wheat, maize, and numerous other crops has opened the door to genomics-assisted breeding, a discipline that uses DNA-level information to make breeding faster, more accurate, and more targeted. By linking specific genomic regions to observable traits, breeders can now select superior plants at the seedling stage itself, well before the trait is expressed physically, thereby saving years of field evaluation. Genomics-assisted crop improvement is not a single technique but a toolkit that includes molecular marker technology, whole-genome sequencing, association mapping, genomic selection models, and precise genome editing platforms. Each tool addresses a different bottleneck in the breeding pipeline, and together they form the backbone of what is often called the next green revolution (Fig 1) (Kumawat et. al., 2024).

Genomics-Assisted Breeding Pipeline

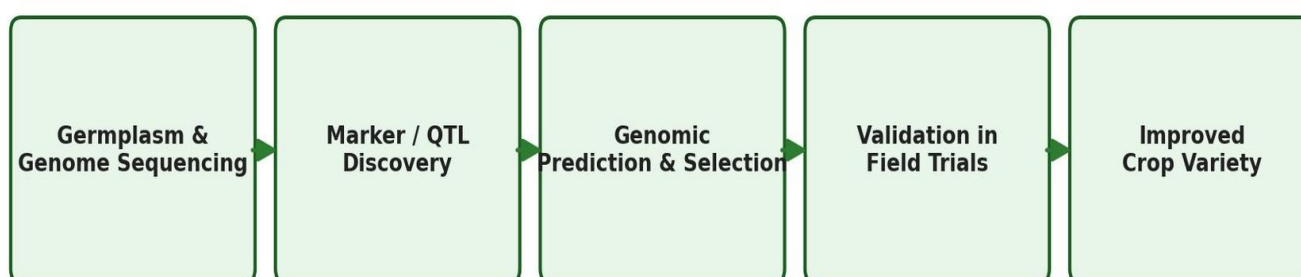


Figure 1: Typical stages in a genomics-assisted crop breeding pipeline

Molecular Markers and QTL Mapping

Molecular markers are identifiable DNA sequences whose inheritance can be tracked and correlated with a trait of interest. Early marker systems such as RFLP and RAPD have largely given way to more informative and reproducible markers like SSRs (microsatellites) and SNPs (single nucleotide polymorphisms). Using biparental or multi-parent mapping populations, researchers can perform QTL mapping to pinpoint chromosomal regions associated with traits such as drought tolerance, grain quality, and disease resistance. Once a QTL is validated across environments, the flanking markers become a reliable tag that breeders can use for years without needing to re-evaluate the underlying phenotype every generation (Hasan et. al., 2021).

Marker-Assisted Selection (MAS)

Marker-assisted selection uses the markers linked to a known QTL or gene to select plants carrying the desirable allele, without waiting for the trait to appear in the field. MAS is especially valuable for traits that are difficult, slow, or destructive to measure directly, such as resistance to a soil-borne pathogen or tolerance to submergence. A well-known

success story is the introgression of the SUB1 gene into popular rice varieties to confer flash-flood tolerance, achieved through marker-assisted backcrossing while keeping the recurrent parent's other desirable characteristics intact. MAS is most effective for traits controlled by one or a few major genes, but its accuracy diminishes for complex, polygenic traits (He et. al., 2014).

Genomic Selection (GS)

For traits governed by many genes of small effect, such as yield or overall stress resilience, genomic selection has proven far more powerful than single-marker approaches. GS uses genome-wide marker data from a training population with known phenotypes to build a statistical prediction model, which is then applied to estimate the breeding value of new, unphenotyped individuals based on their marker profile alone. Because selection decisions can be made purely from genotype data, GS dramatically shortens the breeding cycle and allows simultaneous improvement of several complex traits. It is now routinely applied in maize, wheat, and dairy cattle breeding programmes worldwide, and its use in vegetable and horticultural crops is expanding rapidly as sequencing costs continue to fall (Table 1) (Roorkiwal et. al., 2021).

Table 1: Comparison of Key Genomics-Assisted Breeding Approaches:

Approach	Best Suited For	Technology	Typical Outcome
Marker-Assisted Selection (MAS)	Traits controlled by one or few major genes (e.g., disease resistance)	SSR / SNP markers linked to a known gene	Precise introgression of a target gene via backcrossing
Genomic Selection (GS)	Complex, polygenic traits (e.g., yield, drought tolerance)	Genome-wide markers + statistical prediction models	Early, whole-genome estimate of breeding value
Genome Editing (CRISPR-Cas9)	Precise modification of a specific known gene	Guide RNA + Cas9 nuclease	Targeted trait change without introducing foreign DNA

Genome Editing: CRISPR-Cas9 and Beyond

Genome editing technologies, particularly CRISPR-Cas9, allow breeders to make precise, targeted changes directly within a plant's own genome rather than merely selecting among existing natural variants. A guide RNA directs the Cas9 enzyme to a specific DNA sequence, where it introduces a cut that the cell repairs, often disabling or subtly altering the targeted gene. This precision has been used to develop rice with improved blast resistance, tomatoes with extended shelf life, and wheat with reduced susceptibility to powdery mildew. Because CRISPR edits can, in many cases, be indistinguishable from naturally occurring mutations, several countries have begun to regulate gene-edited crops separately from transgenic (GMO) crops, which has implications for how quickly these varieties can reach farmers (Kumawat et. al., 2024).

Challenges and Limitations

Despite its promise, genomics-assisted breeding faces real constraints. Building accurate prediction models for genomic selection requires large, well-phenotyped training populations, and phenotyping itself remains a costly, labour-intensive bottleneck compared to genotyping. Many important agronomic traits are strongly influenced by genotype-by-environment interactions, meaning a marker validated in one location or season may not perform reliably elsewhere. Regulatory uncertainty around genome-edited crops varies widely between countries, creating hurdles for commercialisation. Finally, small and marginal farmers, who make up the majority of growers in countries like India, need affordable seed delivery systems and extension support to actually benefit from genomically improved varieties, not just the technology itself (Ahmar et. al., 2021).

Future Outlook

The convergence of falling sequencing costs, high-throughput phenotyping platforms (drones, imaging sensors, and remote sensing), and artificial intelligence-based prediction models is expected to make genomics-assisted breeding faster and more accessible over the coming decade. Pan-genome references that capture the full diversity within a crop species, rather than a single reference genome, are improving the discovery of rare but valuable alleles. Integrating genomic tools with participatory breeding approaches, where farmers help evaluate candidate lines under real field conditions, will be essential to ensure that genomically improved varieties are not only genetically superior but also locally adapted and readily adopted.

Conclusion

Genomics-assisted crop improvement represents a fundamental shift from breeding based on what a plant looks like to breeding based on what its DNA can tell us in advance. Marker-assisted selection, genomic selection, and genome editing each address different breeding challenges, and used together they can substantially shorten the time needed to develop

climate-resilient, high-yielding, and nutritionally superior crop varieties. Realising the full potential of these tools will require continued investment in phenotyping infrastructure, supportive and science-based regulation, and delivery mechanisms that bring the benefits of genomic breeding directly to farmers' fields.

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Export Scenario of Fox Nut (Makhana) from India

Article ID: 74518

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Introduction

Fox nuts, also known as makhana or lotus seeds, are a healthy, low-calorie super food packed with protein, fiber, and essential minerals like magnesium and potassium. They support weight loss, improve heart health, regulate blood sugar, and reduce inflammation.

Makhana, also known as fox nuts or lotus seeds, is a highly nutritious food widely consumed across India.

It is commonly used in snacks, sweets, and fasting dishes due to its light texture and health benefits.

Makhana cultivation requires shallow water bodies such as ponds, wetlands and lakes, making it suitable for specific regions with abundant water resources.

Over the years, certain states in India have developed large-scale makhana farming, but one state clearly leads in production due to its natural advantages and traditional expertise.



Health Benefits

1. **Aids Weight Loss:** High fiber and protein keep you full longer and stop hunger cravings.
2. **Manages Diabetes:** Low glycemic index stops rapid blood sugar spikes.
3. **Supports Heart Health:** High magnesium and potassium help control blood pressure.
4. **Improves Digestion:** Dietary fiber prevents constipation and helps gut health.
5. **Boosts Skin Anti-Aging:** Antioxidants like flavonoids fight free radical damage and protect skin.
6. **Strengthens Bones:** Rich calcium content builds bone density and strength.

Nutritional Ingredients of Makhana

Plain Makhana (fox nuts or lotus seeds) are a light, nutrient-dense snack. Per 100 grams, they provide about 347 to 356 calories, 9.7g of protein, 76.9g of carbohydrates, 14.5g of fiber, and virtually zero fat (0.1g). They are also naturally gluten-free and rich in calcium, magnesium, and potassium.

Macronutrients (Per 100g):

- a. **Calories:** ~347-356 kcal
- b. **Protein:** ~9.7 g
- c. **Carbohydrates:** ~76.9 g
- d. **Dietary Fiber:** ~14.5 g
- e. **Total Fat:** ~0.1 g
- f. **Sugars:** 0 g

Key Minerals & Vitamins:

- Calcium:** Strengthens bones and teeth
- Magnesium:** Supports nerve function and heart health
- Potassium:** Helps regulate blood pressure
- Phosphorus:** Promotes overall cellular health and energy metabolism

Health Highlights:

- Low Fat & Low Sodium:** Makes them a heart-friendly snack option.
- Low Glycemic Index:** Helps maintain steady blood sugar levels without sharp spikes.
- High Satiety:** The combination of fiber and low calories helps curb hunger and supports weight management.

Major Fox Nut (Makhana) Producing States in India

Bihar is the leading state for makhana (foxnut) production in India, accounting for about 80% to 90% of the country's total output.

Other states that cultivate makhana on a smaller scale include West Bengal, Manipur, Tripura, Assam, Jammu & Kashmir, Odisha, Rajasthan, Madhya Pradesh, and Uttar Pradesh.

Farmers in Bihar have been growing makhana for generations, using traditional knowledge along with modern farming methods. The large-scale production in Bihar has made it the leading hub for makhana farming in India.

Share of Makhana in Total Agri Export

The exact monetary share of Makhana (fox nut) in India's total agricultural export basket is **less than 0.1%**, as it remains an emerging, niche commodity compared to major exports like rice, marine products, and spices. However, it is one of the fastest-growing agri-exports, with annual shipments reaching approximately **\$30.5 million (₹255 crore)**.

Strategic Growth Boosters

India exports makhana (fox nuts) to over 50 countries, with the primary global importers being the United States, United Arab Emirates (UAE), United Kingdom, Canada, Australia, and Singapore.

Top Importing Countries

- United States:** The largest buyer; accounts for roughly 30% of total exports due to high demand for vegan and healthy snacks. Takes about 30% to 40% of total exports
- United Arab Emirates (UAE):** A major hub driven by a large South Asian diaspora and strong retail/gifting demand. Accounts for roughly 17% to 20% volume.
- United Kingdom:** Takes about 15% share. Key European entry points include Germany and the Netherlands.
- Canada:** Popular within health-conscious and organic food consumer segments. Ranks high for steady volume.
- Australia & Singapore:** Growing wellness and organic markets that regularly stock functional foods. Singapore, Malaysia, and Australia show steady year-over-year import growth.
- Japan & European Union (Germany, France):** Emerging regions importing makhana for functional foods and healthy aging products.

Table no -1 India's Makhana (Fox Nut) production trends and cultivation methods:

Area and production of Makhana (Fox Nut) in India		
Year	Seed production (MT)	Area (hect)
2020	25000-27000	23000-25000
2021	27000-28000	46000-48000
2022	28000-30000	55000-57400
2023	30000-32000	57000-58000
2024	32000-35000	58000-60000
2025 E	35000-40000	60000-63000

Source: APEDA

Table no -2 Methods of Makhana (Fox Nut) Cultivation in India:

Methods of Makhana (Fox Nut) Cultivation in India		
Method	Key Feature	Benefit
Pond Based Traditional, Most Widely	Traditional, Most Widely used	High Yield, Low Input Cost
Field Based	Suitable for non-pond Areas	Expands Cultivation to New Regions
Makhana + Fish (Integrated)	Dual Production System	Higher Profit, Efficient Resource Use

Source: APEDA

India leads global Makhana production, with Bihar contributing ~80-85% of the world's supply. From 2020 to 2025, cultivation area grew 40-50% (25,000-27,000 to 35,000-40,000 hectares), and production nearly doubled (32,000-35,000 to 60,000- 63,000 MT), driven by improved farming practices, traditional pond-based and field-based cultivation, and integrated Makhana fish systems.

1. These systems enhance profitability and resource use, expanding cultivation to new regions.

2. India has a strong opportunity to position Makhana as a premium healthy snack in global markets, leveraging the production dominance, rising superfood demand, and high-margin value-added products, especially in health-conscious markets like the US, EU, Middle East, and South-East Asia.

Table -3 Indian Makhana export trends for last five years (2020-2025):

Year	Qty exported in MT
2020	6700
2021	9320
2022	14500
2023	20080
2024	25130
2025	14000

Size	Grade	Usage	Category
12-15 MM	4 Suta	Economical, widely used in flavoring	Regular
15-18 MM	5 Suta	Popular for regular snacking	Good
18-21 MM	6 Suta	Premium market grade	High
> 21 MM	7 Suta	Extra-large, export-ready, high-value	Premium

Conclusion

The global export scope for Makhana (fox nuts) is **highly lucrative and expanding rapidly**, with India commanding a near-monopoly by producing approximately **90% of the world's global supply**. Driven by a global shift toward plant-based, gluten-free superfoods, Indian makhana exports reached **25,130 metric tons** valued at **₹255 crore (~\$30.5 million)**,

India controls over 90% of the global makhana supply. Within India, the state of **Bihar acts as the primary hub**, cultivating 85-90% of the entire global volume. This grants Indian exporters unmatched leverage over global pricing and supply chains.

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Plant-Microbe Partnerships: How Beneficial Microorganisms Help Crops Survive

Article ID: 74519

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Introduction

Plants continuously interact with microorganisms living around their roots and within plant tissues. These beneficial microorganisms can influence plant growth, nutrient acquisition and tolerance to environmental stresses.

Drought, salinity and extreme temperatures can disturb plant water relations, nutrient balance and cellular metabolism. Beneficial microorganisms can help plants cope with these stresses by improving root development, regulating hormones, maintaining antioxidant defence and supporting nutrient uptake.

Understanding these plant-microbe interactions are therefore important for developing sustainable strategies for climate-resilient agriculture.

Where Do Beneficial Microbes Live?

Beneficial microorganisms are commonly found in the **rhizosphere**, the soil region influenced by plant roots, and may also colonize the root surface or internal plant tissues.

Important groups include plant growth-promoting rhizobacteria (PGPR), rhizobia, arbuscular mycorrhizal fungi and beneficial endophytic microorganisms. These microbes can establish close associations with plants and influence several physiological processes.

Recent studies describe the plant-associated microbiome as an important component of plant adaptation to environmental stress.

How Microbes Promote Plant Growth

Beneficial microbes can stimulate plant growth through several mechanisms. Some bacteria produce plant hormones such as indole-3-acetic acid (IAA), while others improve nutrient availability through phosphate solubilization, nitrogen fixation and siderophore production.

Certain microorganisms produce **ACC deaminase**, an enzyme that can reduce stress-induced ethylene accumulation. Lower ethylene levels can support root growth and help plants maintain development under adverse conditions.

These combined effects can improve root architecture and increase the plant's ability to acquire water and nutrients.

Helping Plants Fight Salinity Stress

Salinity creates both osmotic stress and ion toxicity. Excess sodium (Na^+) can disturb potassium (K^+) balance and impair important cellular processes.

Beneficial microorganisms can improve plant performance under salinity by supporting water and nutrient uptake, regulating ion balance and enhancing antioxidant defence. They may also stimulate the accumulation of osmoprotectants and influence genes involved in stress adaptation.

Plant growth-promoting microorganisms have therefore attracted considerable interest as potential biological tools for improving crop performance in salt-affected soils.

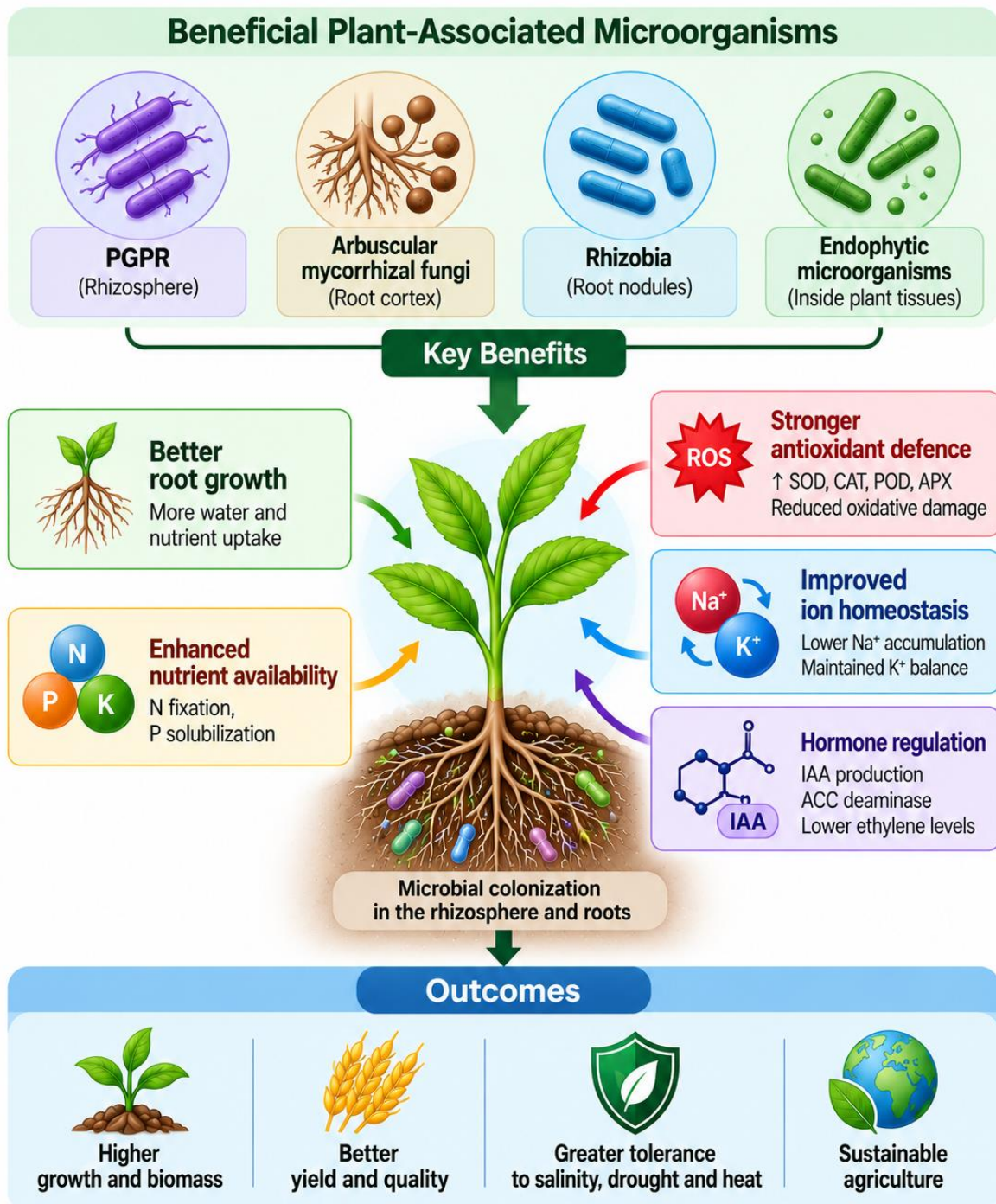


Figure 1. Major mechanisms through which beneficial plant-associated microorganisms improve crop growth and abiotic stress tolerance

Microbes and Oxidative Stress

Abiotic stresses often increase the production of reactive oxygen species (ROS). Excessive ROS can damage membranes, proteins and other cellular components.

Beneficial microorganisms can strengthen the plant antioxidant system by influencing enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POD) and ascorbate peroxidase (APX).

Thus, microbial associations can help maintain redox balance while allowing controlled ROS signalling required for stress responses.

Mycorrhizal Fungi: Extending the Root System

Arbuscular mycorrhizal fungi form symbiotic associations with plant roots and develop fungal structures that extend into the surrounding soil.

These fungal networks can increase the effective soil volume explored by roots and improve water and nutrient acquisition. Under salinity, mycorrhizal associations have also been linked with improved photosynthesis, antioxidant responses, ion regulation and accumulation of compatible solutes.

From Microbes to Molecular Responses

Plant-microbe interactions are not limited to changes in root growth. Microbial signals can influence plant hormones, antioxidant pathways and stress-responsive gene expression.

Modern techniques such as transcriptomics, metagenomics and metabolomics are helping researchers identify how microbial communities interact with plants under stress. These approaches may allow the identification of microbial strains and molecular pathways associated with improved stress tolerance.

Such knowledge can support the development of targeted microbial inoculants for specific crops and environments.

From Laboratory to Field

Although beneficial microorganisms show considerable potential, their performance can vary under field conditions. Soil properties, climate, crop genotype, microbial competition and agricultural practices can influence successful microbial colonization.

Therefore, promising microbial strains need to be evaluated across different environments before large-scale application. Combining microbial inoculants with suitable agronomic practices may provide a more reliable approach to improving crop resilience.

Conclusion

Beneficial microorganisms represent an important biological resource for sustainable and climate-resilient agriculture. Through improved nutrient acquisition, root development, hormone regulation, antioxidant defence and stress-responsive signalling, plant-associated microbes can strengthen crop adaptation to drought, salinity and other environmental stresses.

Future research integrating microbiology, molecular biology, genomics and plant physiology will be essential for converting these natural plant-microbe partnerships into reliable agricultural technologies.

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Plant Stress Memory: How Crops Remember and Prepare for Future Stress

Article ID: 74520

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Introduction

Plants cannot move away from drought, salinity, heat or other environmental stresses. Instead, they continuously adjust their physiology and molecular responses to survive changing conditions. Interestingly, plants can retain information from an earlier stress exposure and respond differently when the stress occurs again.

This phenomenon is known as **plant stress memory**. Previous stress exposure can prime plants for faster or stronger responses during subsequent stress, contributing to plant resilience under fluctuating environments.

What is Plant Stress Memory?

Stress memory does not mean that plants have a nervous system or memory like animals. Rather, previous stress can leave molecular and physiological changes that influence subsequent responses.

These changes may occur at the level of gene expression, proteins, metabolites, hormones and chromatin structure. As a result, a previously stressed plant may activate protective responses more rapidly when exposed to stress again.

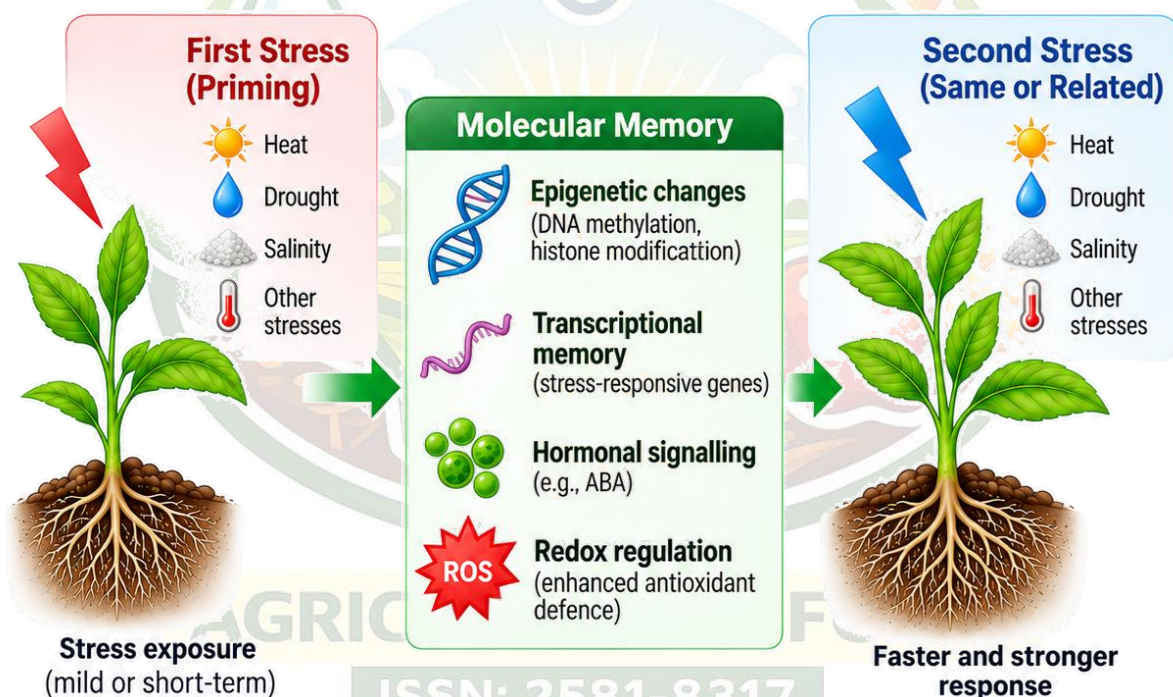


Figure 1. Molecular and physiological mechanisms involved in plant stress memory and improved response to recurrent stress

Epigenetics: The Molecular Memory

Epigenetic regulation is an important component of plant stress memory. Stress exposure can modify **DNA methylation**, **histones** and **chromatin organization**, thereby changing the accessibility and activity of stress-responsive genes.

Small RNAs can also participate in regulating gene expression during stress. These modifications may persist after the original stress has disappeared, providing a molecular basis for enhanced responses during later stress exposure.

Transcriptional Memory

One of the most important features of stress memory is **transcriptional memory**. Some genes remain activated or become more strongly activated when the plant encounters the same or a related stress again.

For example, a previous drought or heat episode can modify the expression pattern of stress-responsive genes, allowing plants to react more efficiently during subsequent exposure. Transcriptional memory can therefore connect earlier environmental experience with future gene regulation.

Hormones and Reactive Oxygen Species

Plant hormones also contribute to stress memory. **Abscisic acid (ABA)** plays a central role in drought and osmotic stress responses, while interactions with other hormones help coordinate growth and defence.

Reactive oxygen species (ROS) are also important. Although excessive ROS can damage cells, controlled ROS production acts as a signalling mechanism. Previous stress can modify antioxidant capacity and redox signalling, helping plants respond more effectively to later stress.

Can Stress Memory Help Crop Improvement?

Stress memory has potential applications in agriculture. **Priming treatments** can expose plants or seeds to mild stimuli before severe stress, potentially preparing their defence systems for future challenges.

Modern approaches such as transcriptomics, epigenomics, metabolomics and genome-wide analysis can help identify molecular markers associated with stress memory. Such information may support the selection and development of crops with improved resilience.

However, stress memory is influenced by stress intensity, duration, plant developmental stage and genotype. Therefore, laboratory observations must be carefully validated under field conditions.

From Plant Memory to Climate-Resilient Crops

With climate change increasing the frequency of repeated and unpredictable stresses, understanding stress memory could become increasingly important. Researchers are exploring whether molecular and epigenetic information can be incorporated into breeding and crop-management strategies.

Recent work has also highlighted **epibreeding**, in which useful epigenetic variation may be identified and potentially exploited alongside conventional genetic approaches. Emerging technologies such as epigenome-wide association studies and CRISPR-based epigenome editing may further improve our ability to study these mechanisms.

Conclusion

Plant stress memory represents an important mechanism through which crops can improve their response to recurring environmental challenges. Epigenetic modifications, transcriptional regulation, hormones, ROS signalling and metabolic changes work together to establish this adaptive memory.

Understanding these mechanisms can provide new opportunities for developing climate-resilient crops. The major challenge is to translate molecular discoveries into reliable agricultural strategies that improve stress tolerance without compromising growth and yield.

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Plant Biostimulants: Nature-Based Tools for Climate-Resilient Agriculture

Article ID: 74521

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Introduction

Climate change, salinity, drought, heat and nutrient limitations are increasingly affecting crop productivity. Plants exposed to these stresses experience reduced growth, impaired photosynthesis and increased oxidative damage.

Plant biostimulants are emerging as sustainable tools that can stimulate natural plant processes and improve nutrient-use efficiency, growth and tolerance to environmental stress. They include seaweed extracts, protein hydrolysates, amino acids, humic substances and beneficial microorganisms.

How Do Biostimulants Help Plants?

Biostimulants can influence several physiological and biochemical processes. They may promote root development, improve nutrient uptake and enhance photosynthetic activity.

Under stress conditions, biostimulants can strengthen antioxidant defence by increasing the activity of enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POD) and ascorbate peroxidase (APX). This helps plants maintain a better balance between reactive oxygen species (ROS) production and detoxification.

Improving Tolerance to Salinity and Drought

Salinity and drought cause osmotic stress and disturb cellular water balance. Salinity can additionally lead to excessive accumulation of sodium (Na^+), which interferes with potassium (K^+) nutrition.

Biostimulants may improve stress tolerance by supporting root growth, osmotic adjustment, antioxidant defence and nutrient uptake. Some products can also influence stress-responsive signalling and gene expression.

However, their effectiveness depends on crop species, genotype, dose, formulation and environmental conditions. Therefore, field validation is important before large-scale application.

Major Sources of Biostimulants

Seaweed and microalgal extracts: These contain various bioactive compounds that can stimulate plant growth and stress responses. Microalgae and cyanobacteria are also being investigated as promising sources of sustainable agricultural biostimulants.

Amino acids and protein hydrolysates: These products can support nitrogen metabolism, root development and antioxidant activity. They may also contribute to osmotic adjustment under stress.

Microbial biostimulants: Beneficial bacteria and fungi can improve nutrient acquisition, root development and plant stress responses through interactions between microorganisms and plant roots.

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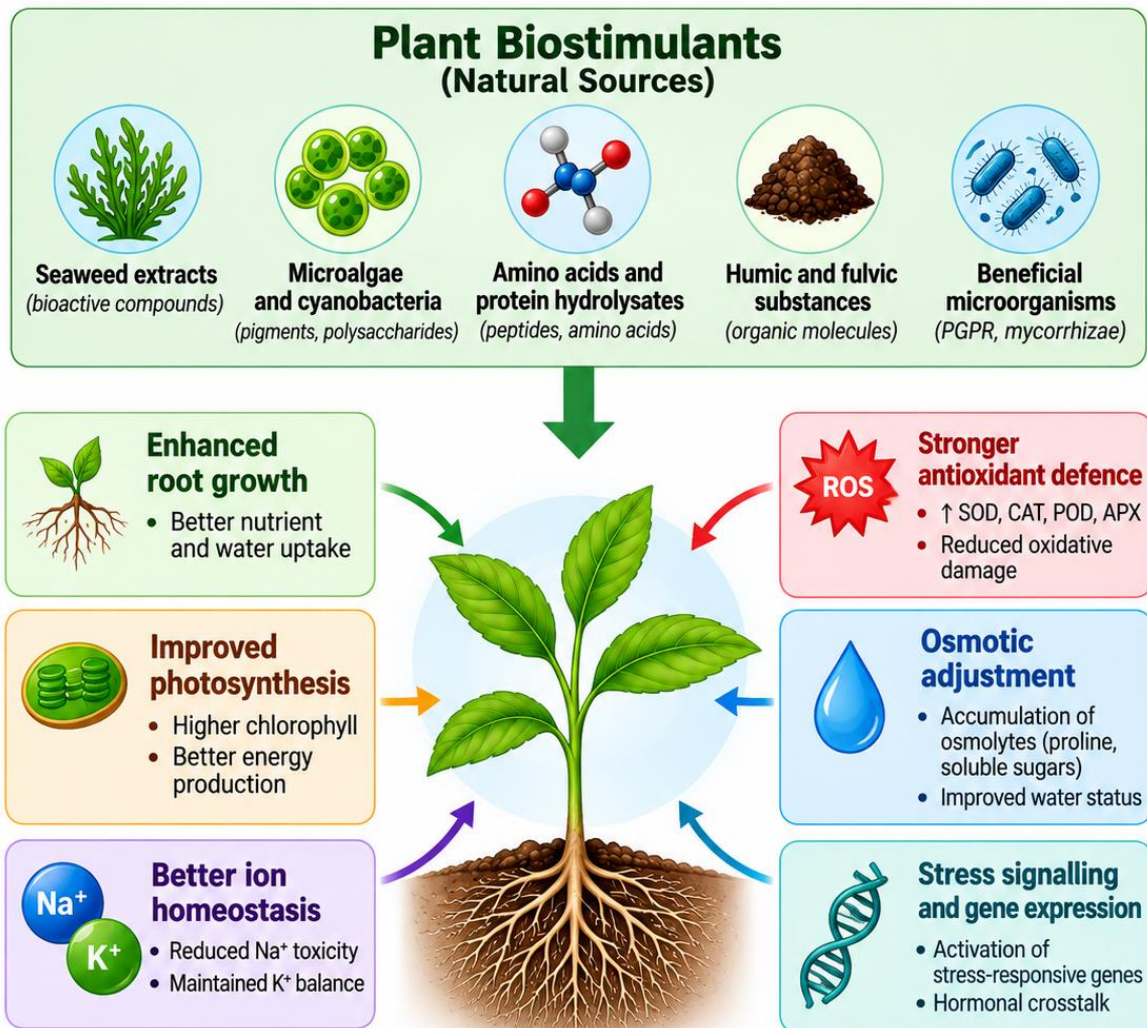


Figure 1. General mechanisms through which plant biostimulants improve crop growth and stress tolerance.

From Molecular Responses to Crop Improvement

Modern molecular technologies are helping researchers understand how biostimulants affect plants. Gene-expression analysis, transcriptomics, proteomics and metabolomics can identify pathways involved in nutrient metabolism, antioxidant defence and stress tolerance.

This knowledge may help develop crop- and stress-specific biostimulant formulations rather than relying only on empirical applications.

A Promising Tool for Sustainable Agriculture

Biostimulants should not be considered replacements for fertilizers or good agronomic practices. Instead, they can complement existing crop-management strategies by helping plants use nutrients and environmental resources more efficiently.

Their successful integration with precision agriculture, breeding and molecular biotechnology could contribute to more resilient and sustainable crop production.

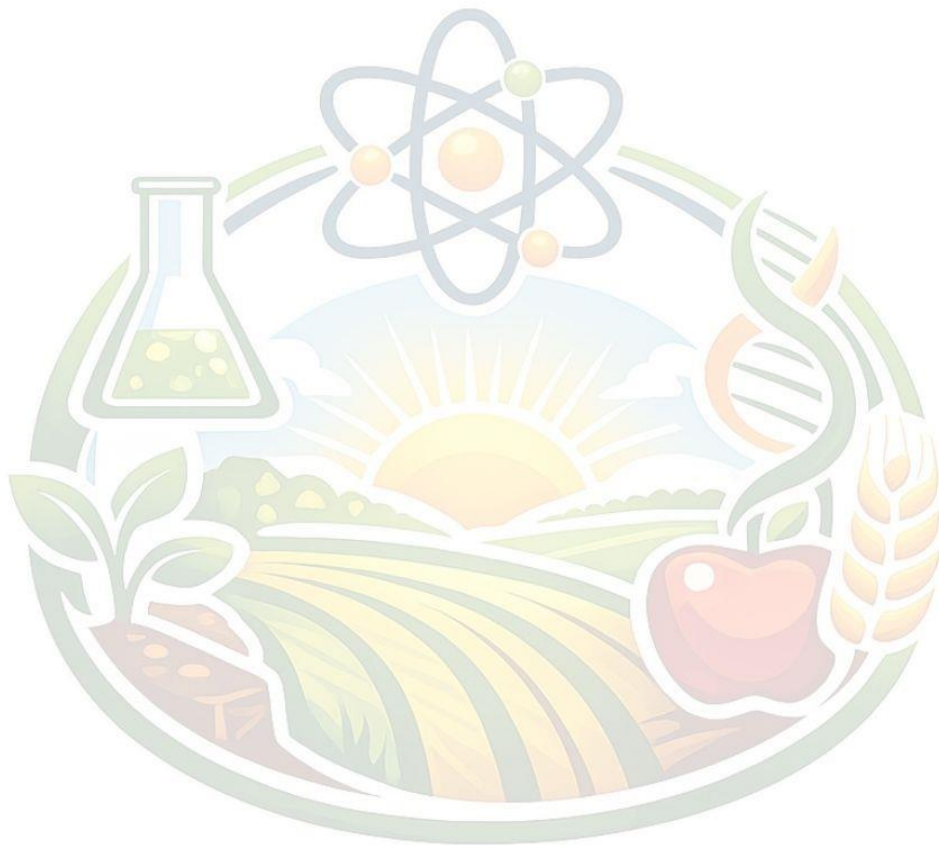
Conclusion

Plant biostimulants offer a promising nature-based approach for improving crop growth and resilience under environmental stresses. By supporting root development, nutrient uptake, antioxidant defence and stress signalling, they can enhance the natural adaptive capacity of plants.

Future research should focus on standardized formulations, appropriate doses and reliable field validation to ensure consistent benefits across crops and environments.

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Freeze Drying Technology: Astronauts' Food Now in the Commercial Market

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Summary

In India, every year, millions of rupees worth of collected fruits and vegetables go waste, turning into garbage due to the lack of proper processing technology. If the produce is dried using traditional methods like sun-drying, its taste, color, and nutritional value are destroyed. As a solution to this problem, 'Freeze Drying' (drying by freezing), an advanced food engineering technology, has emerged as a highly effective remedy. This is the same technology used to create long-lasting food for scientists going to space. In this process, by completely removing the water content from the substance, food items last for years without developing mold or pests. This article details the scientific process of freeze drying, its benefits, and the commercial opportunities it presents for our farmers and agri-entrepreneurs.

Introduction

Farmers in Maharashtra take record production of mangoes, bananas, grapes, strawberries, and various types of leafy vegetables. However, when all the produce comes to the market at the same time, because the supply exceeds the demand, market prices crash drastically. Keeping produce in cold storage requires continuous electricity and huge expenditure. Under such circumstances, adding value to agricultural produce remains the only financial way forward.

To make food last longer, we dry it in the sun or in hot-air dryers. But due to heat, essential vitamins in fruits get burnt, their original color turns blackish-brown, and the taste changes. A revolutionary technology that overcomes all these limitations is freeze-drying. In technical language, it is also called 'lyophilization.' Initially extremely expensive and limited only to preparing food for astronauts and soldiers in war, this engineering has now become available in the commercial market for the general public and entrepreneurs.

Detailed Scientific Process of Freeze Drying

In standard dryers, the substance is heated to evaporate water, but in freeze drying, the substance is dried in an extremely cold environment without applying heat. This technology works mainly in three stages:

Stage 1: Primary Preparation and Cutting First, fresh fruits or vegetables brought from the field are thoroughly washed and cleaned. After that, they are sliced or cut into uniform thin pieces using a machine. It is essential for the pieces to be uniform so that the subsequent process occurs evenly across all parts.

Stage 2: Deep Freezing The cut pieces are placed in a special chamber, where the temperature is brought down to minus 30°C to minus 40°C. Due to this ultra-cold temperature, every drop of water inside the fruits turns into ice. The faster the substance is frozen, the smaller the ice crystals that form, which prevents the original cell structure of the substance from getting damaged.

Stage 3: Direct Conversion of Ice into Vapor This is the most crucial and magical stage of this technology. The frozen material is placed into an airtight 'vacuum chamber,' from which the air pressure is completely drawn out. Because the pressure is reduced extremely low, a special scientific phenomenon occurs: the ice does not melt. Instead, the ice directly converts into vapor (gas). This scientific process is called 'sublimation'. This vapor is sucked out by the machine. As a result, without leaving any moisture inside the fruit, it becomes completely dry.



Fig.1 State-of-the-art freeze drying machine used for large-scale production

Amazing Benefits of Freeze-Dried Food

- 1. 100% Nutrition, Taste, and Original Aroma:** Since no heat is applied to the fruit or vegetable, its natural taste, color, aroma, and vitamins remain 100% intact. In appearance, this food looks just as attractive as fresh food.
- 2. Shelf Life of 2 to 5 Years:** Generally, in normally dried food, 10% to 12% water remains, due to which mold or pests attack it after a few days. However, because of freeze drying, 98% to 99% of the water in the substance is removed. Since no water is left behind, this food easily lasts for 2 to 5 years without any preservatives (chemicals).
- 3. 90% Savings in Transportation Costs:** Fruits and vegetables contain nearly 80% to 90% water alone. Once this water is removed, the weight of the substance becomes extremely light. For example, if there is 1 kg of fresh strawberries, after freeze drying, its weight remains only 100 grams. Because of this, transportation costs are significantly reduced when sending goods abroad or to other states.
- 4. Re-freshening Method (Rehydration):** The greatest charm of this dried food is that when you put these items back into water, they absorb the water and, in just 2 to 5 minutes, return to their original, juicy state, looking as if they were freshly cut.



Fig.2. Fresh mangoes on the left and freeze-dried mangoes on the right—no change in color and shape.

Commercial Opportunities for Farmers and Agri-Entrepreneurs

In today's commercial market, there is a huge demand for freeze-dried products. Its usage has increased significantly in the following sectors:

1. Ready-to-Eat Food: Sprouted pulses (moong, matki), upma, poha, and khichdi are freeze-dried and packed. This is proving to be a boon for travelers and students living abroad.

2. Ice Cream and Bakery Industry: Companies purchase freeze-dried fruit powder and pieces in large quantities to use natural fruit pieces (e.g., mango, strawberry, and chikoo) in ice cream, chocolate, and dairy products.

3. Farmer Producer Organizations (FPOs): Our farmers can come together and start a small-scale freeze-drying industry at the village level by obtaining loans and up to 40% subsidy under the government's 'Pradhan Mantri Formalisation of Micro Food Processing Enterprises' (PMFME) scheme.



Fig. 3. Astronauts' food technology has now reached our home kitchens

Conclusion

Freeze drying technology is a modern food engineering marvel capable of altering the future of the agricultural sector. Through this, farmers can completely prevent the wastage of their produce and, even during a market slump, store their dried produce to sell at the right time for the right price. This step of science that emerged from astronauts' plates is now ready to strengthen our rural economy. If our young farmers embrace this modern technology, the dream of transforming from 'Farmer to Entrepreneur' will surely become a reality!

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Nurturing Brains, Building Futures: Parenting Tips for Infant Stimulation

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Abstract

The first 1,000 days of life are the foundation for brain development, with over a million neural connections forming every second. Infant stimulation-through touch, sound, sight, movement, and play-helps parents nurture these connections and shape a child's future potential. Simple acts like talking, singing, reading, massage, and play not only enhance language, motor skills, and memory but also strengthen emotional bonding. Parents play a pivotal role as the first educators, directly influencing lifelong learning, resilience, and well-being. By fostering stimulation early, families contribute not just to individual growth but also contributing to the overall development and prosperity of society."

Introduction

Infant stimulation refers to a variety of activities and interactions designed to engage a baby's senses and promote physical, emotional, and cognitive development during the crucial early years of life. The first 1,000 days of life (from conception to age two) are critical for brain development-over one million new neural connections are formed every second during this period. This period, often called the "window of opportunity," and it shapes the brain's architecture for future learning and behaviour.

Why Infant Stimulation is Crucial-Brain Development & Neuroplasticity

In the first years of life, a baby's brain grows very quickly, forming billions of connections (Synapses) between brain cells. These connections help babies learn and understand new things at an amazing speed. Through synaptic pruning, the brain strengthens frequently used connections while eliminating unused ones, ensuring more efficient functioning.

Modern neuroscience confirms that early sensory and emotional experiences shape how a child learns, communicates, and interacts with the world. Early sensory and emotional interactions create a strong base for memory, problem-solving, communication, and emotional regulation. Babies who receive consistent stimulation often achieve milestones faster and develop greater curiosity and adaptability. Infancy is marked by critical developmental windows for language, motor coordination, and sensory processing; if these areas are not adequately stimulated during this period, acquiring these skills later becomes more challenging.

Everyday activities like talking, reading, singing, and gentle touch help build strong brain pathways. Because a baby's brain is very flexible (neuroplastic), it can easily adapt to new experiences, laying a strong foundation for future learning, problem-solving, and emotional growth.

Scientific Evidence & Research Findings on Infant Stimulation

- 1. Attention and Learning:** Responsive interaction and age-appropriate stimulation provide infants with opportunities to explore, attend to their surroundings and develop early learning and problem-solving skills.
- 2. Language Development:** Talking, singing, reading and responding to an infant's sounds and gestures support early communication and language development.
- 3. Brain Development:** Everyday sensory experiences involving sight, sound, touch and movement provide rich input that supports the development of neural connections involved in learning, memory and emotional development.
- 4. Long-Term Development:** Consistent, responsive and developmentally appropriate experiences during infancy can contribute to positive cognitive, language, social-emotional and motor development over time.

How Can We Stimulate Our Infants

Today's generation of parents is raising children in a world dominated by screens, busy schedules, and smaller family structures. This shift requires intentional stimulation practices to ensure babies receive adequate face-to-face interaction, tactile experiences, and emotional bonding that technology alone cannot provide. Here are different areas of stimulation to support various aspects of a baby's development.

Sensory Stimulation

- 1. Auditory Stimulation:** Engaging a baby's sense of hearing through sounds, rhythms, and voices.

Ways to Stimulate: Talking to the baby in a gentle tone, singing lullabies, clapping hands, using rattles, or playing soft instrumental music.

Benefits: Enhances language acquisition, listening skills, and sound recognition. Babies start recognizing voices, tones, and even the rhythm of speech, laying the foundation for early communication.



2. Visual Stimulation: Stimulating the baby's sense of sight with shapes, colors, and movements.

Ways to Stimulate: Showing high-contrast cards, colorful toys, mirrors, or mobiles that hang over the crib. Babies also love focusing on faces—especially smiling or expressive ones.

Benefits: Improves visual tracking, focus, and attention span, while fostering curiosity and recognition of patterns.



3. Tactile Stimulation: Using touch to help the baby explore textures and sensations.

Ways to Stimulate: Gentle massage with baby-safe oil, letting the baby touch soft fabrics, water play during bath time, or running fingers softly over the baby's arms and legs.

Benefits: Builds sensory integration, increases body awareness, improves circulation, and creates emotional bonding with caregivers.



4. Smell and Taste Exploration: Introducing the baby to safe and pleasant smells and flavours as part of sensory development.

Ways to Stimulate: Letting babies smell familiar scents like their caregiver, mild natural aromas, or safe food smells. Offering new tastes during weaning (after 6 months) like pureed fruits or soft veggies.

Benefits: Stimulates sensory curiosity, supports feeding readiness, and helps in developing preferences and comfort with new foods.



5. Vestibular Stimulation: Stimulating the inner ear system responsible for balance and coordination.

Examples: Rocking the baby in arm, gentle bouncing on your lap, carrying the baby in a sling, or playing with position changes like tummy time or side-lying.

Benefits: Promotes balance, spatial awareness, postural control, and muscle development-key for future milestones like sitting, crawling, and walking.



Cognitive and Motor Stimulation

Encouraging thinking, problem-solving, and physical development through play and interaction.

Examples: Providing toys like stacking cups, rattles, blocks; encourage reaching, grasping, crawling and exploring. Use play mats for movement practice and **floor play** to build muscles and coordination.

Benefits: Enhances brain growth, improves fine and gross motor skills, and lays the foundation for learning and independence.



Responsive Caregiving

1. Talk, sing, smile, and maintain eye contact during feeding, bathing, and play.
2. Respond to the infant's cues (crying, cooing, reaching) with warmth and attention.
3. Provide consistent comfort and affection to build trust and security

Provide Safe Exploration Space

1. Ensure a clutter-free, hazard-free area for free movement.

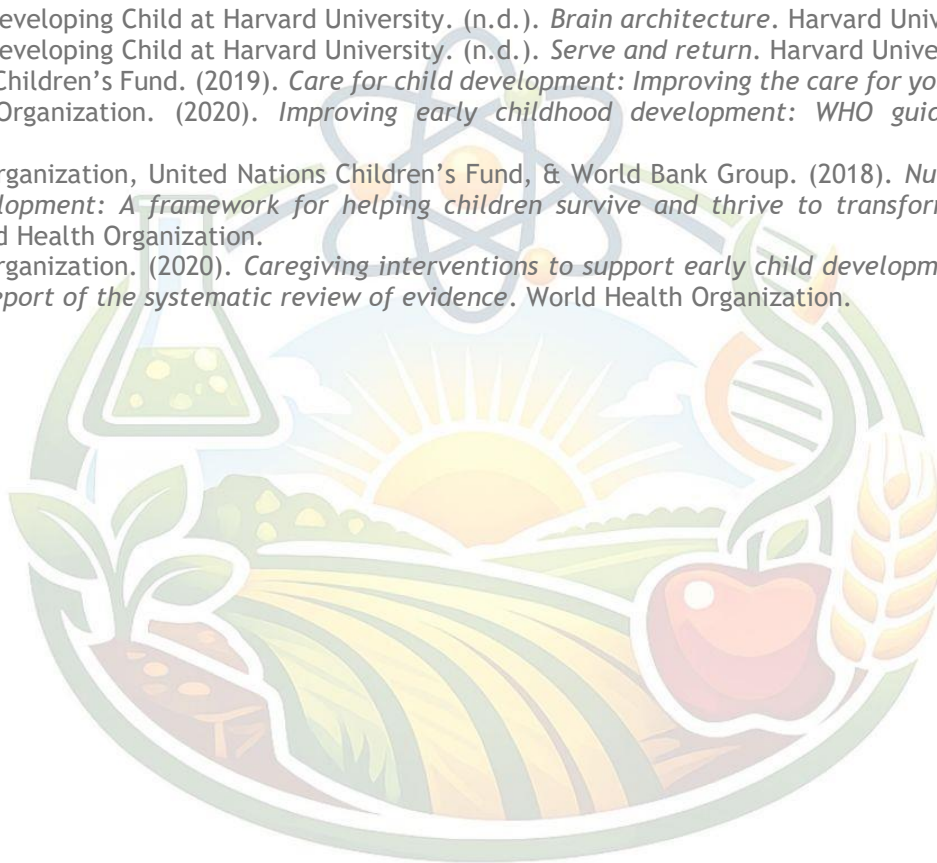
2. Rotate toys to keep baby interested and stimulated.
3. Allow independent exploration while staying close and engaged.

Conclusion

Infant stimulation is not about buying expensive toys or advanced gadgets-it's about quality interactions that help babies explore their world. A few minutes of focused, loving attention every day builds not only intelligence but also emotional security and resilience. In today's generation, where distractions are everywhere, parents must consciously carve out time for these moments. Combining traditional approaches like massage, singing, and storytelling with creative modern methods (Montessori toys, nature walks) gives babies the best start in life. By providing safe, engaging, and nurturing stimulation, caregivers not only support developmental milestones but also strengthen their emotional bond with the baby. Every smile, every touch, and every word matters in shaping a happy, confident, and curious child.

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The Digital Childhood: How Screen Exposure Shapes Young Minds and Future Learning

Article ID: 74524

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Abstract

Digital screens have become an integral part of contemporary childhood, particularly during the early years. Smartphones, tablets, televisions and other digital devices are increasingly used by parents to entertain, engage, feed, calm and occupy young children. While technology can provide opportunities for learning and communication, excessive or unsupervised screen exposure may interfere with experiences fundamental to healthy development, including face-to-face interaction, active play, adequate sleep, language-rich conversations and exploration of the physical environment. The concern becomes particularly significant when screens are routinely used as a “babysitter” or as the primary strategy for managing children’s boredom, tantrums, mealtimes or emotional distress. A 2025 WHO report found that 42% of children spent at least two hours a day on screens on weekdays, rising to 78% on weekends. Excessive screen use can displace essential developmental experiences and reduce children’s opportunities for meaningful interactions and age-appropriate activities.

This article aims to provide an understanding of the possible effects of excessive screen exposure on **overall child development**, particularly cognitive, language, social-emotional, physical and behavioural development, and how these effects may influence children’s learning and developmental outcomes in later years. It also discusses practical **strategies and implications for parents, caregivers and educators**, including establishing age-appropriate screen boundaries, encouraging active play and face-to-face interactions, promoting screen-free routines, selecting developmentally appropriate content and engaging with children during screen use.

Keywords: Early Childhood, Screen Time, Screen Dependence, Digital Media, Child Development, Parenting and Technology.

Introduction & Current Scenario

Childhood has changed considerably in the digital era. A generation ago, children were more likely to spend their free time playing outdoors, looking at picture books, talking to grandparents, drawing, building with blocks or simply experiencing the natural environment. Today, a young child may become familiar with a smartphone or tablet before learning to read or write.

India is already witnessing a significant rise in screen exposure during the early years of childhood. A 2025 systematic review and meta-analysis of 10 Indian studies involving 2,857 children under five found that young children spent an average of 2.22 hours per day on screens-more than twice the one-hour daily limit recommended for children aged 2-4 years. An earlier population-based Indian study reported excessive screen time in 73% of children under five, with increased screen exposure associated with developmental delays, particularly in language and communication. More recently, a 2026 study from rural Haryana found excessive screen time among 50.5% of children aged 2-4 years. These findings suggest that screen exposure is no longer merely an urban or adolescent issue-it is becoming part of the everyday experience of India’s youngest children.

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Why Early Childhood Matters

Early childhood is often described as the foundation stage of life because nearly 90% of brain development occurs before the age of five. During this period, the brain undergoes rapid development, and neural connections are strengthened through responsive caregiving, language-rich conversations, play, movement and exploration. Young children learn primarily through interaction with people and through active exploration of their surroundings. Every interaction-whether reading a story, stacking blocks or talking during mealtime-helps strengthen pathways that support thinking, communication, emotional regulation and learning. Therefore, when opportunities for these meaningful experiences are reduced, children’s developmental opportunities may also diminish.



Brains are built over time, from the bottom up.



- In the **first three years of life**, the brain is most impressionable, forming more than **1 million new neural connections every second**.
- The **billions of connections** that form between neurons in the early, most active years provide either a strong or weak foundation for connections that form later.

While technology has undoubtedly brought new opportunities for learning, communication and entertainment, its increasing presence in the everyday lives of young children raises important questions about what they may be missing during these crucial years of development. For many families, digital devices have become a practical solution to everyday challenges. A parent preparing food may give a child a mobile phone to keep them occupied, while during meals, a video may be used to encourage the child to eat. During travelling, cartoons may be used to prevent boredom, and when a child cries or throws a tantrum, a phone may quickly restore calm. In busy households, screens can also provide parents with a much-needed temporary break. However, these concerns become particularly important because the first few years of life are a period of rapid brain, language, social, emotional and physical development, during which children need rich, real-world experiences to learn and develop.

How Today's Screen Habits Shape Tomorrow's Learners

The effects of excessive screen exposure are not limited to childhood—they can influence the skills children carry into school and later life. Early learning depends on attention, language, curiosity, self-regulation and social interaction. These abilities develop gradually through thousands of everyday experiences rather than through passive observation alone. When screen exposure becomes excessive, it may affect children across multiple areas of development, with potential implications for their cognitive, language, social-emotional, physical and overall well-being. The major areas of concern are discussed below:

- 1. Cognitive development and attention:** Early childhood is when children develop attention, memory, problem-solving, curiosity and executive functions through hands-on exploration and play. Research involving young children suggests that more programme viewing and background television are associated with poorer cognitive outcomes, although the effects vary according to content and context.
- 2. Language and communication:** Children develop language through repeated back-and-forth interaction with adults and other children. When passive screen viewing replaces conversation, storytelling, questioning and shared reading, opportunities for language learning may decrease. A recent systematic review found that high levels of passive or unsupervised screen use were often associated with weaker language outcomes, while interactive use with caregiver participation appeared less concerning. This is particularly relevant in India: a population-based study of children under five reported an average screen exposure of **2.39 hours/day**, with **73%** classified as having excessive screen time; higher exposure was associated with developmental delay, particularly in language and communication.
- 3. Social and emotional development:** Children learn empathy, cooperation, sharing, turn-taking and emotional regulation through real relationships and social experiences. Excessive solitary screen use may reduce these opportunities. Importantly, research also shows that **co-use with caregivers is associated with better cognitive outcomes** than solitary use.
- 4. Physical and motor development:** Young children need to run, jump, climb, manipulate objects, draw, build and explore. More sedentary screen time can displace these experiences, reducing opportunities for motor development and physical activity. India's 2025 systematic review found that children under five were spending an average of **2.22 hours/day** on screens across the studies reviewed.
- 5. Sleep and readiness to learn:** Screen use can also affect children's routines and sleep. Sleep is closely connected with cognitive development and learning; a systematic review found associations between healthier sleep trajectories and better developmental and intelligence scores in early childhood.

Recommendations and Suggestions

Reducing the developmental impact of screen exposure requires more than simply limiting the amount of time children spend on digital devices. The most effective approach is to create a balanced environment in which children have regular opportunities for conversation, imaginative play, outdoor exploration, physical activity, shared reading, social interaction and adequate sleep. Every hour spent engaging in meaningful real-life experiences can contribute to the development of skills that no digital device can fully replace. Therefore, the focus should be on what children do instead of screen use and how parents, caregivers and educators can create supportive alternatives.

The following recommendations provide practical, developmentally appropriate strategies that parents and caregivers can incorporate into children's daily routines. Each recommendation focuses on reducing the displacement of essential developmental experiences while promoting specific benefits for children's overall growth and learning.

No.	Recommendation	With Screen - What Parents Can Do	Without Screen - What Parents Can Do	Development Supported
1	 Set Clear Screen-Time Boundaries	Decide when, where and for how long screens can be used. Avoid open or on-demand access throughout the day.	Establish predictable periods for play, conversation, reading, meals and family interaction.	Self-regulation, attention & overall development
2	 Make Screen Use Interactive	Watch with the child, ask questions, explain new words and encourage the child to respond rather than simply watch.	Talk, tell stories, sing songs, read picture books and ask questions about everyday experiences.	Language, cognitive & social development
3	 Replace Screen Time with Active Play	If a digital activity involves movement, encourage the child to imitate the actions rather than remaining seated throughout.	Provide blocks, puzzles, pretend play, drawing, dancing, outdoor games, running, jumping and climbing.	Cognitive, creative, physical & motor development
4	 Do Not Use Screens as the Main Way to Manage Emotions	Avoid automatically giving a phone/tablet whenever the child is bored, crying or frustrated.	Comfort the child, name emotions, talk about feelings, sing, cuddle, breathe together or offer a quiet activity.	Emotional regulation & social-emotional development
5	 Protect Sleep and Screen-Free Routines	Avoid screens close to bedtime and keep devices out of the child's sleeping space.	Develop a calming bedtime routine with bathing, storytelling, reading, talking or soft music.	Sleep, emotional well-being, memory & learning readiness
6	 Create a Screen-Free Environment for Exploration	Use digital content only as a starting point—for example, watch a short video about animals or plants.	Take the child outside to observe real plants, animals, nature and surroundings, or involve them in simple household activities.	Curiosity, sensory, cognitive & physical development
7	 Prioritize Real Relationships	Use video calls meaningfully to connect with grandparents or relatives, with an adult helping the child participate in conversation.	Encourage play with siblings, peers, grandparents and caregivers; practise sharing, cooperation and turn-taking.	Social, language & emotional development
8	 Parents Should Model Balanced Digital Habits	Avoid constantly checking phones while interacting with children; demonstrate purposeful rather than continuous device use.	Have screen-free family meals, conversations, walks, games and shared activities.	Attachment, communication, social-emotional & overall development

Conclusion

Technology is now part of childhood, and completely eliminating screens is neither realistic nor necessary. The real challenge is ensuring that digital media does not take the place of the experiences that children need most.

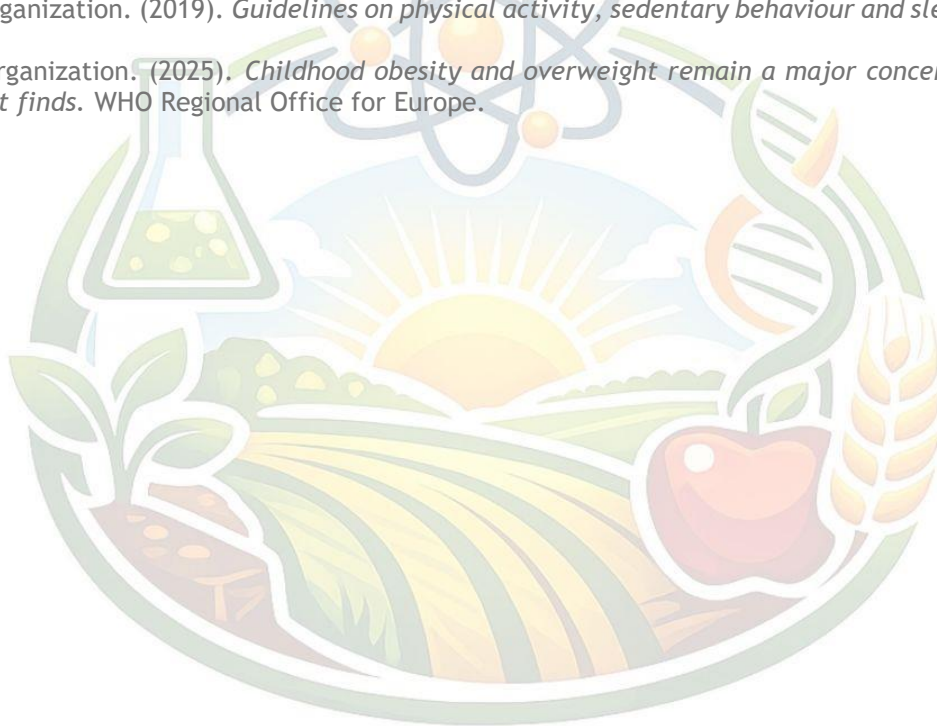
A young child needs more than colourful images and entertaining sounds. Children need conversations, hugs, movement, play, stories, nature, exploration, imagination, friendships and responsive adults. These experiences help build the

foundations of language, thinking, emotional regulation, relationships and physical development. Children who regularly practise listening, questioning, sharing ideas, solving problems and managing emotions are better prepared for school than children whose daily experiences are dominated by passive digital engagement. Therefore, the goal is not to eliminate technology but to ensure that screens support learning rather than replace learning.

The future of healthy childhood is therefore not about choosing between technology and traditional childhood. It is about creating a balance in which **technology supports development without taking over development.**

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Digital Twins for Food Processing Plants

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Summary

Digital twins (DTs) are dynamic virtual replicas continuously synchronized with physical assets via real-time sensor and control data. They are emerging as a powerful tool for food processing plants. Originating in aerospace and manufacturing, DTs are now being adopted in the food sector to address challenges unique to the industry: variable raw materials, stringent safety regulation and energy-intensive unit operations. A DT integrates four layers i.e data acquisition, modeling (physics-based, data-driven, and hybrid), connectivity/compute and visualization to enable real time monitoring, predictive quality/safety assessment and process optimization. Despite clear benefits, adoption is constrained by data limitations, model validation challenges, interoperability/cybersecurity risks and cost barriers.

Keywords: Digital twin; Food processing; Industry 4.0; Process optimization; Real-time monitoring; Food safety; Data-driven modelling.

Introduction

A digital twin (DT) is a dynamic virtual replica of a physical asset, process or system that is continuously synchronized with its real world counterpart through real time data from sensors, control systems and information platforms. In practice, this means the digital model 'looks like, acts like and links to' the physical object. This enables live monitoring, simulation, prediction and optimization of performance across its life cycle. While early formulations emphasized product lifecycle management, contemporary definitions in food and manufacturing stress on two way data flow and decision support: the twin not only reflects current conditions but also anticipates future states and informs actions that are fed back to the plant.

The digital twin concept originated in aerospace and advanced manufacturing. Initially it was used to mirror spacecraft and complex engineered systems which later spread to automotive, energy and smart factories as core elements of Industry 4.0. In recent years the food sector has begun adopting digital twins for supply chains, processing lines and entire plants. It is driven by the need for greater visibility, traceability and predictive control in complex operations.

Food processing stands to benefit from digital twins because it combines high variability, stringent regulation and energy intensive unit operations in ways that challenge conventional control and planning. Raw materials such as grains, fruits and meats vary in composition, moisture and microbial load which causes process behaviour and product quality to fluctuate even under fixed set points. At the same time, the industry must comply with strict food safety and quality standards where deviations can lead to recalls, regulatory penalties or brand damage. Many core operations like thermal processing, drying, extrusion, fermentation are energy and water intensive and sensitive to small changes in feedstock or equipment condition. A digital twin provides a unified, real-time "living model" of these processes which allows engineers to simulate scenarios (e.g., different raw-material batches, equipment degradation or cleaning schedules), predict safety and quality outcomes and optimize energy use before implementing changes on the shop floor. This capability is valuable for designing processes, reducing waste and maintaining compliance in an environment where both inputs and constraints are inherently variable.

Core Technology Components

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digital twin for a food processing plant is built from four tightly coupled layers: data acquisition, modeling, connectivity and compute and visualization/interface. Together, they convert raw sensor and control data into a live, predictive virtual plant that can be monitored, simulated and optimized in near real time.

1. Data acquisition layer: This layer links the physical plant to its digital counterpart using:

- IoT sensors and instruments for temperature, pressure, flow, level, humidity, gas composition, vibration, power and product quality attributes (e.g., NIR, pH, Brix, water activity).
- PLC/SCADA and control systems that provide setpoints, alarms, actuator states and batch/recipe data via OPC-UA, Modbus or proprietary drivers and often integrated with MES/ERP/LIMS for batch and quality context.

2. Modeling layer: The modeling layer encodes how the plant behaves:

- Physics based models use first principles equations for heat and mass transfer, fluid dynamics and reaction kinetics (e.g., microbial inactivation, Maillard reactions) in operations such as thermal processing, drying and extrusion. They are interpretable and align with safety logic and implemented as reduced order models for speed.

b. Data driven / ML models learn patterns from historical process and quality data to predict product quality, shelf-life, energy use or equipment failures. These handle complex, nonlinear relationships under variable raw materials but require large and clean datasets.

c. Hybrid models combine mechanistic structure with data-driven corrections or parameter estimation, balancing accuracy and explainability (e.g., thermal models corrected by ML for raw-material shifts).

3. Connectivity and compute layer: This layer moves and processes data across edge and cloud, and helps to maintain the digital thread linking raw materials, process, quality and distribution over time.

a. Edge computing handles time critical tasks (filtering, feature extraction, fast inference) on local hardware

b. Cloud platforms provide scalable storage, heavy model training, scenario simulation and cross-plant analytics which integrates with supply chain systems.

c. IoT platforms and protocols (MQTT, OPC-UA, REST, streaming frameworks) manage device identity, security and data pipelines between sensors, edge and cloud.

4. Visualization and interface layer: This layer determines how people interact with the twin:

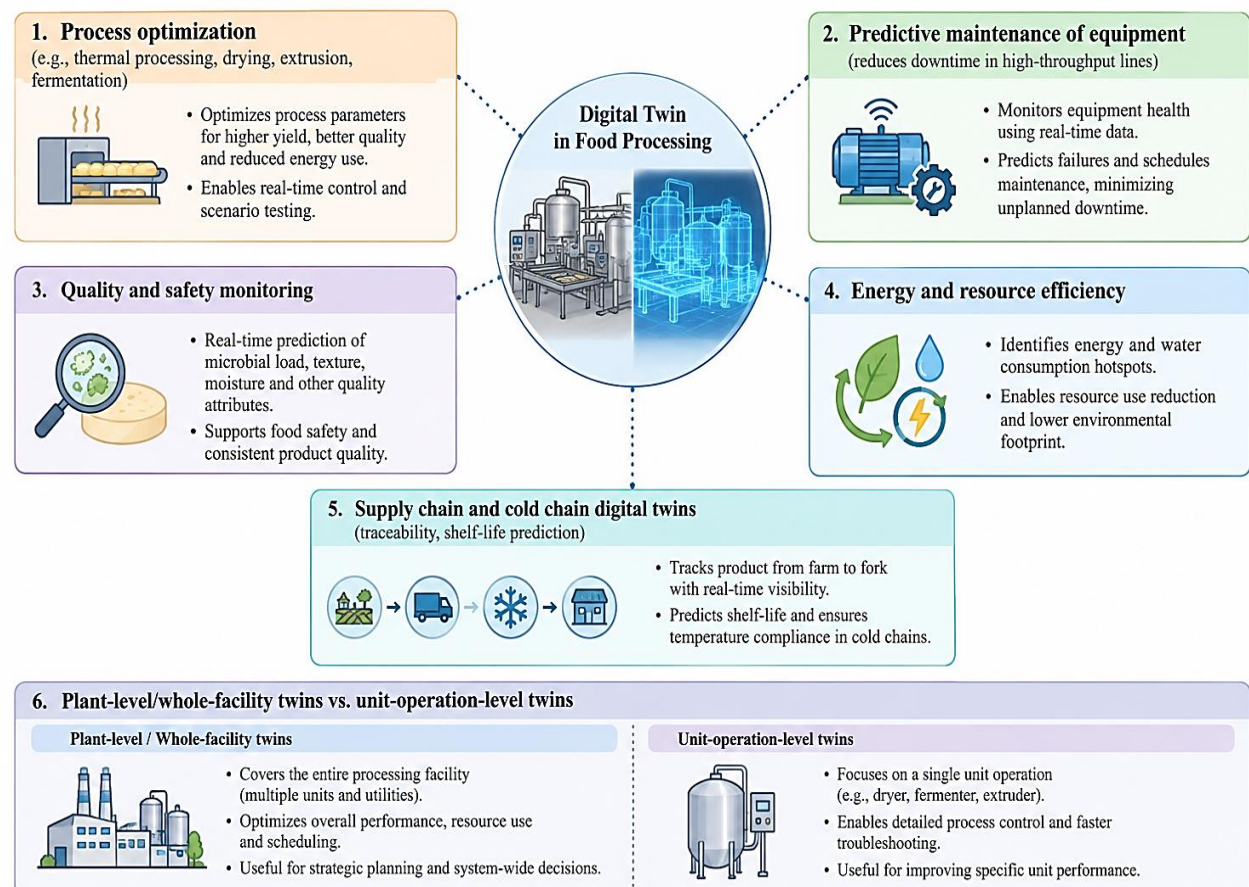
a. Operational dashboards show real-time process variables, equipment status and alarms, with “what-if” panels to test set points or recipes in the twin before applying them on the line.

b. Engineering work benches support batch comparisons, energy/water breakdowns, model diagnostics and scenario simulations often integrated with SPC/DOE tools.

c. Decision support interfaces deliver alerts and recommendations (quality deviations, shelf-life flags, maintenance windows, energy optimizations) through role based views for operators, quality managers and plant leaders.

Applications in Food Processing

Applications in Food Processing



Challenges and Limitations

Deploying digital twins in food processing faces several practical barriers. First, data quality and sensor coverage are often limited: many plants rely on legacy equipment with sparse instrumentation and harsh conditions (steam, cleaning chemicals, biofouling) which can degrade sensor performance while high accuracy inline quality sensors remain costly.

Second, model validation and calibration are complex because raw materials and biological processes (e.g., fermentation, microbial growth) are highly variable and requires extensive tuning and frequent updates as formulations or suppliers change. Third, interoperability and cybersecurity are concerns: heterogeneous PLC/SCADA/MES systems and limited common standards make integration difficult and greater connectivity increases the risk of cyber attacks on safety-critical systems. Finally, SMEs face cost and capability barriers such as high upfront investment in sensors, platforms, expertise and dependence on external vendors which can slow or prevent adoption despite the potential benefits.

Conclusion

Digital twins offer food processing plants a unified, real-time framework to simulate, predict and optimize operations that are otherwise difficult to control due to raw material variability and process complexity. By coupling physics based and data driven models with continuous sensor feedback digital twins support improved quality assurance, energy efficiency and equipment reliability across the plant lifecycle. However, realizing this potential at scale will require addressing sensor cost and coverage, model calibration for biological variability, cross-system interoperability and accessibility for smaller processors alongside continued standardization efforts across the sector.

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Post Harvest Management in Food Processing

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Introduction

The food processing industry is highly fragmented across several key sub-segments: fruits and vegetables, dairy, alcoholic beverages, meat and poultry, marine products, grain milling, packaged foods, and beverages. Most entrepreneurs operate at a small scale within the unorganized sector, which drives over 70% of total output by volume and 50% by value. In contrast, the organized sector—while smaller—is expanding rapidly. Overall, the industry divides into unorganized (42%), small-scale (33%), and organized (25%) enterprises, with food processing accounting for just 9% of India's total manufacturing output. The food processing sector is characterized by high fragmentation across diverse categories:

- 1. Core Segments:** Fruits and vegetables, dairy, alcoholic beverages, meat and poultry, marine goods, grain processing, convenience foods, and packaged drinks.
- 2. Sector Split:** The market comprises unorganized (42%), small-scale (33%), and organized (25%) players.
- 3. Market Dynamics:** Small, unorganized operators dominate overall production, generating more than 70% of industry volume and 50% of value. However, the organized segment is experiencing the fastest rate of growth.
- 4. Economic Share:** Food processing currently constitutes 9% of total manufacturing in India.

Fruits & Vegetables

The fruits and vegetables processing industry remains highly fragmented, dominated by household and small-scale operators with modest annual capacities of up to 250 tonnes. While traditional output centers on staples such as fruit pulps, juices, squashes, jams, pickles, chutneys, and canned or dehydrated produce, the portfolio has expanded to include newer offerings like retort-pouched vegetable curries, canned mushroom goods, dried produce, and fruit juice concentrates. Driven by strong export demand, sectors producing ready-to-serve beverages, frozen and dehydrated goods, processed mushrooms, and curried dishes have experienced notable growth.

Packaged / Convenience Foods

The consumer food sector encompasses a wide range of ready-to-eat and ready-to-cook items, snacks, pasta, cocoa products, soft drinks, and baked goods, with the bakery segment demonstrating steady, year-on-year production growth. Anchoring this category are bread and biscuits, which together yield roughly 4.00 million tonnes annually and form the largest consumer food segment. However, production remains heavily skewed toward unorganized, small-scale enterprises: bread manufacturing is reserved for the small-scale sector, with 60% of output originating from unorganized bakers and 40% from organized firms, while unorganized operators control an overwhelming 80% share of biscuit production.

Soft Drinks

After packed tea and packed biscuits the soft drink segment is considered to be the 3rd largest in the packaged foods industry. Over 100 plants are engaged in aerated soft drinks industry and provide huge employment. It has obviously attracted one of the highest FDI in the country. Strong forward and backward linkages with glass, plastic, refrigeration, sugar and the transportation industry further strengthen the position of the industry. Soft drink segment has a huge potential in the Indian market, as a vast portion of the market is still to cover.

Major Issues

Value addition and food processing primarily aim to curb post-harvest losses while generating rural income and employment. To achieve this, promoting decentralized, small-scale processing units directly within agricultural production catchments is essential, as it enables the immediate utilization of local produce and creates vital off-farm jobs. However, realizing this potential requires addressing the critical drivers behind severe post-harvest losses and the structural bottlenecks hindering the sector's growth, as outlined below.

Reasons for Huge Post-Harvest Losses

Severe post-harvest losses and bottlenecks stem from a combination of prolonged, multi-tiered supply chains—where quality and volume deteriorate at every exchange—and a widespread lack of scientific training among farmers who focus almost exclusively on yield rather than handling. Critical farm-level primary processing, such as washing, sorting,

cleaning, and grading, is routinely bypassed, setting off accelerated decay during subsequent storage. This vulnerability is compounded by acute infrastructural deficits: despite national capacities of roughly 25 million metric tons for grain storage and 24 million metric tons for cold storage, vast quantities remain exposed to rain, sunlight, low humidity, and physiological deterioration. Compounding these deficits are substandard transport and handling practices, including the reuse of worn, moisture-permeable gunny bags, the destructive use of loading hooks, and rough physical handling that inflicts widespread mechanical injury, bruising, and breakage that spoil produce long before it reaches consumers.

Constraints for the Development of Food Processing Sector

The food processing sector's growth has been severely curtailed by structural and economic bottlenecks, including fragmented landholdings that yield non-uniform produce unsuitable for commercial processing, an acute scarcity of processing-grade crop varieties, and severe deficits in cold storage, warehousing, quality-testing infrastructure, and localized processing machinery. These supply-side handicaps are further exacerbated by intermediary-laden supply chains, exorbitant transport, packaging, and inventory costs, steep capital requirements for viable units, high taxation, overlapping regulatory standards, and restrictive policies on commodity procurement, movement, and storage. At the consumer level, a strong cultural preference for fresh produce, high price premiums on ready-to-eat items, and a demand skewed toward basic primary and secondary goods (such as flours, milled pulses, and spices) restrict convenience foods to narrow urban markets; however, confronting these obstacles highlights clear pathways for transformation, where scaling capacity through workforce training, robust handling and storage protocols, advanced physical and chemical post-harvest treatments, and decentralized processing infrastructure within catchment areas can drastically cut post-harvest losses and unlock the industry's potential.

Role of CIPHET in Promoting Entrepreneurship in Food Processing

Dedicated to fostering rural micro-enterprises, ICAR-CIPHET, Ludhiana empowers entrepreneurs during technology transfer and licensing by pairing hands-on training to build technical confidence with bankable project reports to facilitate institutional financing. The institute's broad achievements span the entire post-harvest continuum, encompassing optimized pre-harvest regimens, harvesting maturity indices, specialized harvest tools, catchment-level sorting, grading, and precooling machinery, safe drying protocols, modern rural godowns, and evaporatively cooled storage structures. Beyond infrastructural advancements, CIPHET actively drives entrepreneurship through dedicated development programs (EDPs), consultancy, and the commercialization of an extensive array of proprietary technologies and value-added formulations—including pomegranate aril extractors, banana comb cutters, mobile agro-processing units, rotary maize shellers, soybean and groundnut-based dairy alternatives, extruded snacks, and ready-to-eat products like mustard saag and makhana kheer mix, alongside novel shelf-life extension techniques such as modified atmosphere and shrink packaging.

Conclusion

Because our socioeconomic and agribusiness landscape differs substantially from that of Western nations, we should adapt—rather than blindly adopt—Western technologies to process indigenous crops through decentralized, small-scale units within production catchments. This localized approach ensures that processing by-products are recycled and utilized productively at the village level instead of contributing to urban industrial pollution, while simultaneously curbing post-harvest losses and generating vital rural employment.

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Post Harvest Processing for Pulses

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Pulse milling refers to the unit operations involved in removing the outer fibrous seed coat (dehulling) and separating the cotyledons into two halves (splitting). In India, milling is conventionally categorized into wet and dry methods, with dry milling being the predominant approach in commercial mills now a days in India. The practical unit operations comprise cleaning, pre-conditioning, dehulling, splitting, separation, and packaging.

Processing Challenges and Yields

Some pulses—notably pigeon pea (arhar), black gram (urad), green gram (moong), and lentil (masur)—exhibit strong adherence between the seed coat and cotyledons, making dehulling difficult for processing. In traditional ways, this requires repeated abrasive passes using carborundum emery rollers which gives higher losses during the process.

1. Traditional Pre-Conditioning Drawbacks: Traditional pre-conditioning relies on alternate wetting and sun drying to loosen the husk bond. Because this method often achieves insufficient loosening, excessive abrasive force and manual labour and time is needed during processing, which generates substantial higher brokens and powder.

2. Yield Recovery: Practical yields in traditional mills typically range from **45% to 55%**, falling well short of the theoretical potential yield of **62% to 65%**. Modern pre-conditioning techniques, such as microwave pre-conditioning and other alternate approaches, effectively bridge this gap by minimizing milling losses and maximising milling recovery.

3. Pre-processing: Edible oils, such as linseed oil, are frequently applied during dry milling to enhance surface gloss and market appeal.

Method of Green Gram (Moong) Processing

Dry milling is being done for green gram which involves sequential pre-conditioning and mechanical separation:

1. Dry Pre-Conditioning: The grains are treated with oil and water to loosen the tightly bound husk, followed by thorough sun drying.

2. Dehulling and Splitting: Pre-conditioned pulses are further processed in dehulling machines equipped with abrasive emery rollers to simultaneously remove the hull and split the cotyledons.

3. Separation: Pulses are aspirated to remove the light powder fractions, followed by size-grading screens to isolate split dal from brokens, Gota (dehulled-unsplitted) and unhulled pulses.

4. Pulse Recovery: Due to high adherence of the seed coat and subsequent brokens, maximum green gram milling yields remain relatively low, typically ranging between **62% and 65%**.

Practical and Commercial Dry Milling Method (Dal Milling)

Although processing units vary across different pulses, commercial dry milling standardizes into six primary unit operations: cleaning and grading, pitting, oil treatment, pre-conditioning, dehulling/splitting, and polishing.

1. Cleaning and Grading: Raw pulses are separated from foreign matter—such as dust, chaff, and grit—and graded by seed size using reel-type or rotary sieve cleaners.

2. Pitting: Cleaned pulses pass through an emery roller machine with a tapered annular clearance between the abrasive roller and the outer casing. As the grain goes the narrowing clearance, due to frictional contact cracks and scratches the fibrous seed coat develops. This abrasion pitting promotes deeper penetration of oil in subsequent stages. Minor quantities of grain dehull and split prematurely during this step and are screened out.

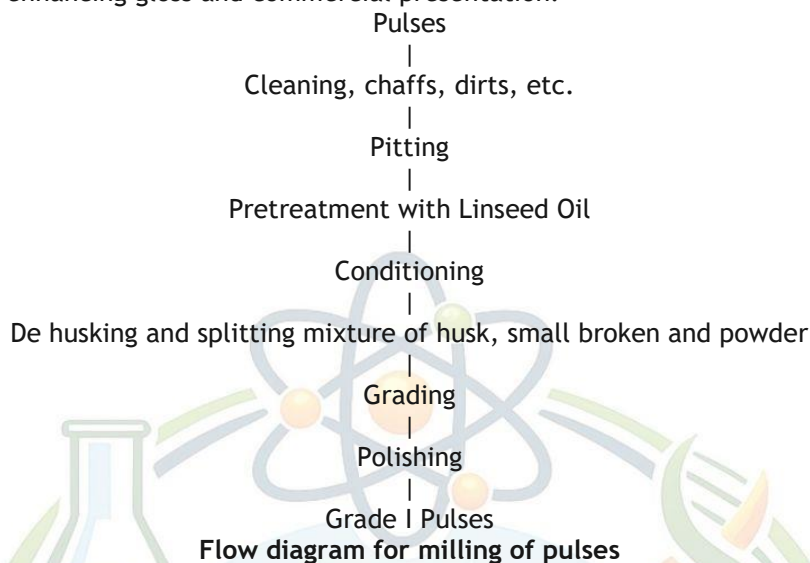
3. Oil Pretreatment: The pitted grain is sent through a screw conveyor and uniformly blended with edible oil (commonly linseed oil at **1.5 to 2.5 kg per ton**). The batch is then held on the floor for approximately **12 hours** to facilitate oil diffusion into the seed coat.

4. Pre-Conditioning and Drying: Pulses undergo cyclic wetting and drying over a **2- to 4-days** period:

- Batches are exposed to sun drying, followed by moisture addition (**3% to 5%**) via an overhead drip mechanism inside a screw conveyor.
- The grain is spreaded for roughly **8 hours** to allow moisture equilibrium, then dried again in the open sun.
- This process repeats until the seed coat is sufficiently loosened, with final drying reducing grain moisture to **10% to 12%**.

5. Dehulling and Splitting: Conditioned pulses enter emery roller units (commonly termed *pulse milling* machines). A single pass typically yields a ~50% dehulling efficiency. Dehulled grains split concurrently; an aspirator removes the light hull fraction, and vibrating sieves isolate the split dal. Unhulled grains undergo re-conditioning and subsequent dehulling passes (repeated **2 to 3 times**) to achieve maximum recovery.

6. Polishing: The finished split dal is treated with minimal amounts of water, edible oil, or a water-oil emulsion to apply on the cotyledon surface, enhancing gloss and commercial presentation.



Unit Operations and Machinery

Practical commercial mills deploy a sequence of dedicated mechanical unit operations:

- 1. Cleaning and Grading:** Raw pulses undergo preliminary screening via reciprocating or rotary sieve cleaners to remove foreign contaminants, while graders separate the materials based on the size.
- 2. Pitting & Pre-Conditioning:** Cleaned pulse grains pass through abrasive roller machines to scratch the seed coat for developing cracks. A continuous pre-processing machines blends the pitted pulses with measured quantities of water and edible oil.
- 3. Dehulling, Splitting with Aspiration:** Roller machines or disc shellers execute simultaneous dehulling and splitting. Integrated blowers aspirate light hull and fine powder fractions away from the dal.
- 4. Grading, Separation and Polishing:** Vibratory and rotary sieve separators isolate split dal from unhulled grains, whole dehulled seeds (*Gota*), and broken, sorting the finished product into commercial grades.

Yield Analysis and Milling Losses

Raw pulse grains typically arrive with **2% to 5%** foreign impurities, insect-damaged grains, and excess moisture. Anatomically, cleaned pulses comprise **10% to 15%** seed coat (hull) and **2% to 5%** germ.

- 1. Actual vs. Potential Recovery:** Traditional commercial recovery rates range between **45% and 55%**, falling significantly below the theoretical maximum yield of **62% to 65%**.
- 2. Sources of Loss:** The yield deficit is primarily driven by excessive abrasive force and uncontrolled mechanical impact during dehulling and splitting, which converts valuable cotyledon mass into broken fragments and fines.
- 3. Modern Alternatives:** Adopting advanced pre-conditioning techniques such as continuous pre milling treater—loosens the seed coat more uniformly, enabling single-pass processing that approaches theoretical yield limits while substantially reducing byproduct losses.

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Multi-factor Fuzzy Time Series Model: A Smart Mathematical Tool for Soil Fertility Assessment

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Introduction

Soil is the foundation of agriculture and plays a vital role in crop production, food security and environmental sustainability. A healthy soil supplies essential nutrients, stores water, supports beneficial microorganisms and provides a favorable environment for plant growth. However, soil fertility is not a fixed property. It changes continuously with rainfall, irrigation, fertilizer application, crop rotation, cultivation practices and climatic conditions. Important

Soil properties such as pH, organic carbon, nitrogen, phosphorus, potassium, electrical conductivity and soil moisture influence crop growth. Weather factors such as rainfall and temperature also affect nutrient availability and soil-water relationships. Therefore, assessing soil fertility using only one parameter may not provide a complete picture of the actual condition of a field.

Traditionally, farmers depend on soil testing and laboratory analysis to understand soil nutrient status. Soil testing remains an important and reliable practice, but repeated testing may be time-consuming and may not fully represent the dynamic changes occurring in the field. With the development of mathematical modelling, Artificial Intelligence (AI), machine learning and digital agriculture, new approaches are emerging to support faster and more intelligent soil assessment. One promising approach is Fuzzy Time Series (FTS).

Fuzzy Time Series is particularly useful when agricultural data contain uncertainty, variability and imprecision. It represents observations using understandable linguistic terms such as Low, Medium and High, instead of relying only on exact numerical values. Fuzzy Time Series has also been applied to agricultural forecasting, including rainfall prediction, providing a mathematical basis for extending the approach to other agricultural problems.

The proposed Multi-factor Fuzzy Time Series (MFFTS) model extends this concept by considering several soil, climatic and agricultural management factors simultaneously. It provides a mathematical framework for understanding how changing soil and environmental conditions may influence future soil fertility.

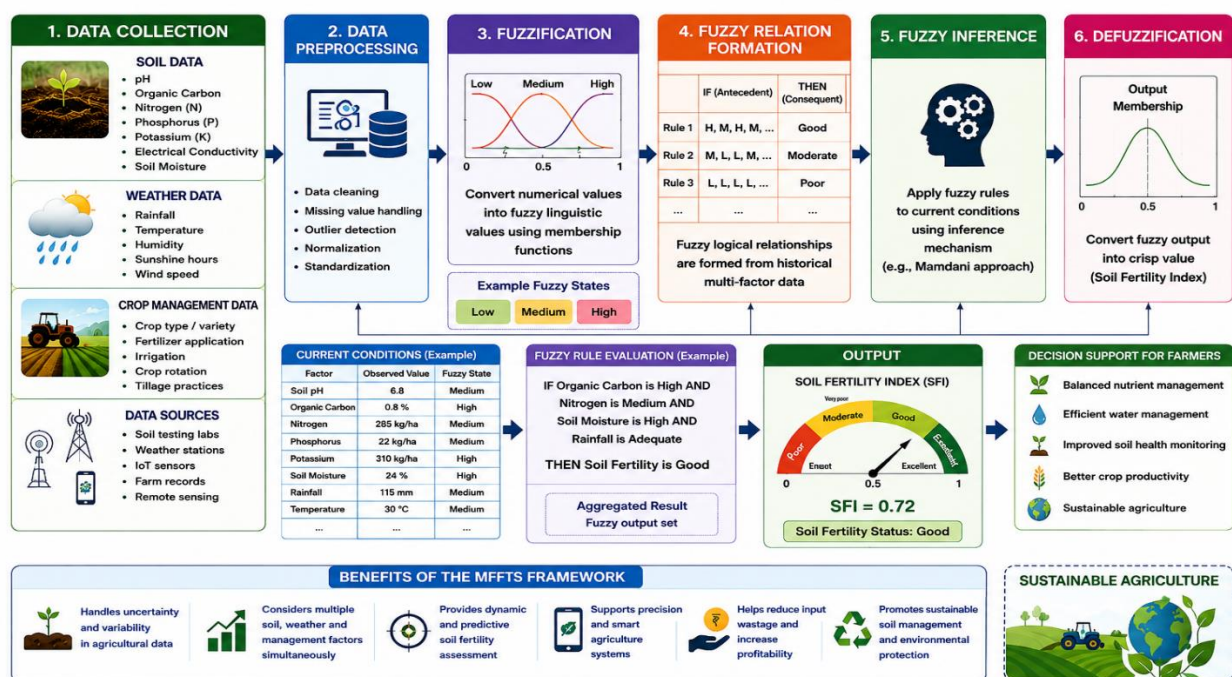


Figure 1. Smart Multi-factor Fuzzy Time Series framework showing the transformation of soil, weather and crop-management data into an estimated Soil Fertility Index for sustainable agriculture

Why Soil Fertility Prediction is Important

Soil fertility has a direct influence on crop establishment, plant growth, yield and quality. Imbalanced nutrient application may result in nutrient deficiency, excessive fertilizer use, increased production costs and environmental problems.

For example, nitrogen is essential for vegetative growth, phosphorus supports root development and reproductive growth, while potassium contributes to plant strength, water regulation and stress tolerance. However, the requirement for these nutrients is influenced by soil pH, organic matter, moisture, crop type and climatic conditions.

Therefore, an effective soil fertility assessment system should consider the **combined influence of several factors** rather than examining individual parameters separately.

Major factors that can be incorporated into the proposed model include: Soil pH, Organic carbon, Nitrogen, Phosphorus, Potassium, Electrical conductivity, Soil moisture, Rainfall, Temperature, Irrigation, Fertilizer application, Crop rotation.

What is Fuzzy Time Series?

Fuzzy Time Series is a mathematical forecasting technique designed to handle uncertain and changing data. Unlike conventional time-series models that mainly use precise numerical observations, fuzzy models can represent information using linguistic categories.

For example, soil moisture can be represented as:

Low → Medium → High

Similarly, nitrogen availability may be described as:

Deficient → Moderate → Adequate

and overall soil fertility may be expressed as:

Poor → Moderate → Good → Excellent

This makes fuzzy modelling easier to interpret and closer to the way farmers and agricultural experts describe field conditions.

Multi-factor Fuzzy Time Series for Soil Fertility

A conventional Fuzzy Time Series model may focus on one variable. Soil fertility, however, is influenced by many variables simultaneously. The proposed MFFTS approach therefore considers a group of soil, climatic and management parameters together.

Let the soil and environmental condition at time t be represented by

$$X_t = [pH_t, OC_t, N_t, P_t, K_t, SM_t, RF_t, T_t]$$

Where

- pH_t = soil pH
- OC_t = organic carbon
- N_t = nitrogen
- P_t = phosphorus
- K_t = potassium
- SM_t = soil moisture
- RF_t = rainfall
- T_t = temperature

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Each numerical observation can be converted into fuzzy linguistic states such as **Low, Medium and High**.

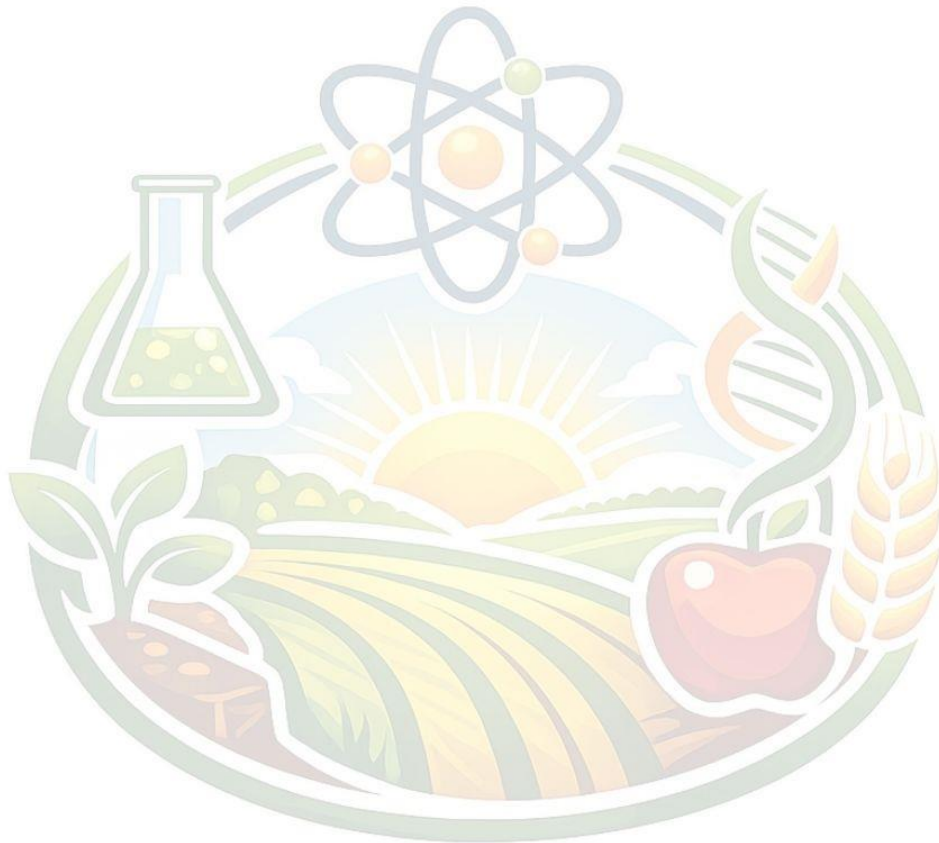
Conclusion

The Multi-factor Fuzzy Time Series (MFFTS) model offers a smart, mathematical approach to assessing soil fertility by handling the inherent uncertainty and dynamic interactions of agricultural environments. By integrating multiple parameters—such as soil chemistry, moisture, and weather patterns—into unified fuzzy linguistic states, the model provides a more holistic and realistic picture of field conditions than traditional single-variable analyses.

Ultimately, this framework bridges the gap between static laboratory tests and dynamic field realities. By transforming complex data into a simplified Soil Fertility Index (SFI), MFFTS serves as an effective decision-support tool, enabling farmers to forecast nutrient transitions, optimize fertilizer application, reduce cultivation costs, and promote sustainable agriculture.

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Dragon Fruit Farming: A Profitable Alternative in the Face of Climate and Labour Challenges

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Abstract

Facing water scarcity and rising labour costs, a 60-year-old farmer in Madhampatty, Coimbatore, shifted from conventional orchards of coconut, banana, papaya and sapota to dragon fruit (*Hylocereus* spp.), a drought-tolerant, nutrient-rich crop new to the region. Starting with the Jambo Red variety and later adding Marocco Red, Taiwan Pink and Yellow varieties sourced from Gujarat and Manipur, he raised 11,000 plants across 5 acres on a low-cost pole system. With organic nutrition, minimal irrigation and eco-friendly pest control, the orchard turned productive within three years, yielding up to 6 tonnes per acre and fetching ₹140-150 per kg. His initiative offers a replicable, climate-resilient model for semi-arid, rain-shadow regions of the Western Ghats and similar agro-climatic zones across India.

Keywords: Coimbatore, *Hylocereus*, Nutrient management, Semi-arid, Water scarcity.

Introduction

In the face of escalating water scarcity and rising agricultural input costs, farmers across India are seeking resilient and economically viable alternatives to traditional crops. In this context, dragon fruit (*Hylocereus* spp.), a drought-tolerant, nutrient-rich fruit crop, has emerged as a promising solution. One such pioneering effort has taken root in Madhampatty, Coimbatore district, Tamil Nadu, where a 60-year-old farmer, Mr. Ponnusamy, successfully initiated dragon fruit cultivation under semi-arid conditions. Confronted with challenges in maintaining conventional orchards like coconut, banana, and papaya due to limited water availability and high labour costs, Mr. Ponnusamy turned to dragon fruit, an unconventional choice for the region. His efforts not only led to a productive and profitable venture but also marked the introduction of this exotic crop to the rain shadow region of the Western Ghats. This article chronicles his journey, exploring the agronomic practices, varietal selection, nutrient and pest management strategies, economic returns, and the broader implications of dragon fruit cultivation for sustainable farming in similar agro-climatic zones.

Dragon fruit (*Hylocereus* spp.), also known as Pitaya or Pitahaya and belonging to the family Cactaceae, is an important tropical fruit crop rich in antioxidants, vitamins and minerals, and is known to help guard against cancer, diabetes, cardiovascular, respiratory, gastrointestinal and urinary diseases (Nishikito *et al.*, 2023). It is also rich in dietary fibre and low in calories (Nishikito *et al.*, 2023). It has drawn worldwide attention owing to its novel flavour, colour and attractive appearance along with its enormous health benefits. It has gained great commercial potential in India through consumer preference for new and exotic, phyto-chemically rich nutrient fruits, and through its adaptability to new environments with abiotic stress tolerance such as drought and temperature extremes. Although 14 *Hylocereus* species have been reported worldwide, only four *H. undatus*, *H. monacanthus* (syn. *H. polyrhizus*), *H. costaricensis* and *H. megalanthus* (syn. *Selenicereus megalanthus*), are mostly cultivated (Korotkova *et al.*, 2017). Among these, *H. undatus* is widely cultivated in Indian states such as Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, Punjab and West Bengal (Das *et al.*, 2025). As a recently introduced fruit crop in India, dragon fruit offers vast unexplored scope for research and innovation, including identifying varieties suited to specific purposes such as red dragon fruit for dye extraction and varieties with high antioxidant and medicinal properties.

India's dependence on imported dragon fruit largely from Thailand, Malaysia, Vietnam and Sri Lanka has been rising steadily, from a few hundred tonnes in 2017 to several thousand tonnes in recent years (Ministry of Agriculture and Farmers Welfare, 2023), prompting the Ministry of Agriculture and Farmers Welfare to promote domestic cultivation of the crop, locally renamed Kamalam, under the Mission for Integrated Development of Horticulture (MIDH) (Ministry of Agriculture and Farmers Welfare, 2023). The area under dragon fruit in India, only around 3,000 hectares a few years ago and largely concentrated in Karnataka, Kerala, Tamil Nadu, Maharashtra, Gujarat, Chhattisgarh, Odisha, West Bengal, Andhra Pradesh and the North-East, is targeted to expand to 50,000 hectares within five years, with a Centre of Excellence for Kamalam set up at ICAR-IIHR, Bengaluru, to support planting material, post-harvest handling and value addition (Ministry of Agriculture and Farmers Welfare, 2023; Das *et al.*, 2025). It is against this backdrop of growing national interest and import substitution that individual grower experiences such as that of Mr. Ponnusamy in Coimbatore assume importance, offering field-level evidence of the crop's suitability for water-scarce regions of the country.

Sowing Success in Coimbatore: The Journey of a Visionary Farmer

Climate and Soil Suitability for Semi-Arid Regions: Dragon fruit is well suited to tropical and sub-tropical regions with a dry, sunny climate, tolerating temperatures from as low as 6°C to as high as 40°C, though it performs best between 20°C and 35°C (Das *et al.*, 2025). It requires only about 500-1,200 mm of annual rainfall, considerably less than conventional fruit crops such as banana and papaya, and cannot tolerate waterlogging, making well-drained soils essential (Das *et al.*, 2025). Sandy loam soils rich in organic matter, with a pH of around 5.5-7.0, are ideal, though the crop can also establish on degraded or shallow soils where other fruit crops struggle (Das *et al.*, 2025). These traits closely match the semi-arid, rain-shadow conditions of the Western Ghats in and around Coimbatore, which explains why a crop with no earlier cultivation history in the district could be established successfully by a first-generation grower such as Mr. Ponnusamy.

Establishing the Orchard: Dragon fruit cultivation was initiated in Coimbatore by a 60-year-old farmer, Mr. Ponnusamy, at Madhampatty, Coimbatore district, Tamil Nadu. He maintained various orchards, including coconut, banana, papaya and sapota. Due to restricted water supply and rising labour costs about half of the expenditure going towards labour wages and irrigation, it became increasingly difficult to maintain these orchards. He began looking for semi-arid plant or fruit species that could survive with less work and attempted dragon fruit cultivation, which resulted in a successful crop with a bountiful harvest. He was the first to introduce dragon fruit cultivation in the Coimbatore area, despite initial scepticism about the crop's survival in the rain shadow region of the Western Ghats. He started with the Jambo Red variety and later extended to three more varieties: Morocco Red, Taiwan Pink (Figure 1) and a yellow variety. The plants were sourced from Gujarat and Manipur. He procured one cutting for around ₹125 and erected around 550 poles with 2,200 plants per acre, with each pole supporting 4 plants. Over the course of 2020, he planted 11,000 plants across 5 acres. The cost of cultivation of dragon fruit works out to about ₹2.5 lakh per acre.

Planting System and Support Structure: Being a climbing cactus with aerial roots, dragon fruit needs a permanent support structure. Commercial growers in India typically use concrete or stone pillars, 6-7 feet tall, topped with a tyre or a circular ring, on which 3-4 cuttings are trained per pole; a wire-trellis system is also gaining popularity for its lower cost. Pole spacing commonly ranges between 2 m × 2 m and 3 m × 3 m, translating to roughly 450-1,200 poles per acre depending on the system chosen. Mr. Ponnusamy adopted a comparatively dense layout of about 550 poles with four plants per pole 2,200 plants per acre, across his 5-acre, 11,000-plant orchard, planted in 2020 using cuttings sourced from Gujarat and Manipur. This one-time investment in poles, along with planting material, forms the bulk of the establishment cost, but the crop's 20-25-year productive life allows this cost to be amortised over a long orchard lifespan.

Nutrient and Pest Management: Nutrient management is carried out using a mixture of farmyard manure (FYM) and poultry waste at the rate of 25 kg every six months, along with application of a complex NPK fertilizer ('All 19') every three months. Intercultural operations such as weeding and removal of excess cladodes are carried out weekly. For plant protection, a commercial formulation ('green miracle') is sprayed at 1 litre per acre to reduce sun damage, while a combination of neem oil and soap oil: 350 ml neem oil and 50 ml soap oil diluted in 600 ml of water to make 1 litre, is sprayed at 1 litre per acre to control mealybug populations. Besides mealybugs, dragon fruit orchards in India are commonly affected by sap-sucking pests such as aphids and scale insects, and by fruit flies whose maggots damage ripening fruit (Das *et al.*, 2025); these are managed through field sanitation, need-based botanical or chemical sprays, and methyl-eugenol traps. On the disease side, anthracnose (*Colletotrichum* spp.), stem/soft rot and stem canker are the most frequently reported problems in Indian dragon fruit plantings, particularly under poor drainage or high humidity (Das *et al.*, 2025), and are best contained through the use of disease-free planting material, timely pruning and disposal of infected cladodes, and avoidance of overhead irrigation that keeps the stem surface wet.

Flowering, Yield and Economic Returns: Flowering begins between 5 and 6 am and closes by around 7 am. The average fruit size ranges from 350 to 500 grams. Dragon fruit is harvested in two seasons, May and November, with each cladode resting for about 15 days between a harvest and the next flowering, giving mostly two yields per season; flowering to harvest takes about 45 days. The fruit fetches a reasonable price of ₹140-150 per kg. Yield in the first year is around one tonne per acre, rising to 3 tonnes in the second year and 6 tonnes in the third year.

Post-Harvest Handling and Marketing: Dragon fruit is a non-climacteric, highly perishable fruit with a shelf life of only about 5-7 days at ambient temperature, so prompt handling after harvest is important (Paull, 2014). Fruits are typically harvested by external skin colour rather than by firmness, sorted and graded by size and freedom from blemish, and packed in ventilated crates to minimise bruising during transport. Pre-cooling and storage at around 6-10°C can extend shelf life to nearly two weeks (Paull, 2014), though most smallholder growers in India, including in Coimbatore, sell fresh produce quickly through local and wholesale markets rather than investing in cold storage. Mr. Ponnusamy's fruits fetch a farm-gate price of ₹140-150 per kg, comparable to prevailing market rates for the crop, underlining the income advantage dragon fruit offers over conventional orchard crops once the plantation comes into full bearing.



Figure 1: Cross sectional view of Taiwan Pink dragon fruit variety

Government Support and Future Outlook: Recognising dragon fruit's potential to substitute imports and diversify farm income on marginal and water-scarce land, MIDH has set a target of expanding the crop's area nationally to 50,000 hectares within five years (Ministry of Agriculture and Farmers Welfare, 2023), supported by a dedicated Centre of Excellence for Kamalam at ICAR-IIHR, Bengaluru, that is working on improved planting material, post-harvest protocols and value-added products. Tamil Nadu, and the Coimbatore region in particular, with its extensive semi-arid and rain-shadow tracts currently under water-intensive orchard crops, is well placed to benefit from this push. Mr. Ponnusamy's experience moving from high-cost, high-labour orchards to a low-water, long-lived dragon fruit plantation that pays back its establishment cost within a few years – offers a practical, field-tested template that extension agencies and fellow farmers in similar agro-climatic zones can draw upon as the crop's cultivated area expands across the country.

Conclusion

Owing to its ecological characteristics, health benefits and commercial value, dragon fruit has become a cost-effective crop option across various parts of the country and a driving force for sustainable development, particularly in promoting the sustainable use of ecosystems in the Coimbatore region. The high adaptability and tolerance of the pitaya to a wide range of severe environmental conditions explain the success of this experimental planting model in the region. This model can be adapted on a larger scale by farmers across the country and can contribute significantly to national economic growth and to improving farmers' standard of living.

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Healing the Soil: The Retrospect and Prospects of Conservation Agriculture in India

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Summary

Conservation Agriculture offers a sustainable alternative to India's input-intensive conventional farming by addressing resource depletion, stubble burning, and soil degradation through three core pillars: minimum soil disturbance (zero-till), permanent soil organic cover via residue retention, and diversified crop rotations involving legumes. Supported by mechanized interventions like Laser Land Levelling, Turbo Happy Seeders, Direct-Seeded Rice, and permanent bed planting, field evidence shows that CA maintains or improves crop yields while reducing water usage by up to 40%, slashing soil erosion from 21.1 to 2.6 t/ha, and substantially boosting soil organic carbon and beneficial biological life like earthworms. Despite its expansion to over 6.5 million hectares, widespread scaling requires overcoming hurdles such as the competing use of crop residues for livestock fodder and fuel, high machinery capital costs for smallholders, and the learning curve of navigating weed control and yield variability during the first 1 to 3 transition years.

Introduction

For decades following the Green Revolution, intensive cultivation powered India's food security. However, this production boost brought hidden ecological costs: declining factor productivity, depleting groundwater tables, worsening air pollution from stubble burning, and degrading soil organic carbon. To build long-term sustainability and resilience against climate change, farming must transition from input-heavy cultivation to resource-saving practices. Conservation Agriculture offers a path to sustain high yields while actively restoring natural resources.

The Three Pillars of Conservation Agriculture

Conservation Agriculture replaces repeated plowing and biomass removal with three core ecological principles:

- 1. Minimum Soil Disturbance:** Drastically reducing or eliminating tillage (zero-till) preserves soil architecture, limits carbon oxidation, and protects subterranean micro-ecosystems.
- 2. Permanent Soil Organic Cover:** Retaining crop residues on the surface shields the soil from rainfall impact and solar radiation, curtails weed growth, conserves moisture, and builds organic matter.
- 3. Diversified Crop Rotations:** Rotating diverse crops, especially integrating legumes alongside cereal heavy-feeders, breaks pest and weed life cycles while enhancing natural nutrient cycling.

Key Elements of the Transformation Strategy

Category / Practice	Conventional Agriculture	Conservation Agriculture
Tillage & Erosion	Excessive tillage and soil erosion	No till / drastically reduced tillage
Residue Management	Residue burning or incorp	Surface retention of residues
Organic Amendments	Use of ex-situ FYM / composts	Use of in-situ organics / composts
Manuring Practices	Green manuring (incorporated)	Brown manuring (surface drying)
Machine Traffic	Free-wheeling of farm machinery	Controlled traffic
Management Strategy	Crop-based management	Cropping system-based management
Cropping Pattern	Single or sole crops	Intercropping / relay cropping
Land Preparation	Uneven field levels	Precision laser land leveling

(Gupta and Sayre, 2007)

Key CA Interventions and Mechanization in India

India's adoption of CA expanded following the introduction of inverted-T openers and Zero-Till (ZT) drills in the early 1990s through CIMMYT and GBPUAT, Pantnagar, alongside the Rice-Wheat Consortium. Today, Indian farmers utilize several mechanized interventions:

- 1. Zero-Till Seed Drills & Turbo Happy Seeders:** Enable direct drilling of seed and basal fertilizer into standing rice stubble without preliminary field prep, eliminating residue burning.
- 2. Laser Land Levelling (LLL):** A laser-guided drag scraper smoothens field gradients to a constant slope within a 2 mm tolerance. This serves as an entry point for CA, cutting irrigation run-time and saving 20-30% of field water.

- 3. Direct-Seeded Rice (DSR):** Sowing paddy directly on dry or unpuddled moist soil replaces labor-intensive seedling transplantation, slashing irrigation requirements by 35-40% while reducing seepage and percolation losses.
- 4. Permanent Bed Planting:** Cultivating crops on raised beds while routing water through adjacent furrows minimizes waterlogging, prevents lodging, and cuts seed and fertilizer use.
- 5. Crop Residue Management:** Permanent soil cover through crops residue, mulch or manure crop. Supply substrate for soil organic matter build up and soil life. Buffering against severe impact of solar radiation and rainfall. Smothering of weeds. Alter the soil microclimate for plant root & micro-organism.
- 6. Diversified Crop Rotations:** Offer a diverse “diet” to the soil micro organisms. Exploring different soil layers for nutrients and recycle. Minimize population growth rate of pest species. Crop rotations involving legumes help in biological nitrogen fixation, enhancing biodiversity.

What the Field Evidence Shows?

Multi-location research across diverse Indian agro-ecosystems highlights the operational and agronomic benefits of CA:

Parameter	Conventional Agriculture	Conservation Agriculture	Impact & Evidence
Wheat Productivity	High input costs, yield plateaus	Maintained or elevated grain yields over 11+ seasons	Sustained higher long-term wheat yields under ZT in Haryana (<i>Malik et al., 2008</i>)
Water Productivity	Low; high field application losses	Up to 20-40% water savings	Paddy water productivity increased from 0.78 to 1.14 kg/m ³ under LLL in Punjab (<i>Kaur et al., 2012</i>)
Soil Organic Carbon	Depleted due to plowing and residue removal	Significant build-up in surface and upper layers	Double no-till raised surface organic carbon up to 2.51% compared to 1.47% under conventional tillage in NE India (<i>Ghosh et al., 2010</i>)
Soil Biological Health	Suppressed beneficial soil life	Markedly higher earthworms and microbial activity	Earthworm counts reached 380,000 per unit under double no-till vs 60,000 under conventional plowing (<i>Ghosh et al., 2010</i>)
Soil Loss & Run-off	Severe topsoil wash-off and erosion	Drastically mitigated runoff velocity	Full surface residue mulching curtailed soil loss from 21.1 t/ha down to 2.6 t/ha (<i>Bhatt and Khera, 2006</i>)

Overcoming Challenges for Widespread Adoption

While India's CA footprint has grown by more than 430% since 2014—reaching over 6.5 million hectares (FAO, 2024) several hurdles remain:

- 1. Resource Competition:** In many rural communities, crop stubble is heavily utilized as dry livestock fodder or fuel, creating trade-offs with surface mulching.
- 2. Machinery Access for Smallholders:** Advanced machinery like the Turbo Happy Seeder and laser levellers require high capital investment. Expanding Custom Hiring Centres (CHCs) and rental service providers is critical to grant access to small and marginal farmers.
- 3. The Transition Mindset:** Shifting from clean-tilled plots to residue-covered fields requires farmers to adapt weed management and unlearn long-held cultivation traditions. Initial yield variability during the first 1 to 3 transition years must be bridged through extension services, farmer field schools, and targeted input incentives.

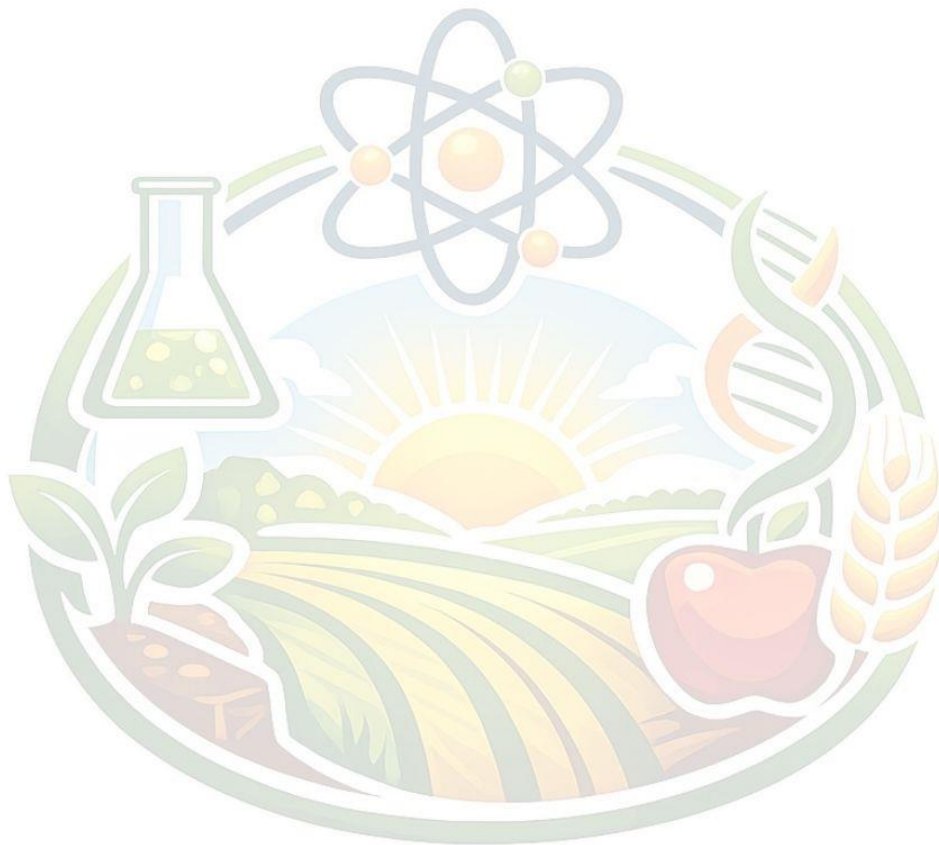
By expanding beyond the Indo-Gangetic Plains into rainfed ecologies and rice-fallows, Conservation Agriculture can turn India's agricultural lands into resilient carbon sinks, conserving soil and groundwater while safeguarding farmer livelihoods.

Conclusion

Soil & Resource Preservation: Minimizing soil disturbance through conservation tillage and practicing crop residue management keeps the soil covered, prevents erosion, and boosts organic matter. **Biodiversity & Resilience:** Utilizing diversified crop rotations naturally enhances soil fertility. **Precision Field Management:** Adopting specialized methods like bed planting improves water-use efficiency and crop rooting zones. **Resource Optimization:** Implementing laser land levelling ensures a completely flat field for uniform water distribution, which perfectly complements resource-saving techniques like direct seeded rice (DSR) by drastically reducing water and labor requirements.

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Use of Nanofertilizers in Horticulture

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Abstract

Nanofertilizers are emerging as an innovative approach for improving nutrient management and enhancing productivity in horticultural crops. Increasing pressure on agricultural production, declining nutrient-use efficiency, nutrient deficiencies, and environmental concerns associated with conventional fertilizers have created a need for more efficient and sustainable nutrient delivery systems. Nanofertilizers, generally formulated using nanoscale materials, can provide nutrients through slow, controlled and targeted release, thereby improving plant uptake and reducing nutrient losses through leaching and immobilization. Both macronutrient and micronutrient nanofertilizers, including nano-NPK, zinc, iron, boron, silicon, calcium and other formulations, have shown potential for improving plant growth, chlorophyll content, photosynthesis, yield and produce quality. Chitosan-based nanofertilizers are particularly promising because of their biodegradable, antimicrobial and growth-promoting properties. Their application in vegetables and fruit crops has demonstrated improvements in yield, fruit quality, nutrient-use efficiency and stress tolerance. However, concerns related to phytotoxicity, nanoparticle accumulation, effects on soil microorganisms, environmental safety, formulation stability and lack of standardization remain. Therefore, further research, crop-specific recommendations, proper regulation and risk assessment are essential for the safe and effective adoption of nanofertilizers in sustainable horticultural production.

Keywords: Nanofertilizers, Nanotechnology, Nutrient-use efficiency, Horticultural crops and Sustainability.

Introduction

The continuous growth of the global population is expected to place substantial pressure on agricultural systems, with food production needing to increase considerably by 2050 to meet future demands. This situation highlights the importance of adopting innovative and efficient technologies for improving crop cultivation, productivity, and yield, particularly in horticultural crops. Nanotechnology has emerged as a promising tool with diverse applications throughout horticulture, including crop production, input management, post-harvest handling, storage, packaging, and transportation. At the same time, challenges such as imbalanced fertilizer application, nutrient deficiencies, poor fertilizer-use efficiency, and declining soil quality need to be addressed to achieve sustainable production. Nanofertilizers offer considerable potential in this regard because they can improve nutrient availability and uptake, increase fertilizer-use efficiency, and minimize nutrient losses that may contribute to environmental problems such as eutrophication. They may also help overcome deficiencies of both macro- and micronutrients in horticultural crops. Therefore, the application of nanofertilizers represents an emerging approach for enhancing crop growth, productivity, nutrient management, and sustainable horticultural production.

Nano-Based Micronutrient Fertilizers

Micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and molybdenum (Mo) play vital roles in plant growth, development, and metabolic processes. Although these nutrients are required only in small quantities, their adequate availability is essential for maintaining proper crop performance and productivity. They are commonly incorporated into macronutrient fertilizers in small amounts to improve nutrient availability and promote healthy plant growth. However, micronutrient deficiencies are widespread in many calcareous soils of Asia because of nutrient immobilization and limited availability, which can result in physiological disorders, poor crop development, and reduced fertilizer-use efficiency. In this context, nanoformulations of micronutrients offer a promising approach for improving nutrient availability, soil health, and overall plant vigor. Nanostructured forms of zinc, including zinc oxide and zinc sulfate, can enhance the correction of zinc deficiency and improve the efficiency with which plants utilize applied fertilizers. Similarly, the development of nano-based molybdenum formulations may help minimize nutrient losses through leaching and reduce fixation in the soil, thereby improving its availability to plants and supporting better crop growth and productivity.

Nanofertilizers

Nanofertilizers are advanced nutrient-delivery systems developed using nanoscale materials, generally within the range of 1-100 nm, to support plant growth, development, productivity, and overall performance. Their small particle size and controlled-release characteristics can facilitate efficient absorption and utilization of nutrients through plant roots and foliage. Nutrients may be incorporated into protective polymer coatings, nanoporous materials, or nanotube-based structures, allowing their gradual and regulated release according to crop requirements. Such controlled nutrient delivery can extend nutrient availability over an extended period while reducing nutrient losses and minimizing potential negative impacts on soil, plants, and the surrounding environment. The application of nanofertilizers may also improve crop nutritional quality, nutrient-use efficiency, and fertilizer effectiveness by limiting nutrient leaching. Nanofertilizers containing essential macronutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur have shown considerable promise for enhancing crop productivity. However, further development is required to formulate efficient nano-macronutrient products with greater plant uptake, reduced soil immobilization and nutrient leaching, improved nutrient-use efficiency, and minimal environmental risks.

Chitosan Based Nanofertilizer

Chitosan, a naturally occurring, biodegradable, and linear polysaccharide, has attracted considerable attention in horticulture because of its potential to stimulate plant growth and its antimicrobial and agrochemical properties. Its biodegradability, bioadsorption capacity, and bactericidal activity make it a suitable and environmentally friendly material for the development of nanofertilizers and nano-based agricultural formulations. Research has demonstrated that chitosan-based nanomaterials can positively influence several aspects of crop performance, including seed germination, vegetative growth, and overall yield. In addition to improving plant development, these nanomaterials possess antimicrobial properties that can contribute to the management of plant diseases. Therefore, chitosan-based formulations have considerable potential as sustainable alternatives to conventional synthetic fungicides for protecting fruits and vegetables while reducing the environmental burden associated with chemical inputs.

Nanotechnology-Based Plant Nutrition

Plant nano-nutrition is an emerging approach that utilizes engineered nanoparticles, including zinc oxide (ZnO), silicon dioxide (SiO₂), iron oxide, copper oxide (CuO), and manganese-based oxides, to supply essential nutrients required for plant growth, development, and productivity. These nano-sized nutrient carriers can provide nutrients in a more controlled and targeted manner, thereby improving nutrient availability and enhancing **nutrient-use efficiency**. Although conventional fertilizers continue to play a major role in maintaining horticultural productivity, the adoption and application of nanofertilizers at the global level remain relatively limited. Nevertheless, various engineered nanomaterials have demonstrated considerable potential for use in nano-fertilization. For example, CeO₂ nanomaterials have been investigated in relation to radish root development, Cu-kinetin nanomaterials have shown potential in kidney bean roots, while TiO₂ and activated-carbon-based SiO₂ nanocomposites have been explored for their applications in cucumber production. These developments indicate that plant nano-nutrition could become an important component of more efficient and targeted nutrient management in horticultural crops.

Nanofertilizer Applications in Horticultural Crops

Vegetables: Nanofertilizers have shown promising effects on the growth, yield, and nutrient-use efficiency of various vegetable crops. Nano-NPK fertilizers improve productivity and fertilizer-use efficiency in potato, while nanofertilizer application enhances fruit number, weight, and diameter in tomato and cucumber. Bio-organic nanofertilizers can improve photosynthesis and productivity in sugar beet, whereas nanofertilizers enhance chlorophyll content and leaf development in long bean. Positive effects on plant growth, height, stem diameter, biomass, protein, and yield have also been reported in drumstick, faba bean, red bean, and other crops. Nano-iron chelates further improve chlorophyll, protein, and yield, while *Cucurbita pepo* responds with better germination, photosynthesis, water-use efficiency, and plant defense. Overall, nano-based fertilizers can enhance fertilizer-use efficiency and crop productivity (Wang et al., 2011).

Fruits: Nanotechnology offers considerable potential for improving the growth, yield, and quality of horticultural crops, particularly in developing countries. Nano-Zn, nano-B, and other nanofertilizers have been reported to improve productivity and fruit quality in crops such as **pomegranate, mango, and date palm**, while foliar application can also help reduce fruit cracking in pomegranate. Nano-NPK formulations may serve as an alternative to conventional fertilizers by supplying nutrients efficiently and supporting healthy plant growth.

In apple, nano-biofertilizers have enhanced plant height, stem diameter, leaf area, and chlorophyll content. Nanofertilizer treatment of bitter almond seeds has also improved germination compared with conventional chemical fertilizers. In flame seedless grapevine, application of amino-mineral nanofertilizer at 0.1% has resulted in better yield, berry coloration, and fruit quality. Overall, nanotechnology represents a promising approach for improving nutrient-use efficiency, crop productivity, and fruit quality in horticultural production.

Constraints and Environmental Implications of Nanofertilizers

Nanofertilizers offer promising opportunities for sustainable agriculture and horticulture by improving crop productivity and nutrient-use efficiency. However, their uptake, transformation, and movement within plants may produce both beneficial and adverse effects. Limited research, inadequate formulation and standardization, and insufficient risk assessment and monitoring remain major barriers to their wider adoption. Phytotoxicity is a particular concern because plant responses vary according to the type and concentration of nanomaterials. For instance, silver nanoparticles can negatively affect wheat growth, while uncoated nano- Al_2O_3 may restrict root development in crops such as cucumber, soybean, cabbage, maize, and carrot. Nanoparticle accumulation may also reduce plant growth, photosynthetic pigments, and chlorophyll levels. Furthermore, nanomaterials can interact with soil microorganisms, influence nutrient uptake, cross cellular membranes, and interfere with biochemical and enzymatic processes. Some carbon-based nanomaterials may even modify gene expression and suppress seedling or root development. Therefore, although nanofertilizers have considerable agricultural potential, further long-term research is essential to establish their safety, appropriate application rates, environmental impacts, and overall risk-benefit profile.

Future Prospects of Nanofertilizers

Improving horticultural production technologies is essential for meeting the growing demand for food and achieving global food security. Nanotechnology offers a promising approach to fertilizer management because nanomaterials can deliver nutrients efficiently even at relatively low concentrations. Nanofertilizers have the potential to improve crop productivity, nutrient-use efficiency, plant growth, yield, and resilience to climate-related stresses. They can also help overcome both macro- and micronutrient deficiencies and support higher productivity in multiple crops. However, their widespread application requires **appropriate regulations, standardized formulations, and safety guidelines** to minimize possible adverse effects on soil health and beneficial microorganisms. Further research is needed to develop stable, crop-specific nanofertilizer formulations and to evaluate their long-term effectiveness, toxicity, and environmental safety in horticultural systems.

Conclusion

Nanofertilizers represent a promising advancement in nutrient management for horticultural crops, with the potential to improve nutrient-use efficiency, plant growth, yield, and produce quality. Their nanoscale characteristics allow more controlled and targeted nutrient delivery, which may enhance nutrient uptake while minimizing losses through leaching, fixation, and excessive fertilizer application. Formulations such as nano-NPK, nano-Zn, nano-Fe, nano-B, silicon-based nanomaterials, and chitosan-based nanofertilizers have demonstrated encouraging responses in various fruit and vegetable crops. They may also improve plant tolerance to environmental stresses and reduce dependence on conventional fertilizers. Nevertheless, concerns related to phytotoxicity, nanoparticle accumulation, soil microbial activity, and environmental and human health must be carefully addressed. The effectiveness of nanofertilizers can vary with nanoparticle type, concentration, application method, crop, and environmental conditions. Therefore, standardized formulations, crop-specific application rates, long-term field evaluation, monitoring mechanisms, and appropriate regulatory frameworks are essential for their safe adoption. With systematic research and responsible application, nanofertilizers could become an important tool for sustainable horticultural production, efficient resource utilization, and long-term food security.

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Masters of Adaptation: How Plant Pathogens Change Strategies to Survive

Article ID: 74532

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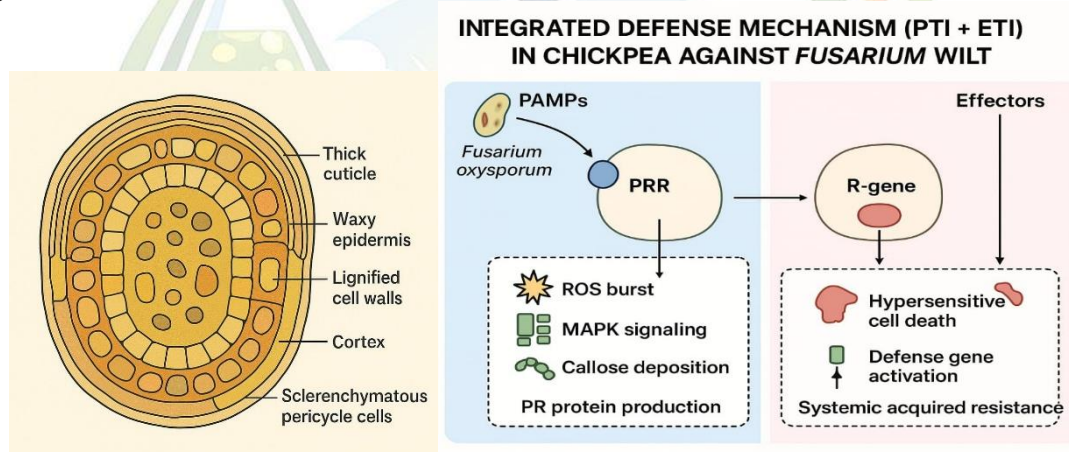
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Introduction

Every day, in gardens, fields and woods, there's an unseen conflict where plants and the diseases that infect them go back and forth. Even though plants are rooted in the ground, they still carry complex immune systems, chemical tricks and physical defences, wrapped in layers. Meanwhile the pathogens, bacteria, viruses, fungi and oomycetes have built remarkable strategies to outperform these barriers.

Plants and their First Line of Defense

Plants aren't just passive hosts. Their first line of defence includes physical barriers such as the waxy cuticle, rigid cell walls, and regulated stomatal openings. These are supported by antimicrobial compounds as well as an innate immune system that can detect invading microbes. Pattern-triggered immunity or PTI, is the part that recognizes conserved microbial signatures, but then effector-triggered immunity ETI provides a more specific response against pathogen-derived molecules. Together, these mechanisms form a dynamic interaction often described the “zig-zag” model of plant immunity.



Pathogens: Masters of Molecular Manipulation

To overcome plant immunity, pathogens send out effector like molecules that interfere with the host defences and other cell routines. Fungal pathogens hide certain molecules that should've triggered plant recognition, while bacterial pathogens can inject effectors directly into plant cells using specialised secretion systems. Oomycetes also seem to send effectors that interfere with host cellular functions. These strategies enable pathogens suppress immunity leading to an infection. Pathogens can further **reprogram the host from within**. They achieve this by manipulating plant hormones, including salicylic acid, jasmonic acid, and auxin, so defence reactions change, nutrient allocation shifts and cellular processes follow. Some pathogens take advantage of programmed cell death to obtain resources, whereas others suppress it to maintain living host tissue. Certain fungi can shift between biotrophic and necrotrophic lifestyles during an infection, which indicates flexibility range of pathogens.

The Viral Strategy for Survival

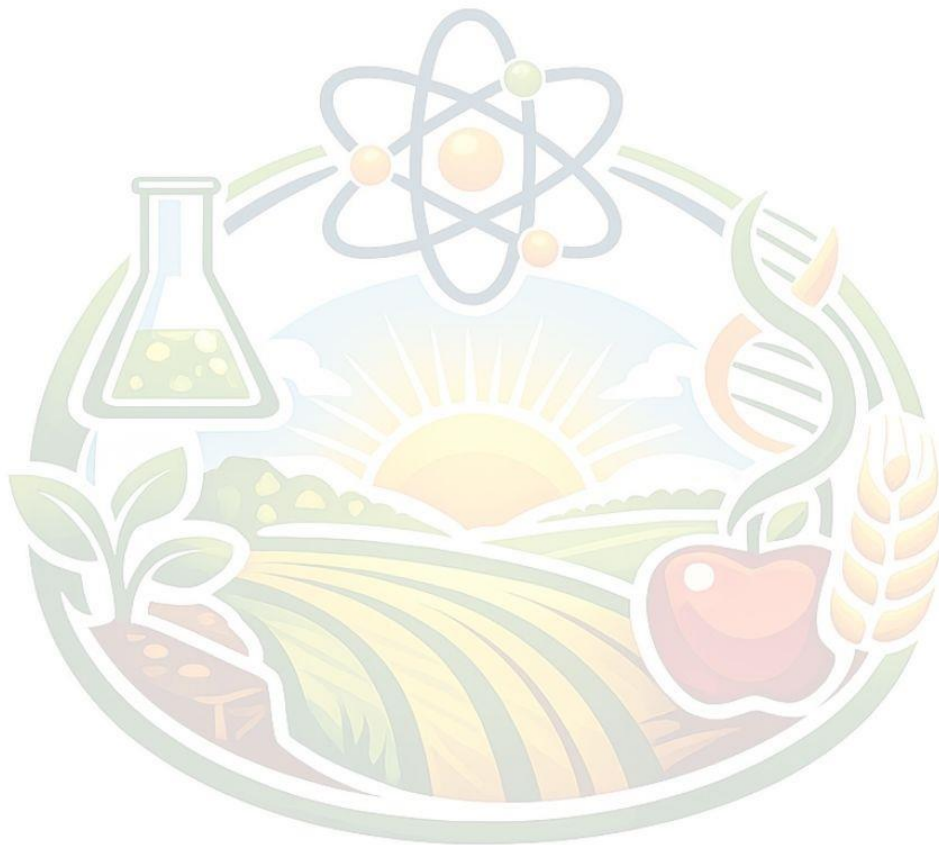
Plant viruses have a simple structure but employ highly effective mechanisms to evade host defence. The major target is the plant's RNA silencing system. It basically recognises and then degrades outside foreign genetic material. Hereafter, the viruses produce suppressor proteins which interfere with the pathway, triggering the evolution of new plant defense mechanisms at the molecular level.

Adapting to Change: The Continuing Struggle Between Plants and Pathogens

Pathogen adaptation is influenced not only by host resistance but also by environmental conditions. Temperature, humidity, drought and salinity can influence pathogen development, reproduction and even the disease severity. Climate

change alters pathogen distribution and their interactions with susceptible crops may change, which may end up exposing plants to disease pressures. Because pathogens adapt so well, it becomes a big hurdle for sustainable crop protection. Resistance based on a single gene can be defeated when pathogen populations evolve or lose the matching target. This has contributed to the famous **“boom and bust”** pattern of resistance in several crop diseases.

The key lies not in achieving permanent control, but in developing durable and adaptable management strategies. Combining multiple resistance genes, quantitative resistance, biological control, cultural routines and careful chemical use, can make it difficult for pathogens to overcome plant defences. For example, RNA based disease management, may hold considerable potential. Ultimately, the plant-pathogen relationship is an ongoing negotiation. Pathogens survive by altering their strategies, while plants keep strengthening their defences. Understanding pathogen adaption and evolution is fundamental to developing durable crop protection strategies capable of maintaining their effectiveness overtime.

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From Microbiome to Disease: When the Microbial Balance is Lost?

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Introduction

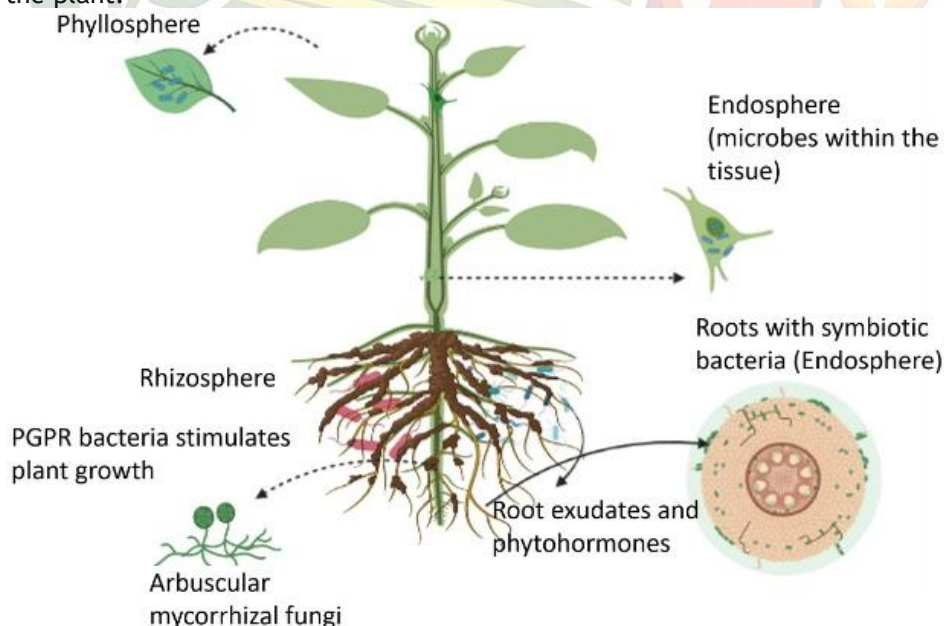
Plants live in close association with a wide range of microbial communities viz., bacteria, fungi and other microorganisms that inhabit the rhizosphere, the phyllosphere and even inside plant tissues. These microbes are found in large numbers around and within plants, and they are not just passive inhabitants. Most of the times they establish helpful relationships with their hosts. Such interactions evolved over millions of years and helps with plant development, nutrient uptake, coping with stress and disease resistance. Consequently, plant disease is understood not simply as an interaction between host and a single pathogen, but as the outcome of complex interactions among the plant, pathogen and its microbial community.

Plants as Holobionts: An Integrated Living System

The term “microbiome” refers diverse set of microorganisms associated with a plant, while holobiont comprises the plant and its resident microbiome as one linked ecological and physiological system. Often described as the plant’s “second genome”, the microbiome has a shared genetic and metabolic capacity that extends well beyond that of the host. So, in a way, it provides functions that plants can struggle with independently including taking up nutrients, dealing with stress, and defending the host against pathogens.

The Plant Microbiome: Rhizosphere, Phyllosphere and Endosphere

A plant hosts different microbes in different niches. The rhizosphere, the soil around roots, gets enriched by the roots-release compounds, that attracts specific microbes. The phyllosphere, leaves and stems, a much harsher environment exposed to sunlight, temperature shifts and drying, so it’s a more challenging place. Inside the plant, the endosphere harbours harmless endophytes, living quietly in tissues. Each niche supports a distinct microbial community shaped by its environment and the plant.

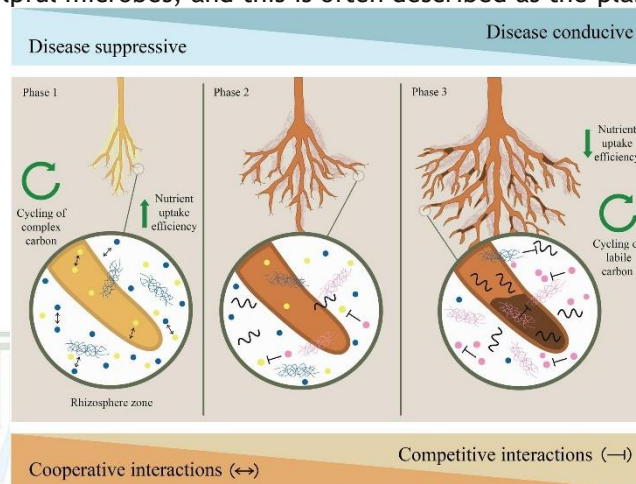


What the Good Microbes Do?

Beneficial microbes improve nutrient access, help plants grow and protect from diseases. They fix nitrogen, solubilise phosphorus, strengthen nutrient uptake and they produce growth-promoting compounds too. They suppress pathogens by competing for resources, producing antimicrobials or attacking them directly, as *Trichoderma* spp. does via mycoparasitism. Others activate induced systemic resistance (ISR), so the plant is prepared to respond faster to future infections.

Soils that Fight Back: Disease Suppressive Soils

Some soils can naturally suppress disease even when pathogens and susceptible plants are still there. A classic example is take-all decline in wheat, where the disease severity drops after wheat is grown repeatedly. In this situation, certain bacteria that produce antifungal compounds contribute to natural protection. So, disease suppressive soils are the key models for understanding microbial defense. This equilibrium can be disturbed by monocropping, excessive fertilizer and pesticide input and soil degradation which reduce microbial diversity. and keystone taxa that help the whole community resist pathogens. People sometimes call this disruption “**dysbiosis**” even though the word is still being refined in plant microbiome research. Plants can actively rebuild the balance. When challenged by soil-borne pathogens, they may alter their root exudates to recruit helpful microbes, and this is often described as the plant’s “cry for help”.



Microbial Allies in Disease Management

Some of the recognized microbial defenders are *Bacillus* spp., *Pseudomonas* spp. and *Trichoderma* spp. In general, they suppress pathogens via antimicrobial compounds, competition, siderophore production, mycoparasitism and activation of plant defence. This has shifted disease management from just killing off the pathogens to strengthening the microbial community. Microbiome engineering, microbial consortia and practices that preserve beneficial microbes are becoming more prominent. The future of plant disease management may therefore depend not only on attacking the pathogens, but also on nurturing the invisible allies that help plants fight back on their own.

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Export Potential of Meghalaya's Geographical Indication Tagged Crops

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Abstract

Meghalaya's three agricultural Geographical Indication (GI) tagged crops viz, Khasi Mandarin, Lakadong Turmeric and Memong Narang occupy markedly different positions on the path from local recognition to global trade. Khasi Mandarin has the most advanced export record moving from a one-tonne trial shipment to Dubai in 2022 to a 20-tonne consignment by December 2023 and a direct Guwahati-Dubai air-cargo route by November 2024, aided by its role in the award-winning Cherrapunji Eastern Craft Gin. Lakadong Turmeric, prized for a curcumin content nearly four times the global average, has reached small trial markets in the US, UK and Netherlands and is now backed by the ₹175.45 crore Mission Golden Spice. Memong Narang, by contrast, has recorded no export shipment to date. The article examines the export data, infrastructure gaps and market opportunities governed by Gulf demand, nutraceutical buyers, and the Act East connectivity shaping each crop's trajectory.

Introduction

Meghalaya holds three agricultural Geographical Indication (GI) crop tags viz. Khasi Mandarin (*Citrus reticulata*), Lakadong Turmeric (*Curcuma longa*) and Memong Narang (*Citrus indica*). Out of the 254 agricultural GIs registered in India, Northeast has 32 agricultural crops that have been granted GIs comprising 16 per cent of the national total. Northeast India's broader agricultural export base grew 85.34 per cent over six years, from USD 2.52 million in 2016-17 to USD 17.2 million in 2021-22, with the Gulf, Bangladesh, Bhutan and Europe as the main destinations (FreshPlaza, 2022a; FreshPlaza, 2022b; North East Today, 2022). Export wise each of these three crops now sits at a different point on the road from a certified hill product to a genuine export earner. This article sets aside the legal mechanics of GI registration and looks instead at what has actually moved right from the shipments made, the volumes reached, the buyers found and the gap that still separates a pilot consignment from a sustained trade.

Khasi Mandarin: A Proven Export Pilot

Grown across the Khasi and Jaintia Hills and GI-certified since 2015 (Certificate No. 231, held by NERAMAC, Guwahati, with 62 active Authorised Users), Khasi Mandarin benefits from the Northeast's outsized share of India's citrus basket which supplies roughly 43.6 per cent of the country's citrus output. Its export trail began in 2022, with a one-tonne consignment promoted through the Lulu Group's Dubai retail network and a trial shipment of 1.5 to 2 tonnes to Doha and Bahrain. (FreshPlaza, 2022a; FreshPlaza, 2022b; The News Mill, 2022; India Today NE, 2022). By December 2023 that volume had scaled to 20 metric tonnes in a single consignment i.e., a twenty-fold jump and by November 2024 the first direct air-cargo shipment flew straight from Guwahati to Dubai, cutting transit time for a fruit that does not travel well. (IANS, 2023). Khasi Mandarin is slo one of twelve botanicals infused into the award-winning Cherrapunji Eastern Craft Gin, opening a craft-spirits channel alongside fresh fruit.

Lakadong Turmeric: Betting on Curcumin

Cultivated by more than 17,000 farmers across 43-plus villages of the Jaintia Hills, Lakadong Turmeric carries a curcumin content of roughly 7 to 12 per cent (about 9.5 per cent on average) against a global norm of around 2.5 per cent, a scientifically verifiable strength that GI certification (Tag No. 741, granted March 2024) now lets the crop monetise rather than merely claim. Small trial lots have already reached the United States, the United Kingdom and the Netherlands, though most of the crop still moves through domestic markets. (The Print, n.d.). The scale-up is now anchored in Mission Golden Spice, a Rs 175.45 crore, five-year (2025-2030) mission led by the Ministry of Development of North Eastern Region and the North Eastern Council. It targets cultivation across 2,500 to 7,500 hectares by 2030, a farmer price realisation rising from Rs 30-40 to Rs 80 per kg, a Rs 100 crore Lakadong economy by FY 2028-29, direct benefit to 17,500-plus farmers and 3,000-plus women-led jobs built around a planned curcumin-extraction facility, High Performance Liquid Chromatography (HPLC) quality-testing labs and digital branding under 'Brand North East.'

Memong Narang: An Export Story Yet to Begin

Memong Narang a wild crop native to the Garo Hills and GI-certified in 2015 (No. 236, also held by North Eastern Regional Agricultural Marketing Cooperation Limited) with 71 Authorised Users, has no recorded export shipment to date and no

dedicated processing infrastructure. Its opportunity lies in its niche, non-mass-market demand in traditional medicine, biodiversity tourism and conservation linked branding remains largely untapped.

Export Status of the Crops and their Opportunities

Crop	GI Status	Authorised Users	Export Status Today	Where the Opportunity Lies
Khasi Mandarin	Certified 2015 (No. 231); NERAMAC, Guwahati	62 active AUs	20 MT to Dubai (Dec 2023); first direct air shipment Nov 2024	Gulf/diaspora retail, craft spirits, juice & citrus-oil lines
Lakadong Turmeric	Certified March 2024 (No. 741); Cooperative Union, Jowai	18 societies; AU registration under way	Small trial lots to US, UK, Netherlands; mostly domestic sale	Nutraceutical/pharma curcumin extract; Mission Golden Spice pipeline
Memong Narang	Certified 2015 (No. 236); NERAMAC, Guwahati	71 active AUs	No recorded export shipment to date	Traditional medicine, biodiversity tourism, conservation branding

Source: Geographical Indication Registry, Chennai 2026

Export Strength and their Constraints

The export strength are:

- Gulf and diaspora markets are already open via the Khasi Mandarin route.
- Craft-spirits and botanical buyers have been shown the way by the Cherrapunji Gin award
- Nutraceutical and pharma buyers are watching Lakadong's curcumin extract
- Organic, clean-label positioning could unlock EU, US and Japanese buyers
- Act East connectivity offers shorter land routes to Bangladesh and Southeast Asia, backed institutionally by APEDA, the Spices Board, NERAMAC and Mission Golden Spice.

The constraints are:

- Cultivation remains fragmented outside cooperative-led pockets
- Cold-chain and extraction infrastructure near the farm gate is weak
- No dedicated Harmonized System code tracking for GI-specific export volumes
- Phytosanitary certification is costly for small producer groups
- Global brand awareness rests on a handful of pilot shipments and
- Meghalaya's landlocked geography adds logistics time that coastal exporters do not carry.

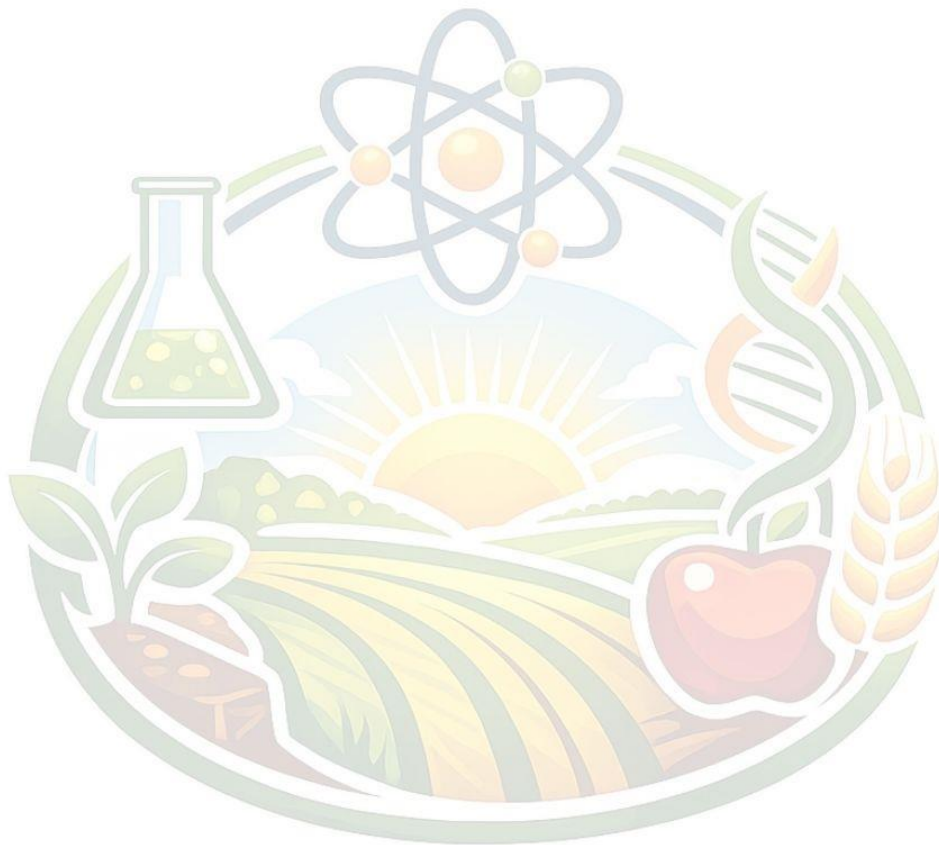
Conclusion

Meghalaya's GI-tagged crops need policy that moves beyond certification toward market delivery. Priority should go to closing the infrastructure gap: cold-chain and pre-cooling units at the farm gate, a dedicated curcumin-extraction facility for Lakadong Turmeric and phytosanitary certification support scaled for small producer groups rather than large exporters. For Khasi Mandarin, the Dubai route should be formalised into standing supply contracts rather than repeated pilot shipments. For Lakadong Turmeric, Mission Golden Spice's targets should be matched with faster rollout of its testing labs and processing units. Memong Narang requires a distinct strategy built around niche, non-mass-market buyers rather than fresh-fruit export. Above all, coordination between APEDA, NERAMAC, the Spices Board and state horticulture departments should shift from awareness-building to sustained, buyer-linked market access.

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Drone Technology for Agriculture in North-East India

Article ID: 74535

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Fig: Drone exhibition at G20 summit by ICAR-IARI, New Delhi.

Introduction

Our fascination with flight has witnessed an extraordinary evolution, from the pioneering days of the Wright brothers' first airplane to the contemporary drone revolution. This transformation has been made possible by the advent of advanced microchips, flight control software, and compact high-rate lithium batteries, which have propelled drone technology into diverse fields. Dynamic Remotely Operated Navigation Equipment (DRONE), offer the flexibility of autonomous flight or manual operation via remote controls units, equipped with joystick. Drones are a marvel of engineering, composed of various critical components that enable their flight and functionality. The frame or chassis, typically constructed from lightweight materials like carbon fiber or aluminum, provides structural support and protection for internal components. The propulsion system, often comprising electric motors and multiple rotors, generates the necessary thrust for flight. Power is sourced from rechargeable lithium-polymer or lithium-ion batteries, with engineers striving to balance capacity and weight for optimal flight times. Flight controller, is the brain of drone and it stabilizes it during flight. Together, these components illustrate the intricate engineering behind the successful operation of drones in a wide range of applications.

One of the most exciting applications of drone technology is in smart farming and precision nutrient management. Equipped with advanced sensors and spraying payloads it enables precision agriculture by sensor based monitoring of crop health and diseases and pest damages providing farmers with valuable data to make informed decisions, reduce resource wastage, and boost crop yields. It can cover vast expanses of land efficiently for spraying pesticide and fertilizers (15/ha) reducing time requirement, environmental impact and human exposure. Following are the major areas in which drone is useful for agriculture:-

- 1. Crop Monitoring** -Drones equipped with advanced sensors and cameras can monitor crop health using vegetation indices.
- 2. Precision Agriculture** -Drones enable precision agriculture by integrating variable rate and GPS technology
- 3. Pest and Disease Detection** -Drones equipped with sensors can identify areas affected by pests or diseases reducing the need for widespread pesticide use.
- 4. Crop Spraying** -Drones can be used for precision aerial spraying of pesticides, herbicides, and fertilizers. This method is more efficient and reduces exposure risks for farmworkers.
- 5. Disaster Response** -In the event of natural disasters like floods or wildfires, drones can assess damage to crops and infrastructure. This information assists in planning recovery efforts and insurance claims.

In India's North-Eastern Region (NER), drones are tackling unique agricultural challenges, including frost damage in maize and assessments of mixed integrated farming systems. Maize, a major crop in North-Eastern India alongside rice, often suffers from frost damage in the upland regions, leading to diminished yields or complete crop failure. Drone technology offers the prospect of real-time frost damage monitoring and yield loss prediction for farmers. Moreover, the North-Eastern region is characterized by integrated farming systems marked by limited diversity and heterogeneity. Consequently, assessing horticultural crops in mixed cropping systems for example pineapple, banana, orange, papaya, ginger, and turmeric, is challenging for both horticulturists and remote sensing experts. Nevertheless, recent advances in the array of sensors mounted on Unmanned Aerial Vehicles (UAVs) have opened up new avenues for the identification, mapping, and monitoring of horticultural crops. Key institutions like ICAR-Indian Agricultural Research Institute (Assam), ICAR Complex for North-Eastern and Hill Regions, and the North-Eastern Space Applications Centre are promoting UAV remote sensing for applications like natural resource management and disaster response. For skilled human resource development to make farms drone ready, Northeast India's first Remote Pilot Training Organization (RPTO), AmtronEduade Drone School is offering training programs to obtain pilot license. Agricultural drones has become the talk of the town among agronomists, students, and farmers in the region as many Krishi Vigyan Kendra (KVK) have procured crop spraying drones to educate farmers and integrate this technology in Assam, Sikkim, Arunachal Pradesh, and Meghalaya. Recently, Nagaland has also launched first of its kind agriculture Kisan Drone at Integrated Extension Training Centre, Medziphema. Complementing this custom hiring centers for drones is going to make this technology more accessible to farmers. Thus it is obvious that, agricultural drones represent a remarkable technological advancement with the potential to revolutionize research and farming practices in India's North-Eastern Region. As it continues to gain momentum, this technology is undeniably poised to play a pivotal role in shaping the region's agricultural future. With respect to drones we can say that the sky is not a limit; rather, it marks just the beginning of a transformative journey in agriculture for this region.

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El Nino and Agriculture in Southern Telangana: Why Digital Agro-Advisory Services Matter

Article ID: 74536

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Introduction

Agriculture in southern Telangana largely depends on the southwest monsoon. For farmers cultivating crops under rainfed conditions, the timing and distribution of rainfall often determine agricultural success more than annual rainfall totals. Over the last decade, climate variability has become increasingly pronounced, and one of the most important drivers of this variability is the El Nino-Southern Oscillation (ENSO) phenomenon. El Nino years are frequently associated with weaker monsoons, delayed rainfall, prolonged dry spells, and drought-like situations across many parts of India. These conditions create substantial challenges for farmers by increasing production risks and reducing farm income stability.

The semi-arid districts of Mahabubnagar, Nagarkurnool, Wanaparthy, Narayanpet, and Jogulamba Gadwal are among the most climate-sensitive regions of Telangana. Agriculture in these districts is characterised by high dependence on rainfall, limited irrigation facilities, declining groundwater resources, and a predominance of small and marginal holdings. As a result, fluctuations in rainfall can significantly affect crop acreage, yields, profitability, and household welfare.

Recent agricultural statistics clearly illustrate the impact of climatic stress on the region. According to the Vyavasya Padipantalu: Agricultural Situation Report, August 2026, the five southern Telangana districts received only 199.46 mm of rainfall against a normal rainfall of 238.24 mm during the period from 1 June to 5 August 2026, representing a deficit of approximately 16.3 percent. During the same period, cultivated area declined from 18,66,139 acres under normal conditions to 11,45,040 acres. At the state level, Telangana received 377.0 mm rainfall against a normal 396.1 mm, while cultivated area declined from 1,32,38,446 acres to 96,74,157 acres. These figures clearly demonstrate how rainfall shortages quickly translate into reduced agricultural activity and heightened economic risks for farming households.

How El Nino Affects Farmers

The influence of El Nino on agriculture extends beyond reduced rainfall. Its effects are felt through several interconnected pathways.

Delayed and Uncertain Sowing

When rainfall is delayed or erratic, farmers often postpone sowing operations. Delayed sowing shortens the effective crop-growing period and can expose crops to unfavorable conditions during flowering and grain-filling stages.

Crop Moisture Stress

Rainfed crops such as cotton, red gram, maize, castor, and pulses are particularly vulnerable to water stress. Inadequate soil moisture during critical growth stages often results in lower yields and increased crop failure.

Higher Production Costs

Farmers usually incur cultivation expenses before the monsoon becomes fully established. In years of poor rainfall, investments in seeds, fertilizers, pesticides, and labour may not generate expected returns, thereby increasing financial losses.

Income Instability

Reduced yields and crop failures directly affect household income, debt repayment capacity, and future investment decisions. Consequently, smallholders become more vulnerable to livelihood shocks.

Information as an Economic Resource

From an agricultural economics perspective, information is a productive resource that helps farmers make better decisions under conditions of uncertainty. Stigler (1961) argued that access to information reduces uncertainty and improves economic efficiency, while Schultz (1975) emphasized the importance of farmers' ability to respond to disequilibrium conditions. Digital technologies provide new avenues for delivering timely agricultural information directly to farmers.

Research has shown that Information and Communication Technologies (ICTs) can reduce information asymmetry and improve farm-level decision-making. Studies by Aker (2011) and Nakasone, Torero, and Minten (2014) suggest that timely access to agricultural information can improve production decisions, market participation, and economic outcomes among farmers.

Role of Digital Agro-Advisory Services

Digital agro-advisory services are increasingly becoming important tools for climate-risk management. Platforms such as:

1. Meghdoot
2. Damini
3. mKisan
4. Kisan Suvidha
5. WhatsApp farmer groups
6. Agricultural university advisories
7. Krishi Vigyan Kendra (KVK) advisories provide farmers with information relating to:
 - a. Weather forecasts
 - b. Sowing windows
 - c. Crop planning
 - d. Irrigation scheduling
 - e. Pest and disease management
 - f. Fertilizer recommendations
 - g. Contingency crop planning

Such services enable farmers to respond proactively rather than reactively to weather-related risks.

How Digital Advisories Support Farmers During El Nino Years

Better Crop and Sowing Decisions: Weather forecasts help farmers determine appropriate sowing dates and crop choices. In rainfall-deficit years, early warnings can assist farmers in selecting drought-tolerant crops or varieties.

Improved Input Management: Digital advisories can guide farmers regarding fertilizer application, irrigation, and plant-protection measures. This helps avoid unnecessary expenditure on inputs when weather conditions are unfavourable.

Drought Preparedness: Access to timely advisories enables adoption of moisture-conservation practices, efficient irrigation scheduling, and contingency measures during dry spells.

Pest and Disease Management: Climate variability often alters pest dynamics. Advisory services provide early warnings that enable preventive action and reduce crop damage.

Reduced Losses and Greater Stability: Studies on climate information services indicate that weather-based advisories can help farmers make adaptive decisions that reduce risk exposure and improve resilience under changing climatic conditions.

Building Climate Resilience

Climate resilience refers to the ability of farming households to prepare for, cope with, and recover from climatic shocks. Digital agro-advisory services contribute to resilience by enabling informed decision-making and timely adaptation. Recent studies indicate that personalized digital advisory systems can improve agricultural performance and strengthen farmers' adaptive capacity under climatic stress.

However, several challenges still limit the effectiveness of digital advisory systems:

- a. Limited digital literacy
- b. Poor internet connectivity in some rural areas
- c. Language barriers
- d. Limited awareness of available platforms
- e. Concerns regarding forecast accuracy.

Addressing these constraints will require coordinated efforts from government agencies, agricultural universities, extension institutions, KVKs, Farmer Producer Organizations (FPOs), and digital service providers.

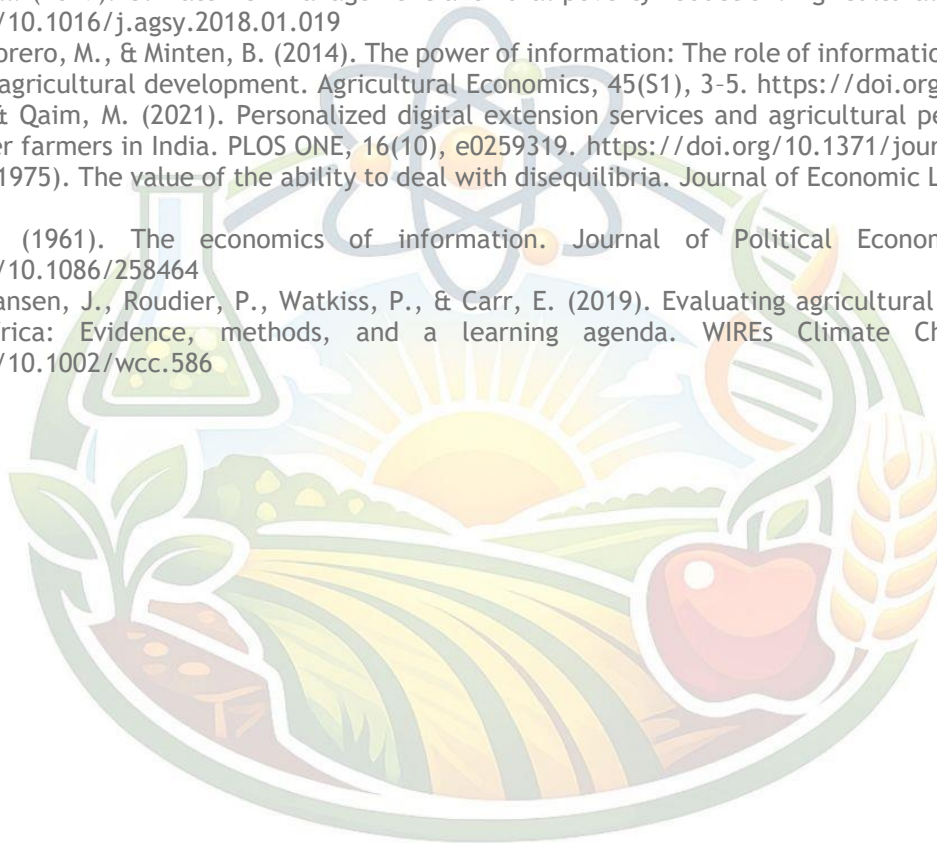
The Way Forward

As climate variability becomes more frequent, the importance of timely and reliable agricultural information will continue to increase. Digital agro-advisory services can play an important role in helping farmers manage climate risks, particularly in drought-prone regions. For southern Telangana, strengthening digital advisory delivery systems, improving last-mile connectivity, and enhancing farmers' digital literacy can significantly reduce vulnerability and improve resilience.

The future of climate-resilient agriculture depends not only on better technologies but also on better information. When farmers receive timely and actionable advisories, they are better equipped to manage uncertainty, minimize losses, and sustain their livelihoods even during challenging El Nino years.

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Forest Fire Management in India: Challenges and Solutions

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Introduction

Forests are among the most valuable natural resources on Earth, providing essential ecosystem services such as carbon storage, biodiversity conservation, soil and water protection and livelihood support to millions of people. However, forests across the world are increasingly threatened by one of the most destructive disturbances, forest fires. While fire is a natural ecological process in many ecosystems, uncontrolled and frequent fires can cause severe damage to forest biodiversity, ecosystem functions and human livelihoods.

India, with its diverse forest types ranging from tropical rainforests of the Northeast to dry deciduous forests of central India and Himalayan forests, experiences significant fire events every year. Forest fires not only destroy vegetation but also affect wildlife habitats, release large quantities of greenhouse gases, degrade soil quality, and reduce the capacity of forests to combat climate change. Effective forest fire management has therefore become an essential component of sustainable forest management, requiring scientific understanding, technological interventions, community participation and coordinated efforts among various stakeholders.

Understanding Forest Fires

A forest fire is an uncontrolled fire occurring in forested areas, affecting vegetation, wildlife and ecological processes. Fire occurrence depends on three primary components, often referred to as the "fire triangle":

1. **Fuel:** Dry leaves, grasses, branches, shrubs and other combustible materials present in forests.
2. **Weather:** Temperature, humidity, rainfall, wind speed and drought conditions influence fire intensity and spread.
3. **Topography:** Slope, aspect and landscape features determine the direction and speed of fire movement.

When these three factors combine under favourable conditions, forest fires can spread rapidly and become difficult to control.

Forest Fires can be Classified into Three Major Types

Ground fires occur below the surface by burning organic matter such as humus and peat.

Surface fires burn grasses, fallen leaves, shrubs, and small vegetation and are the most common type of forest fire in India.

Crown fires spread through the canopy of trees and are highly destructive due to their intensity and rapid movement.

Status of Forest Fires in India

India's forests are highly diverse and the occurrence of fires varies according to forest type, climatic conditions and human activities. The fire season generally extends from February to June, with peak intensity during the summer months before the onset of monsoon. States with extensive forest areas, including those in central India, the Himalayan region and Northeast India, frequently experience forest fire incidents. Tropical deciduous forests are particularly vulnerable due to seasonal dryness and accumulation of combustible biomass.

The forests of Northeast India, including Assam, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Mizoram and Tripura, are ecologically unique and harbour rich biodiversity. Although these forests receive high annual rainfall, seasonal dry periods, shifting cultivation practices, accidental fires and human disturbances can increase fire risk in certain landscapes.

Causes of Forest Fires

Forest fires may occur due to both natural and human-induced causes.

1. **Natural Causes:** Lightning is one of the major natural causes of forest fires in many parts of the world. However, in India, especially in tropical and subtropical forests, natural causes contribute to a relatively smaller proportion of fire incidents.

2. **Human-Induced Causes:** Human activities are responsible for the majority of forest fires in India. Some common causes include:

- a. Agricultural residue burning
- b. Burning of forests for land preparation

- c. Collection of non-timber forest products
- d. Careless disposal of cigarettes and matchsticks
- e. Grazing-related burning practices
- f. Campfires and tourism activities
- g. Intentional fires due to conflicts or land-use changes.

Increasing human pressure around forest areas has made fire management a complex socio-ecological challenge.

Impacts of Forest Fires

- 1. Loss of Biodiversity:** Forest fires can severely affect plants, animals, insects and microorganisms. Slow-growing species, endemic plants and threatened medicinal species are particularly vulnerable. Repeated fires can alter species composition and reduce forest regeneration capacity.
- 2. Carbon Emissions and Climate Change:** Forests act as important carbon sinks by absorbing atmospheric carbon dioxide. Fires release stored carbon into the atmosphere, contributing to greenhouse gas emissions and climate change. Large-scale fires can significantly reduce the carbon storage potential of forests.
- 3. Soil and Ecosystem Degradation:** Intense fires can damage soil structure, reduce organic matter, alter nutrient cycles and increase soil erosion. Loss of vegetation cover exposes soil to rainfall-induced erosion, affecting long-term ecosystem productivity.
- 4. Impact on Human Health and Livelihoods:** Smoke from forest fires contains harmful pollutants that affect air quality and human health. Communities dependent on forests for fuelwood, food, medicinal plants and other resources may face economic losses due to fire-related degradation.

Forest Fire Management Strategies in India

Forest fire management requires a shift from reactive fire suppression to proactive prevention and preparedness.

- 1. Fire Prevention and Awareness:** Prevention remains the most effective approach. Awareness programmes among local communities, forest-dependent populations and visitors can significantly reduce human-caused fires. Community participation is particularly important because local people possess traditional knowledge about forest landscapes and can act as early responders during fire events.
- 2. Fire Risk Mapping and Early Warning Systems:** Modern technologies such as satellite-based monitoring, Geographic Information Systems (GIS) and remote sensing have transformed forest fire management. Satellite platforms provide near-real-time information on fire locations, helping forest departments identify vulnerable areas and undertake timely action. Fire danger rating systems based on weather conditions assist in predicting high-risk periods.
- 3. Fuel Load Management:** Accumulation of dry biomass increases the probability and intensity of fires. Scientific management practices such as controlled removal of excess fuel, creation of fire lines and management of invasive vegetation can reduce fire spread. Fire lines act as barriers by creating gaps in vegetation, limiting the movement of surface fires and providing access routes for firefighting teams.
- 4. Capacity Building and Training:** Forest personnel require regular training in fire behaviour, prevention techniques, safety measures and modern firefighting approaches. Equipped and trained frontline staff play a crucial role in rapid response.
- 5. Integration of Traditional Knowledge:** Many indigenous and forest-dependent communities have developed traditional practices for managing landscapes. Integrating local knowledge with scientific approaches can improve fire prevention strategies, especially in biodiversity-rich regions.

Emerging Technologies in Forest Fire Management

Technological advancement has opened new opportunities for effective fire management.

- 1. Remote sensing and satellite monitoring:** Enables rapid detection and assessment of fire events.
- 2. Drones:** Assist in monitoring inaccessible areas and assessing fire damage.
- 3. Artificial intelligence and machine learning:** Help predict fire probability using climate, vegetation and historical fire data.
- 4. Mobile applications:** Facilitate communication between forest officials and field teams.
- 5. Automatic weather stations:** Provide site-specific weather information for fire risk assessment.

Combining technology with field-based observations can create a more efficient and responsive fire management system.

The Role of Climate Change

Climate change is expected to influence forest fire patterns by increasing temperature, altering rainfall patterns and extending dry periods. Rising temperatures and prolonged drought conditions can increase vegetation dryness and fire

intensity. Therefore, future fire management strategies must incorporate climate-resilient approaches, including restoration of degraded forests, maintaining ecosystem diversity and developing long-term fire adaptation plans.

Building Climate Resilience

Climate resilience refers to the ability of farming households to prepare for, cope with, and recover from climatic shocks. Digital agro-advisory services contribute to resilience by enabling informed decision-making and timely adaptation. Recent studies indicate that personalized digital advisory systems can improve agricultural performance and strengthen farmers' adaptive capacity under climatic stress.

However, several challenges still limit the effectiveness of digital advisory systems:

- a. Limited digital literacy
- b. Poor internet connectivity in some rural areas
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- d. Limited awareness of available platforms
- e. Concerns regarding forecast accuracy.

Addressing these constraints will require coordinated efforts from government agencies, agricultural universities, extension institutions, KVKs, Farmer Producer Organizations (FPOs), and digital service providers.

The Way Forward

Managing forest fires requires a holistic approach involving government agencies, scientific institutions, local communities and civil society. Some key priorities include:

1. Strengthening forest fire monitoring and early warning systems
2. Developing fire-resilient forest management practices
3. Promoting community-based fire prevention programmes
4. Enhancing research on fire ecology and climate interactions
5. Improving firefighting infrastructure and safety measures
6. Restoring fire-affected ecosystems through scientific approaches.

Forest fires are not merely environmental issues; they are challenges affecting biodiversity, climate security and human well-being. A balanced approach that combines scientific knowledge, technological innovation and community participation is essential for protecting India's forests.

Conclusion

Forests represent the natural heritage of a nation and provide invaluable ecological services. Although fire is a natural component of many ecosystems, increasing frequency and intensity of uncontrolled fires pose serious threats to forest sustainability. India's journey towards effective forest fire management requires moving from fire response to fire prevention, from isolated action to collaborative management and from short-term solutions to long-term ecological planning. By strengthening scientific research, empowering local communities and adopting modern technologies, India can safeguard its forests and ensure that these green landscapes continue to support biodiversity, climate regulation and human livelihoods for generations to come.

High-Density Planting in Mango: A Pathway to Higher Productivity and Efficient

Article ID: 74538

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Abstract

Mango is an important tropical fruit crop, but its productivity is often limited by the long juvenile phase, alternate bearing, conventional planting systems, pests and diseases, physiological disorders, and excessive vegetative growth. High-density planting (HDP) and ultra-high-density planting (UHDP) offer an effective approach to increasing productivity per unit area and obtaining higher yields at an earlier stage of orchard development. These systems depend on appropriate plant spacing, regular training and pruning, and efficient canopy management to maintain a balance between vegetative and reproductive growth. HDP and UHDP technologies have also been adopted in other fruit crops, including citrus, papaya, and guava. In mango, their success largely depends on selecting suitable varieties and rootstocks and maintaining a compact, productive canopy through timely management.

HDP and UHDP in Mango

Why is Mango Productivity Often Low?

Mango productivity is influenced by several biological and management-related factors, including:

- Long juvenile or vegetative phase
- Alternate bearing
- Conventional wide-spacing planting systems
- Pest and disease incidence
- Physiological disorders
- Cultivation of varieties not well suited to local conditions
- Predominance of seedling-derived trees with variable performance.

HDP and UHDP aim to address some of these limitations by increasing the number of productive trees per unit area while maintaining manageable tree size and canopy architecture.

High-Density Planting (HDP)

HDP involves planting mango trees at closer spacing than conventional orchards. Greater plant population can increase productivity per unit area, provided that canopy size and light distribution are effectively regulated.

Under North Indian conditions, Amrapali has been planted at 2.5 × 2.5 m in a triangular system, accommodating approximately 1,600 plants/ha. Pinching or removal of terminal buds from new shoots is used to restrict excessive tree growth.

Other examples include:

- Dashehari:** 3 × 2.5 m, approximately 1,333 plants/ha
- Mallika:** 3 × 2.5 m, approximately 1,333 plants/ha

The choice of spacing should consider cultivar vigour, soil and climatic conditions, rootstock, and the intended canopy-management system.

Ultra-High-Density Planting (UHDP)

UHDP uses still closer spacing and requires intensive canopy management to maintain small, productive trees. A spacing of 3 × 2 m has been used in mango, with Alphonso as one example. At this spacing, the plant population is approximately 674 plants/acre.

UHDP is particularly dependent on timely training, pruning, shoot regulation, and canopy renewal. Without regular canopy management, excessive vegetative growth can lead to overcrowding, poor light penetration, reduced flowering, and difficulty in orchard operations.

Mango Varieties Reported for UHDP

State	Varieties
Andhra Pradesh	Alphonso, Alampur Baneshan, Banganapalli, Totapuri (Bangalora), Mallika
Bihar	Bombai, Himsagar, Langra, Chausa
Goa	Fernandin, Mankurad

Gujarat	Alphonso, Kesar
Karnataka	Alphonso, Bangalora, Neelum, Mallika
Madhya Pradesh	Alphonso, Kesar, Ratna
Tamil Nadu	Alphonso, Banganapalli, Imampasand, Totapuri (Bangalora)
Uttar Pradesh	Bombay Green, Dashehari, Langra, Lucknow Safeda, Mallika, Chausa

The suitability of a cultivar for UHDP should be assessed in relation to its vigour, canopy architecture, bearing behaviour, climate, and response to pruning.

Dwarfing Rootstocks for HDP and UHDP

Rootstock selection can contribute to controlling tree vigour and maintaining a manageable canopy under high-density systems. Rootstocks reported for use in mango HDP/UHDP include:

1. **Vellaikolamban:** suitable for Alphonso and Dashehari
2. **Olour:** suitable for Langra and Himsagar
3. **Totapuri Red**
4. **Rumani:** used with Dashehari

Rootstock-scion compatibility and performance should be considered before large-scale adoption because their effects on vigour and productivity can vary with environmental conditions.

Canopy Management in HDP and UHDP

Successful high-density mango production depends largely on maintaining an open, compact, and productive canopy. Training and pruning help regulate tree size, improve light penetration, facilitate orchard operations, and maintain productive shoots.

Training

Training begins during the early development of the grafted plant. The graft is allowed to establish and is then headed back to encourage the formation of well-positioned primary branches.

A commonly followed approach is:

- a. Allow the graft to grow to approximately 1 m above ground level.
- b. Head back the plant at about 60-70 cm during October-November.
- c. Select 2-3 well-spaced primary scaffold branches.
- d. Prune selected primary branches at approximately 60-70 cm to encourage secondary shoots.
- e. Similarly regulate secondary branches to develop a well-distributed tertiary framework.

The objective is to establish a strong framework with adequate spacing between branches and sufficient light penetration throughout the canopy.

Pruning Practices

Pruning in HDP and UHDP is generally carried out in two important stages.

1. Post-Harvest Pruning: The first pruning is carried out around late June or July, immediately after harvest. Major operations include:

Skirting: Removal of low-hanging branches to facilitate fertilizer application, weed management, irrigation, and other orchard operations.

Opening up: Removal of crisscrossing and overcrowded branches to improve light penetration and air circulation.

Hygiene pruning: Removal of dead, diseased, damaged, or unproductive branches to maintain canopy health and reduce potential sources of infection.

2. Pre-Flowering Pruning: A second pruning can be carried out around mid-December, depending on the cultivar and local climatic conditions. Proper timing is important because the objective is to encourage a floral flush rather than excessive vegetative growth.

The operations include:

- a. Skirting
- b. Opening up the canopy
- c. Tip pruning to remove excessive apical growth
- d. Removal of dead, diseased, and damaged branches

Pre-flowering pruning should be completed within a short period, generally **one to two weeks**, to achieve uniform canopy regulation.

Role of Plant Growth Regulators

Plant growth regulators can be used as part of an integrated canopy-management programme. Paclobutrazol has been used in mango to restrict excessive vegetative growth and regulate flowering. In Alphonso, an application of approximately 10 g/tree has been reported for reducing tree height and promoting early and off-season flowering.

However, the response to paclobutrazol depends on cultivar, tree age, soil conditions, application method, and environmental factors. Therefore, its use should follow locally validated recommendations and appropriate regulatory guidelines.

Advantages of HDP and UHDP

Managing forest fires requires a holistic approach involving government agencies, scientific institutions, local communities and civil society. Some key priorities include:

1. Strengthening forest fire monitoring and early warning systems
2. Developing fire-resilient forest management practices
3. Promoting community-based fire prevention programmes
4. Enhancing research on fire ecology and climate interactions
5. Improving firefighting infrastructure and safety measures
6. Restoring fire-affected ecosystems through scientific approaches.

Forest fires are not merely environmental issues; they are challenges affecting biodiversity, climate security and human well-being. A balanced approach that combines scientific knowledge, technological innovation and community participation is essential for protecting India's forests.

Conclusion

HDP and UHDP provide promising approaches for improving the productivity and economic efficiency of mango orchards. Their success depends not simply on increasing plant population, but on the integration of suitable varieties and rootstocks with systematic training, pruning, and canopy management. Maintaining an appropriately sized and well-lit canopy is essential for sustaining flowering, fruit production, and orchard accessibility. With suitable cultivar selection and location-specific management practices, high-density mango production can contribute to more efficient use of land and improved productivity per unit area.

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Multi-Stress Interactions in Fruit Crops: Understanding Plant Responses to a Changing Climate

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Summary

Climate change is increasingly exposing fruit crops to several stresses at the same time, including drought, heat, salinity, waterlogging, and diseases. When these stresses occur together, they can trigger complex physiological, biochemical, hormonal, and molecular responses involving ROS signalling, antioxidant defence, osmotic adjustment, photosynthetic regulation, and ABA-JA-SA crosstalk. Addressing these challenges will therefore require integrated approaches that combine biostimulants, beneficial microorganisms, molecular breeding, omics technologies, and precision agriculture. Such integration can help develop fruit crops that are better adapted to changing climatic conditions while maintaining productivity and fruit quality.

Introduction

Climate change is creating increasingly difficult conditions for fruit production. Rising temperatures, irregular rainfall, drought, salinity, waterlogging, nutrient imbalance, pests, and diseases are often experienced together rather than as isolated stresses. Perennial fruit crops are particularly vulnerable because of their long production cycles and limited ability to avoid unfavourable environmental conditions. The period 2015-2024 was the warmest decade on record, with the global mean temperature approximately 1.24°C above the pre-industrial baseline. These changes are already influencing fruit crop productivity, phenology, and quality. For example, a 50% reduction in water availability may reduce yield by about 20.7%, while salinity levels of 3-4 dS m⁻¹ can result in approximately 28.2% yield reduction.

Multi-Stress: A New Challenge in Fruit Production

Plants exposed to multiple stresses do not simply respond to each stress independently. Instead, the stresses interact and can produce synergistic, additive, or antagonistic effects. A synergistic interaction occurs when the combined stress causes greater damage than would be expected from the individual stresses. In an additive interaction, the effects are approximately cumulative, whereas an antagonistic interaction occurs when one stress reduces the impact of another.

The combination of drought and heat provides a clear example. Drought generally promotes stomatal closure to reduce water loss, while heat stress requires stomatal opening to support evaporative cooling. When both stresses occur simultaneously, these responses can conflict, leading to excessive dehydration, increased leaf temperature, reduced photosynthesis, and oxidative damage. Similarly, the combination of drought and salinity imposes both osmotic stress and ionic toxicity, while waterlogging restricts root respiration and interferes with nutrient uptake.

The sequence in which stresses occur is also important. Simultaneous stresses may disrupt several physiological processes at the same time, whereas exposure to one stress before another can sometimes prime the plant for improved tolerance or, alternatively, increase its susceptibility. These contrasting responses are commonly associated with cross-tolerance and cross-sensitization.

Stress Crosstalk Inside the Plant

Plant responses to multiple stresses are controlled by an interconnected network of physiological, biochemical, and molecular signals. Reactive oxygen species (ROS) are important signalling molecules during stress, but excessive ROS accumulation can result in lipid peroxidation and damage to proteins and DNA. Plants regulate ROS levels through antioxidant systems involving enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidases (POD), together with non-enzymatic antioxidants such as ascorbic acid, glutathione, carotenoids, and flavonoids.

Another important response is the accumulation of compatible solutes, including proline, glycine betaine, trehalose, and mannitol. These compounds help maintain cellular water balance and protect membranes and proteins under stress. However, when several stresses occur together, plants may divert a greater proportion of their resources from growth and reproduction towards survival. This shift can ultimately reduce biomass accumulation, yield, and fruit quality.

Hormonal Crosstalk: The Central Regulatory Network

Plant hormones provide an important communication system through which plants coordinate responses to multiple stresses. Absciscic acid (ABA) has a central role in responses to drought and salinity, particularly through stomatal regulation and osmotic adjustment. Jasmonic acid (JA) and salicylic acid (SA), meanwhile, are strongly associated with

defence against insects and pathogens. The interaction among these hormonal pathways helps determine how plants balance abiotic stress tolerance, biotic defence, and continued growth.

Under drought and salinity, enhanced ABA signalling may suppress aspects of JA- and SA-mediated defence, which can increase susceptibility to some pathogens and pests. On the other hand, exposure to a mild stress before a more severe stress may activate common defence mechanisms and improve subsequent tolerance. These responses highlight the importance of hormonal cross-talk in multi-stress adaptation rather than viewing each hormone as functioning independently.

At the molecular level, calcium signalling and mitogen-activated protein kinase (MAPK) cascades help link stress perception with downstream cellular responses. Transcription factors belonging to the WRKY, DREB, NAC, MYB, and AP2/ERF families regulate stress-responsive genes involved in defence, metabolism, antioxidant activity, and growth. Importantly, combined stresses can produce gene-expression patterns that differ substantially from those induced by individual stresses.

Evidence from Major Fruit Crops

Recent research in major fruit crops demonstrates the practical importance of multi-stress interactions. In grapevine, drought has been reported to reduce downy mildew infection through mechanisms such as stomatal closure and enhanced phenolic defence, whereas heat stress can increase disease severity. When drought and heat occur together, grapevines show distinct physiological and biochemical responses compared with either stress alone.

In banana, arbuscular mycorrhizal fungi (AMF) have improved tolerance to combined salinity and *Fusarium* infection by enhancing plant growth, nutrient uptake, and chlorophyll content, while also stimulating defence-related gene expression and reducing disease severity. In citrus, the combination of nutrient deficiencies with water and heat stress can intensify oxidative damage, alter hormonal responses, and modify transcriptomic patterns, with plants increasingly allocating resources towards survival rather than growth. In mango, fulvic acid and salicylic acid have improved water relations, photosynthesis, antioxidant defence, growth, yield, and fruit quality under combined salinity and heat stress, although the magnitude of the response can vary among cultivars.

Towards Climate-Resilient Fruit Production

The increasing frequency of interacting stresses highlights the need to move beyond single-stress management towards integrated multi-stress strategies. Breeding programmes should therefore consider combined tolerance to drought, heat, salinity, and diseases. Molecular breeding, transcriptomics, metabolomics, and biomarker-based selection can support the identification and development of genotypes with broader stress resilience.

Biological and chemical interventions, including AMF, salicylic acid, and fulvic acid, can improve root function, antioxidant capacity, and stress adaptation. Their effectiveness may be enhanced when combined with efficient irrigation, balanced nutrition, and appropriate disease management rather than being used as standalone treatments.

Future fruit production systems are also likely to make greater use of precision agriculture. Environmental sensors, climate forecasting, disease prediction, and smart irrigation systems can help growers respond to changing field conditions more precisely. Orchard management should therefore focus on interacting stress combinations—such as drought-heat, salinity-nutrient deficiency, and abiotic stress-disease—rather than addressing each stress separately.

Conclusion

Multi-stress conditions are becoming an increasingly important challenge for modern fruit production. Interactions among drought, heat, salinity, nutrient imbalance, and biotic stresses can substantially alter plant physiology, defence mechanisms, productivity, and fruit quality. ROS signalling, osmotic adjustment, Ca^{2+} signalling, MAPK pathways, and ABA-JA-SA hormonal crosstalk form important components of the regulatory network underlying these responses.

Building climate resilience in fruit crops will require a combination of stress-tolerant cultivars, molecular breeding, beneficial microorganisms, targeted elicitors, and precision orchard management. A better understanding of how fruit crops perceive, integrate, and respond to multiple simultaneous stresses will be essential for sustaining yield and quality, supporting farmer livelihoods, and strengthening food security under a changing climate.

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Effects of Soil Salinity on Tropical Fruit Crops: From Growth to Fruit Quality

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Summary

Soil salinity is a major abiotic constraint affecting tropical and subtropical fruit crops by inducing osmotic stress, ionic toxicity, nutrient imbalance, and oxidative stress. These disturbances impair water relations, ion homeostasis, photosynthesis, growth, reproduction, yield, and fruit quality. The severity of damage varies among species and genotypes, with salt-tolerant cultivars and rootstocks showing better ion regulation, osmotic adjustment, and antioxidant capacity. Identifying and utilizing such genetic variation is therefore essential for improving salinity tolerance in fruit crops.

Introduction and Global Perspective

Soil salinity is a major abiotic constraint to sustainable horticultural production worldwide. Many tropical and subtropical fruit crops are relatively salt-sensitive and therefore experience reductions in growth, physiological performance, yield, and fruit quality under elevated salinity. The severity of damage varies with species and genotype, salt concentration and composition, duration of exposure, developmental stage, soil properties, and environmental conditions.

1. Global Extent of Salt-Affected Soils: Salinity affects approximately 20% of irrigated agricultural land worldwide, posing significant challenges to crop productivity and food security. Recent estimates indicate that salt-affected topsoils (0-30 cm) cover about 424 million hectares, while affected subsoils (30-100 cm) extend across approximately 833 million hectares.

In India, around 6.7 million hectares are affected by salinity and related soil degradation, particularly across states such as Gujarat, Uttar Pradesh, Maharashtra, and Tamil Nadu. This has increased research efforts towards salt-tolerant germplasm, suitable rootstocks, improved irrigation management, and soil-reclamation practices.

2. Sources of Soil Salinity: Soil salinity develops through primary (natural) and secondary (human-induced) processes. Primary salinity results mainly from weathering of salt-bearing parent materials and the inland transport of marine salts. Secondary salinity is associated with land-use changes, poor drainage, and prolonged irrigation with saline or poor-quality water. Removal of deep-rooted vegetation can disturb the water balance, promote groundwater rise, and drive salts towards the soil surface. Evaporation then concentrates these salts within the root zone, adversely affecting fruit crop growth and productivity.

Physiological Mechanisms of Salt Stress

Salinity affects tropical fruit crops mainly through osmotic stress, ionic toxicity, nutritional imbalance, and oxidative stress. These responses interact over time, ultimately affecting water relations, growth, photosynthesis, reproductive development, yield, and fruit quality.

1. Osmotic Stress and Impaired Water Relations: The initial response to salinity is predominantly osmotic. Accumulation of soluble salts lowers soil water potential, restricting water uptake by roots and causing physiological drought. Reduced water availability lowers cellular turgor and limits cell expansion and growth. Stomatal closure helps conserve water but also restricts transpiration and CO₂ uptake, thereby reducing photosynthetic activity. Consequently, relative water content (RWC), leaf water potential, leaf expansion, shoot and root growth, and biomass production may decline, particularly in salt-sensitive fruit crops.

2. Ionic Toxicity and Nutritional Imbalance: With prolonged exposure, excessive accumulation of Na⁺ and Cl⁻ can disrupt enzyme activity, membrane stability, and cellular ion homeostasis. Excess Na⁺ also competes with essential nutrients, particularly K⁺, Ca²⁺, and Mg²⁺, thereby disturbing nutrient uptake and transport. Reduced K⁺ availability affects stomatal regulation, enzyme activity, and osmoregulation, while deficiencies of Ca²⁺ and Mg²⁺ can impair membrane stability and chlorophyll synthesis, respectively. Therefore, the ability of a genotype to restrict Na⁺ and Cl⁻ accumulation in leaves while maintaining favourable K⁺/Na⁺ and Ca²⁺/Na⁺ ratios is an important component of salinity tolerance.

3. Oxidative Stress and Biochemical Defence: Salinity-induced metabolic disturbances can increase the production of reactive oxygen species (ROS) such as O₂•⁻, H₂O₂, and OH•. Although ROS also function as signalling molecules at controlled levels, their excessive accumulation causes oxidative damage to lipids, proteins, nucleic acids, and photosynthetic pigments.

To maintain cellular redox balance, fruit crops activate antioxidant defence systems involving enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POX), ascorbate peroxidase (APX), and polyphenol oxidase (PPO), along with non-enzymatic antioxidants including ascorbic acid, glutathione, carotenoids, phenolics, and flavonoids. Compatible osmolytes such as proline also contribute to osmotic adjustment, membrane stabilization, and protection of cellular components. The ability to maintain an effective balance between ROS production and scavenging is therefore a key determinant of salinity tolerance.

Effects of Salinity on Plant Growth and Yield

Salinity can affect tropical fruit crops throughout their life cycle, from germination and seedling establishment to vegetative growth, reproduction, yield, and fruit quality. The severity of these effects depends on crop species, genotype, salt concentration, duration of exposure, and environmental conditions.

1. Seed Germination and Seedling Establishment: Germination and early seedling growth are highly sensitive to salinity. Excess salts reduce water uptake during imbibition and interfere with enzyme activity, reserve mobilization, and cellular metabolism, resulting in reduced germination, emergence, seedling growth, and survival.

Considerable genotypic variation has been reported among fruit crops. In mango, germination declines significantly under NaCl concentrations of approximately 50 mM, while polyembryonic genotypes such as Turpentine, Deorakhio, Olour, and Bappakkai show greater tolerance than Chandrakaran and Kitchener. In citrus and papaya, increasing EC of irrigation water can reduce seedling survival and delay emergence, although rootstocks such as Cleopatra mandarin and Rangpur lime and some papaya cultivars show comparatively greater tolerance. Such variation provides a useful basis for early screening and selection of salt-tolerant genotypes.

2. Vegetative Growth and Biomass Production: Salinity commonly reduces plant height, stem girth, internodal length, leaf area, and shoot and root biomass. These effects become more pronounced as salinity exceeds the tolerance threshold of a particular crop or genotype.

Salinity also alters hormonal balance. Increased ABA accumulation supports stress adaptation, while changes in growth-promoting hormones such as IAA and cytokinins can restrict cell division and expansion. In citrus and other woody fruit crops, enhanced ACC synthesis and subsequent ethylene production may promote leaf senescence and abscission. Toxic ion accumulation in older leaves further accelerates senescence, reducing photosynthetic leaf area and dry matter production.

3. Photosynthetic Efficiency and Pigment Degradation: Photosynthesis is particularly sensitive to salinity. Stomatal closure restricts CO₂ availability, while ionic toxicity and nutrient imbalance can impair chloroplast structure and photosynthetic metabolism. Salinity may also reduce chlorophyll and carotenoid contents through oxidative damage, pigment degradation, and impaired chloroplast function. Reduced nitrogen and magnesium availability further limits chlorophyll synthesis. Consequently, photosynthetic rate, stomatal conductance, and other gas-exchange parameters may decline in salt-sensitive fruit crops such as banana, grape, sapota, and citrus.

4. Effects on Yield and Fruit Quality: The combined effects of reduced growth, photosynthesis, nutrient uptake, and reproductive performance ultimately lead to lower yield and fruit quality. Salinity can adversely affect flowering, pollen viability, fruit set, fruit retention, and fruit development.

In mango (*Mangifera indica* cv. Osteen), increasing soil EC from 1.02 to 2.50 dS m⁻¹ has been associated with reduced fruit yield and a higher proportion of small, less marketable fruits. Similarly, studies in lemon cv. Fino 49 and papaya cultivars Tainin and Red Lady have reported yield reductions of approximately 10% to more than 24%, together with changes in quality attributes such as TSS and titratable acidity.

Overall, the magnitude of yield and quality losses varies among species and cultivars, emphasizing the importance of genotype-specific salinity thresholds when developing management and breeding strategies.

Conclusion

Sustainable fruit production under saline conditions requires an integrated approach combining salt-tolerant cultivars and rootstocks with efficient irrigation, drainage, soil amendments, and appropriate physiological interventions. Future research should integrate conventional breeding with molecular and omics-based approaches to identify reliable markers and develop salt-tolerant fruit genotypes. Such strategies will be important for maintaining fruit yield and quality in salt-affected environments.

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Millets and GLP-1: Nature's Own Appetite Brake “Stop eating sooner, or start the next meal later”

Article ID: 74541

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Introduction

India is still discussing the global syndemic of obesity. The media often portrays obesity as faceless bodies, enlarged waistlines, fast food and BMI numbers, and people are judged for uncontrolled eating before the actual cause is known. Yet diets fail not because of weak willpower but because the body actively fights weight loss. Hunger, blood sugar and body weight are governed by hormones and chemical signals, not only by a person's choice.

Today, nearly one in eight people lives with obesity. The World Health Organization estimates that more than one billion people are now affected, and that about one in five children and adolescents aged 5 to 19 years is overweight. The Lancet Commission has described obesity, undernutrition and climate change together as a “global syndemic”, three crises that feed one another and share common drivers in our food systems (Swinburn *et al.*, 2019). Since 1990 the combined prevalence of overweight and obesity among children and adolescents has doubled, reaching 493 million young people aged 5 to 24 years in 2021 (GBD 2021 Adolescent BMI Collaborators, 2025). India alone has about 14.4 million obese children, the second-largest number in the world after China (GBD 2015 Obesity Collaborators, 2017). As obesity spreads, type 2 diabetes follows close behind. In this health emergency the country needed a superhero, and it arrived not as a diet or a detox plan, but as a hormone.

GLP-1: The Body's Fullness Alarm

Deep inside the intestine, a messenger named glucagon-like peptide-1 (GLP-1) quietly shapes our relationship with food. Released by the L-cells of the gut after a meal, it slows digestion, stimulates insulin release to regulate blood sugar and, most importantly, tells the brain that enough has been eaten. Have you ever felt that you simply do not need another bite? That is GLP-1 at work, the body's built-in appetite brake, tying the gut to the brain along the communication line that keeps hunger and satiety in check. This simple feedback loop has become one of the most exciting discoveries in modern medicine, and a billion-dollar industry.

From Lab Bench to Red Carpet: The Rise of GLP-1 Drugs

Once scientists decoded how GLP-1 slows gastric emptying, triggers insulin secretion and promotes satiety, the race to harness it began. Pharmaceutical chemists engineered synthetic GLP-1 receptor agonists that mimic the natural hormone but resist its rapid breakdown in the blood. Semaglutide, sold as Ozempic for diabetes and Wegovy for obesity, became a household name, followed by liraglutide (Victoza, Saxenda), dulaglutide (Trulicity) and the dual agonist tirzepatide (Mounjaro, Zepbound), while the triple agonist retatrutide is still in clinical trials. In a 72-week trial, people on the highest dose of tirzepatide lost about 21 per cent of their body weight on average, a result once thought impossible without surgery (Jastreboff *et al.*, 2022). Soon GLP-1 drugs were everywhere, from the laboratory bench to Hollywood conversation. Social media dubbed them the “skinny jab” and pharmacies struggled to keep up with demand. The promise was irresistible: a weekly shot that switches hunger off, with no surgery required.

Behind the Hype: The Other Side of the Magic Drug

But every miracle has its shadow (Fig. 1). Common complaints include nausea, vomiting, diarrhoea and stomach pain, while more serious concerns such as pancreatitis, gallbladder disease, gastroparesis and a labelled warning about thyroid tumours have made clinicians cautious. Lean muscle is lost along with fat during rapid weight loss, and the drugs are not recommended during pregnancy, a real constraint for women's health. They also work only while they are being taken; stop, and most people regain the weight. Cost is another barrier. Semaglutide and tirzepatide are now available in India, but a month's supply runs into thousands of rupees, far beyond the reach of much of the population. In the tirzepatide trial most side effects were mild to moderate stomach complaints, yet 4 to 7 per cent of participants stopped treatment because of them (Jastreboff *et al.*, 2022).

For a long time the nausea was treated as an unlucky price for a good drug. Recent work on brain circuits explains it better. In the hindbrain, GLP-1 receptors sit on two separate groups of nerve cells: one produces true satiety, the calm feeling of having eaten enough, while the other produces aversion, the queasy feeling that makes an animal turn away from food. The drugs press both switches at once, and researchers have now shown that the two can be separated (Huang *et al.*, 2024). Part of the appetite loss on a GLP-1 drug is therefore not fullness at all, but a mild sickness signal, and

some people report that meals and other ordinary pleasures begin to feel flat. That reality leads to a compelling question: can nature do what the laboratory does, without the cost and without the side effects?

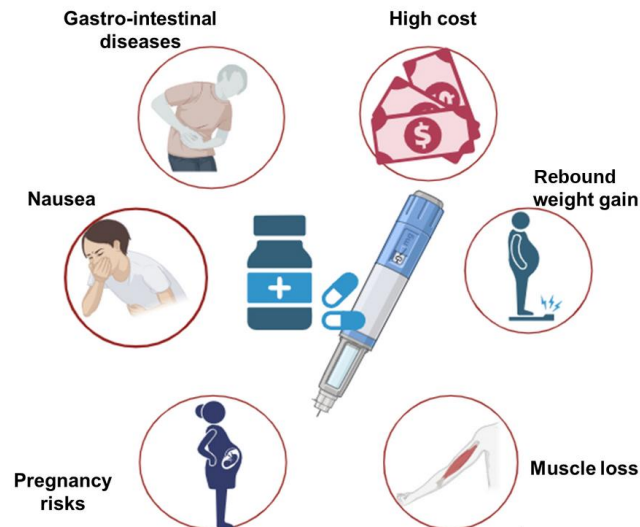


Fig. 1: Reported limitations and side effects of GLP-1 receptor agonist drugs currently on the market (prepared by the authors).

The Millet Answer: Nature's Own Route to GLP-1

For decades the nutritional power of millets stayed hidden in plain sight. Rich in dietary fibre, phenolic compounds and slowly digestible starch, millets are emerging as nature's quiet competitor to synthetic GLP-1. A study from China showed that an enriched polyphenol fraction from foxtail millet, named FMP-60, stimulated GLP-1 secretion from intestinal L-cells (An *et al.*, 2023). The researchers identified eight active phenolic constituents, including ferulic acid, *p*-coumaric acid, 2-hydroxycinnamic acid and coniferaldehyde. In diet-induced obese mice the fraction raised the animals' own GLP-1, improved glucose and lipid metabolism and limited weight gain. Notably, the fraction from whole grain outperformed the same extract prepared after the bran was removed, a clear argument for eating millets whole.

Millets also nurture the gut itself. Their dietary fibre escapes digestion in the small intestine and is fermented by colonic microbes into short-chain fatty acids, chiefly acetate, propionate and butyrate. These act on the free fatty acid receptors FFAR2 and FFAR3 carried by the same L-cells, further stimulating GLP-1 release (Tolhurst *et al.*, 2012). It is a full-circle symphony of metabolism, played not in a laboratory but in the digestive tract (Fig. 2).

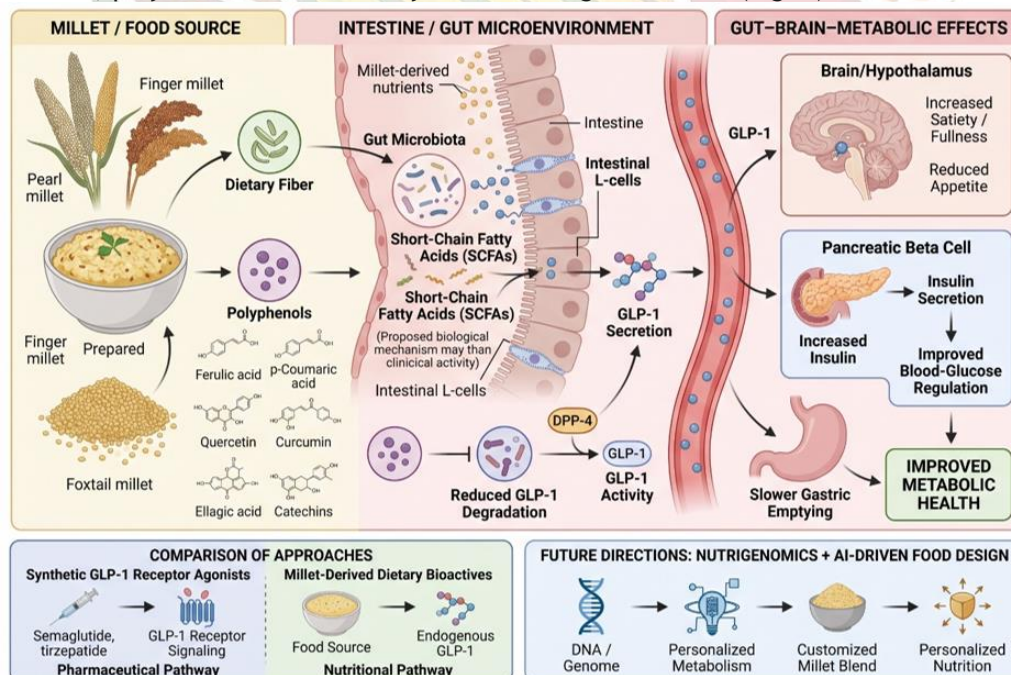


Fig. 2: Potential role of millet-derived bioactives in modulating the gut-brain GLP-1 axis. Dietary fibre and polyphenols from millets reach the intestine, where microbial fermentation yields short-chain fatty acids that act on intestinal L-cells, raising the body's own GLP-1 and signalling to the brain, pancreas and stomach (prepared by the authors).

More Than a Grain: The Polyphenol Powerhouse

Polyphenols, the abundant secondary metabolites of plants, carry health benefits that remain largely unknown to the common people. In diabetes they act as armour: persistent high blood sugar generates reactive oxygen species that damage cells, and polyphenols scavenge these free radicals. Millet polyphenols have a further talent, as they both enhance GLP-1 secretion from the intestinal wall and help protect the hormone once it is released. Finger millet supplies quercetin, ellagic acid and catechins, antioxidants that help protect the insulin-producing beta cells of the pancreas. Ferulic acid, abundant in the bound phenolic fraction of nearly every millet, belongs to a class of plant phenolics shown in laboratory studies to inhibit dipeptidyl peptidase-4 (DPP-4), the enzyme that degrades GLP-1 within minutes of its release. Slowing that enzyme prolongs the action of the body's own hormone, which is precisely the principle behind the gliptin class of diabetes medicines. Together these bioactives weave a natural metabolic defence that echoes the effect of synthetic drugs through the chemistry of an ordinary grain, one that travels from the farm, through the kitchen, to the plate.

Beyond Satiety: From Metabolic Harmony to Personalised Grains

Millet does not merely suppress hunger; they help restore metabolic balance. Their mean glycaemic index of about 53 is roughly 36 per cent lower than that of milled rice and refined wheat, which helps steady blood sugar (Anitha *et al.*, 2021), while their fibre keeps a person full for longer. They are also climate-resilient crops that thrive in arid conditions on minimal inputs, and India already grows them at scale, a rare fusion of nutrition and ecology. The next frontier lies in nutrigenomics and AI-driven food design, where scientists model how specific millet compounds interact with human GLP-1 pathways to predict which combinations could deliver maximum satiety and glucose control. Imagine scanning your genome and receiving a customised millet blend matched to your metabolism, a future in which food is the prescription and satiety is personalised.

Conclusion

Should the world abandon GLP-1 drugs for grains? Not quite. For people with severe obesity or uncontrolled diabetes, pharmaceutical GLP-1 agonists remain important clinical tools, and much of the millet evidence so far comes from cell and animal studies that human trials must still confirm. But for the millions seeking a sustainable, preventive approach, the answer may already be growing in our fields. Bringing millets back onto our plates is a simple, low-cost step. Which would you choose: a millet recipe from your own kitchen, or a drug you must keep taking for life?

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Smart Breeding of Nutrient-Rich Pearl Millet: Integrating Biofortification, Genomics and Precision Selection

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Abstract

Pearl millet is a climate-resilient cereal important for food security in arid and semi-arid Africa and South Asia. Besides energy, it provides protein, fibre and essential minerals, with iron (Fe) and zinc (Zn) as key targets for nutritional improvement. Wide genetic variation for grain Fe and Zn supports genetic biofortification. Genome sequencing, association mapping, SNP genotyping, genomic prediction and phenotyping now enable more efficient selection of nutrient-dense material. This article summarizes smart breeding through germplasm utilization, biofortification, marker-assisted selection, GWAS, genomic selection, high-throughput phenotyping, and integration of nutrition with climate resilience and yield. Fe and Zn can be improved together because of positive genetic associations, but concentration alone is insufficient; stability, bioavailability, yield and grain quality must also guide selection.

Introduction

Pearl millet is well adapted to high temperature, erratic rainfall and low soil fertility where major cereals often perform poorly. Genome sequencing and resequencing have created a foundation for diversity analysis, association mapping, genomic prediction and hybrid improvement. The grain supplies protein, fibre, minerals and bioactive compounds. Fe and Zn are important targets because deficiencies are common in populations dependent on cereal staples. Pearl millet possesses genetic variation for mineral density, and breeding programs have developed high-Fe and high-Zn cultivars. Smart breeding does not replace conventional breeding; it integrates field selection with molecular markers, genomic information, phenotyping and data-driven decisions to improve selection efficiency for multiple traits (Govindaraj et. al., 2024).

Biofortification Through Breeding

Biofortification increases nutrient density through genetic improvement rather than external supplementation. Once a stable, farmer-acceptable cultivar is adopted, improved nutrition can be delivered through normal everyday consumption. Pearl millet shows broad variation in Fe and Zn concentration, supporting the development of high-Fe varieties and hybrids. Research continues to improve micronutrient density while maintaining agronomic performance (Kanatti et. al., 2014).

Conventional Breeding Foundation

Diverse germplasm, landraces, inbred, maintainer and restorer lines provide allelic diversity for combining nutrition with adaptation and yield. Parent selection should consider Fe and Zn alongside yield, maturity, flowering time, disease resistance, drought and heat tolerance, grain size and consumer preference. Because pearl millet is predominantly cross-pollinated, intra-population selection is valuable. Positive genetic association between Fe and Zn also permits simultaneous selection (Fig1) (Pujar et. al., 2020).

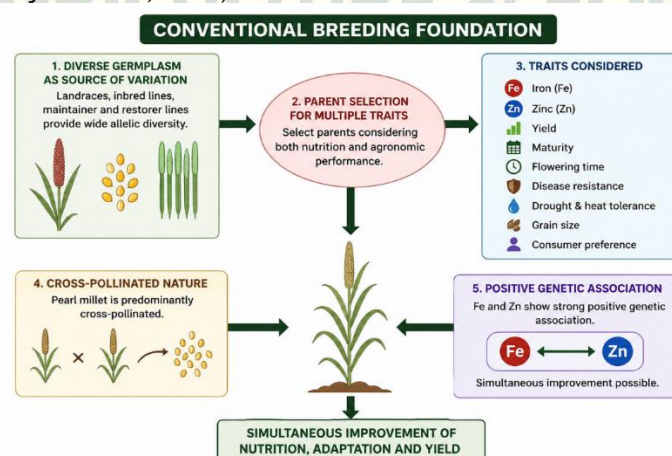


Figure 1: Conventional breeding foundation for simultaneous improvement of nutrition, adaptation, and yield in pearl millet

Marker-Assisted Selection and GWAS

Marker-assisted selection (MAS) uses DNA markers associated with genes or QTL for target traits. Markers can enable early elimination of inferior plants and reduce field and laboratory testing. Trait pyramiding can combine high Fe, high Zn, disease resistance and stress adaptation, while phenotyping verifies the resulting phenotype. However, markers validated in one population require validation across genetic backgrounds. GWAS and genomic resources have expanded the discovery of loci for Fe, Zn and protein. Large SNP datasets have revealed marker-trait associations, shared signals and candidate genes involved in mineral homeostasis. These associations require validation across populations and environments (Srivastava et. al., 2021).

Genomic Selection

Genomic selection uses genome-wide markers to predict breeding values, making it suitable for complex traits controlled by many small-effect genes. A training population can be phenotyped for Fe, Zn, protein and agronomic traits, genotyped, and used to build prediction models. Candidate plants can then be ranked before extensive phenotyping, increasing selection intensity and shortening breeding cycles. Prediction accuracy depends on population size, heritability, marker quality and similarity between training and target environments (Varshney et. al., 2017).

High-Throughput Phenotyping

Molecular breeding is effective only when supported by accurate phenotyping. Nutritional improvement requires reproducible measurement of mineral concentration. Spectroscopy and related approaches can reduce screening cost and time when properly calibrated. Nevertheless, multi-environment testing remains essential because Fe and Zn concentration can respond to soil, rainfall, temperature and management. Standardized sampling and laboratory procedures are therefore important for comparisons (Table 1) (Govindaraj et. al., 2024).

Table 1: Comparison of Molecular Breeding and High-Throughput Phenotyping Approaches for Nutrient Improvement in Pearl Millet:

Breeding Approach	Key Principle	Major Applications	Advantages
Marker-Assisted Selection (MAS)	Uses DNA markers linked to genes/QTL for target traits.	Early selection for high Fe, Zn, disease resistance and stress adaptation.	Reduces field and laboratory testing
GWAS	Identifies marker-trait associations using genome-wide SNP variation.	Discovery of loci and candidate genes for Fe, Zn and protein.	Reveals shared genetic signals
Genomic Selection (GS)	Uses genome-wide markers to predict breeding values.	Ranking candidates for Fe, Zn, protein and agronomic traits.	Increases selection intensity and shortens breeding cycles
High-Throughput Phenotyping	Rapid and reproducible measurement of nutritional and agronomic traits.	Spectroscopy and other rapid methods for mineral screening.	Reduces screening time and cost when properly calibrated.
Multi-Environment Phenotyping	Evaluates traits across diverse environments and seasons.	Testing Fe and Zn stability under different soil, rainfall, temperature and management conditions.	Standardized sampling and laboratory methods improve comparability.

Nutrition and Climate Resilience

Nutritional improvement must be integrated with adaptation. A nutrient-rich cultivar that fails under drought or heat may not be adopted, while a productive but nutrient-poor cultivar provides limited dietary benefit. Breeding should use multi-trait selection indices combining Fe, Zn, protein, yield, maturity, disease resistance, drought and heat adaptation, and grain quality. Trait weights should reflect the production environment and farmer priorities (Velu et. al., 2007).

Bioavailability and Food Quality

High mineral concentration does not automatically ensure nutritional benefit. Absorption depends on mineral form, diet, anti-nutritional compounds and processing. Breeding lines should therefore be assessed for bioavailability and grain quality as well as total Fe and Zn. Decortication, milling, fermentation, malting, germination and cooking can alter nutrient availability. Collaboration among breeders, food scientists and nutritionists is needed to connect genetic improvement with nutritional benefits (Srivastava et. al., 2021).

Practical Breeding Pipeline

A breeding pipeline begins by identifying high-Fe, high-Zn and high-protein donors through germplasm characterization and nutrient screening. Crossing combines nutritional traits with yield and adaptation through pedigree, backcross or hybrid breeding. SNP markers or MAS support early selection, while genomic prediction ranks multi-trait candidates.

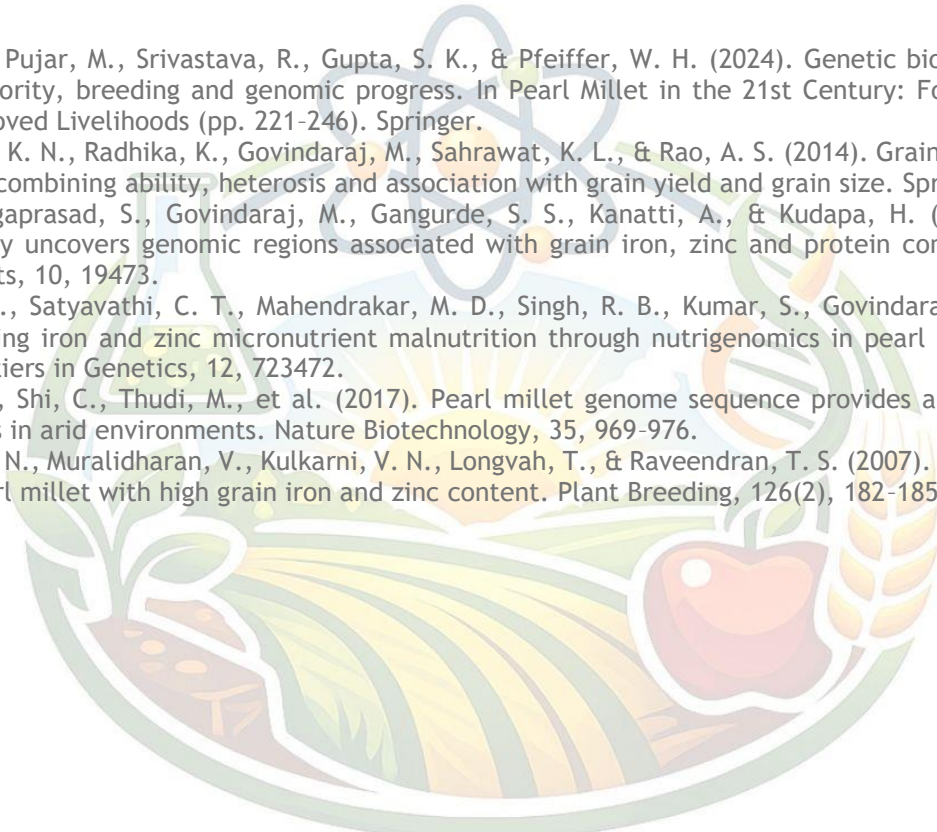
Phenotyping confirms nutrient and agronomic performance, followed by multi-location testing for genotype-by-environment stability. Bioavailability and food quality are then evaluated before participatory testing, seed multiplication and release (Varshney et. al., 2017).

Challenges and Conclusion

Major challenges include genotype-by-environment effects, costly nutrient phenotyping, validation of marker associations, and uncertainty about bioavailability and dietary impact. Selection must avoid compromising yield, maturity, stress tolerance, grain quality or consumer preference. Genomic prediction requires regularly updated training populations, while impact also depends on seed systems, markets, regulation and consumer awareness. Pearl millet therefore provides an opportunity to combine climate resilience with nutrition. Success requires integrating conventional breeding, biofortification, MAS, GWAS, genomic prediction and improved phenotyping, supported by multi-environment testing, food-quality evaluation, strong seed systems and nutrition-sensitive policy. The ultimate goal is not simply higher mineral concentration, but stable, bioavailable, farmer-acceptable and climate-resilient grain delivered at scale.

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The Booth in the Village Square: How CropSync-Enabled Advisory Kiosks are Bringing Verified Farm Guidance to India's FPOs

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Abstract

This article examines the CropSync-enabled Farmers' Advisory Services Kiosk, a village-level digital advisory model deployed at Farmer Producer Organisations across Telangana, using its February 2026 launch at Tekmal Mandal FPO as an entry point. Unlike government or nonprofit AI advisory platforms such as Bharat-VISTAAR or Farmer.Chat, which are funded through public budgets or grants, CropSync's kiosks operate on a hybrid commercial model: farmers receive free, ICAR-backed advisory on crop practices, pest management, weather, and market prices, while the network is funded through targeted advertising and aggregated data sold to input companies, CSR programmes, and agri-fintechs. Drawing on ICAR-IIMR's official press release and CropSync's own published platform data, the article traces how a kiosk session works end to end, presents verified reach figures (around 2,000 farmers across three districts as of 2026), and situates the model within India's wider digital extension landscape. It concludes with a balanced assessment: the advisory itself appears to deliver genuine value, but the model's long-term legitimacy will depend on how transparently farmer consent is obtained and how rigorously "anonymised" commercial data stays that way as the network scales.

Keywords: Advisory Services, CropSync's, agri-fintechs, balanced assessment etc.

Introduction

On 24 February 2026, in a modest Farmer Producer Organisation office in Tekmal Mandal, Telangana, something quietly new was switched on alongside a set of harvesters and millet-processing machines. It wasn't a tractor or a thresher, it was a screen. The ICAR-Indian Institute of Millets Research (IIMR), working with the ICICI Foundation, inaugurated a Custom Hiring Centre and, next to it, a **CropSync-enabled Farmers' Advisory Services Kiosk** a digital booth designed to give member-farmers real-time, scientifically grounded answers to their everyday questions, from pest identification to mandi prices, without waiting for an extension officer to visit.

It's a small installation, benefiting an initial 500-700 member farmers, but it represents a broader model now spreading across Telangana and Andhra Pradesh: physical, village-level kiosks, run by a Hyderabad-based agritech company called CropSync, that combine ICAR-backed agronomic knowledge with a distinctly commercial twist, the advisory is free to the farmer because it is paid for by advertisers and CSR sponsors watching farmer demand in real time.

What is a CropSync-Enabled Kiosk, Exactly?

At its core, a CropSync kiosk is a physical touchpoint typically installed at an FPO office, cooperative society, or village centre where a farmer can walk up, identify themselves, and get an on-the-spot advisory in their own language. According to CropSync's own platform description, the kiosk delivers scientific cultivation practices, crop planning support, pest and disease management guidance, weather-based advisories, and market intelligence, all through a single interface backed by ICAR research.

What sets it apart from a generic touchscreen kiosk or an app is the authentication layer. Every session is tied to a verified farmer ID, created either through an RFID card or a phone number not an anonymous click. CropSync markets this explicitly as a feature: it turns every advisory session into what the company calls a "consent-based, auditable engagement log," which is valuable to the FPOs and ICAR institutes running it, but is also the basis of the company's commercial model, discussed further below.

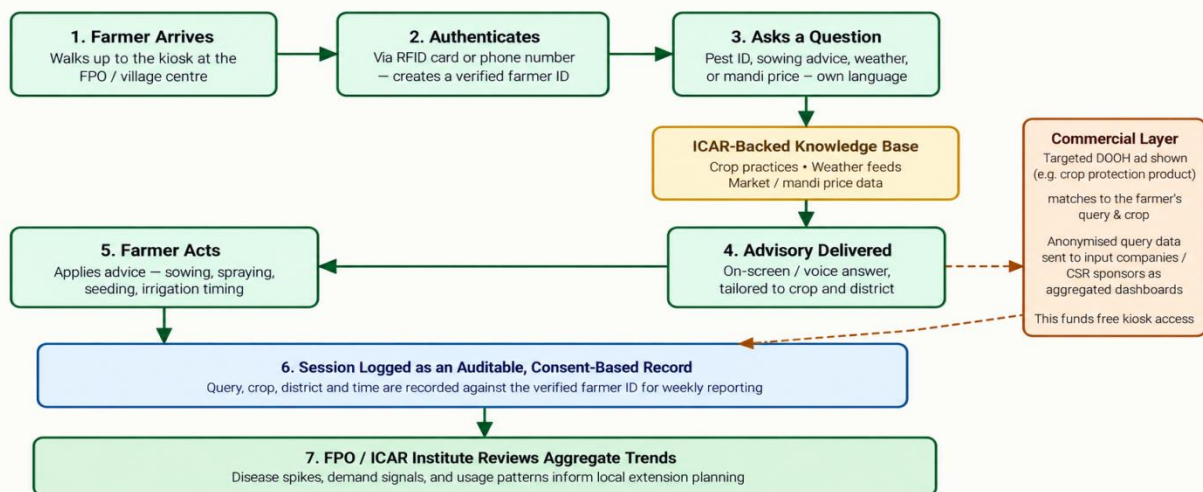
How a Kiosk Session Actually Works

The flowchart traces a typical interaction, from the moment a farmer walks up to the point where an ICAR institute or FPO reviews the resulting data:

1. Farmer arrives at the kiosk installed at the FPO or village centre.
2. Authenticates via RFID card or phone number, creating a verified farmer ID.
3. Asks a question related to pest ID, sowing advice, weather, or mandi price in their own language.
4. The query is checked against an ICAR-backed knowledge base (crop practices, weather feeds, market/mandi price data).

5. Advisory is delivered on-screen or via voice, tailored to crop and district.
6. Farmer acts on the advice of sowing, spraying, selling, or timing irrigation.
7. In parallel, a commercial layer activates: a targeted ad (e.g., a crop-protection product matched to the farmer's query and crop) is shown, and anonymised query data is sent to input companies or CSR sponsors as aggregated dashboards, this is what funds free access to the kiosk.
8. The session is logged as an auditable, consent-based record such as query, crop, district, and time tied to the verified farmer ID.
9. The FPO or ICAR institute reviews aggregate trends like disease spikes, demand signals, usage patterns to inform local extension planning.

Anatomy of a CropSync-Enabled Advisory Kiosk Session



The design is straightforward on the farmer-facing side: authenticate, ask, receive an answer, act on it. What happens in the background is where the model becomes more interesting and, as we'll get to, more debatable.

Where Technology Comes from

CropSync Private Limited is registered in Hyderabad, Telangana, and describes itself as building "rural India's intelligence layer." Its published list of institutional validators and partners includes IIT Ropar's Technology Innovation Foundation, ICAR-IIMR, ICAR-IOR (the Indian Institute of Oilseeds Research), the ICICI Foundation, and smaller agri-fintech and IoT partners such as Dvara E-Dairy, Delta IoT Solutions, and Carbon Mint. As of its most recently published figures, the company reports 2,093 farmers reached through a live kiosk network spanning three Telangana districts namely Rangareddy, Nalgonda, and Kadapa with active expansion underway.

The company also runs what it calls a "COFO" (co-owned FPO) model, under which a Farmer Producer Organisation can co-own a kiosk and share in advisory monetization, while its members get round-the-clock, multilingual crop guidance drawing on ICAR research.

CropSync Kiosk Network: Key Figures

Metric	Reported Figure
Farmers reached (live network, 2026)	2,093
Districts with live kiosk coverage	3 (Rangareddy, Nalgonda, Kadapa)
Institutional validators/partners	IIT Ropar TIF, ICAR-IIMR, ICAR-IOR, ICICI Foundation, ACIC, VGU
Authentication method	RFID card or registered phone number
Pilot deployment example	Tekmal Mandal FPO, Telangana — launched 24 Feb 2026
Initial farmers benefited (Tekmal pilot)	500-700 member farmers
Attendance at Tekmal launch event	~120 farmers
Siddipet cluster deployment (via ICAR-IOR/ICICI Foundation)	2,000+ farmers
Campaign onboarding time (claimed)	Live within 2 weeks

Source: (Figures compiled from CropSync's own published platform data and ICAR-IIMR's official press release, current as of early-to-mid 2026; company-reported figures have not been independently audited.)

What the Tekmal Deployment Actually Included

It's worth being specific about what farmers received at the ICAR-IIMR pilot, since it illustrates how these kiosks are typically bundled with other infrastructure rather than deployed alone. Alongside the CropSync advisory kiosk, the same Tekmal FPO facility housed a Custom Hiring Centre stocked with a combine harvester, tractor, millet baler, ragi thresher-cum-pearler, and a millet cleaner-cum-pearler, plus post-harvest processing equipment; a rava maker-cum-grader, pulveriser, ribbon flour blender, roaster, and vibro separator – aimed specifically at supporting millet value addition and crop diversification. The advisory kiosk, in that context, functions less as a standalone gadget and more as one layer of a broader push to combine mechanisation, processing capacity, and digital extension under one FPO roof.

The Business Model and Why It Deserves Scrutiny

Most publicly funded digital advisory platforms in India, from the government's Bharat-VISTAAR to nonprofit tools like Digital Green's Farmer.Chat, are structured as public goods: free to farmers, funded by government budgets or philanthropic grants, with no commercial layer attached to the advice itself. CropSync's kiosk network takes a different, hybrid approach, and being fair to the model means naming both sides of that trade-off plainly.

The case for it: Extension services in India are chronically under-resourced, and a self-funding model that doesn't depend entirely on annual government budgets or grant renewal cycles could, in principle, be more sustainable. CSR programmes get auditable, farmer-authenticated impact data instead of self-reported estimates genuinely useful for demonstrating compliance with India's Companies Act Schedule VII CSR obligations. And input companies gain real-time visibility into pest and disease pressure that could, if used responsibly, help them position products or supplies where they're actually needed rather than through blanket distribution.

What deserves closer attention: The same data stream that helps an FPO plan extension work also becomes a targeting signal for advertisers. A farmer asking about "stem borer in paddy" is, in the company's own words, shown a biostimulant advertisement matched to that exact query meaning the advisory moment and the sales moment are fused together. CropSync states that analytics shared externally are aggregated and anonymised, and that farmer consent is obtained at registration, which are meaningful safeguards. But farmers using a kiosk for agronomic advice may not always fully register that their query patterns are simultaneously feeding a B2B marketing and intelligence product sold to the very companies whose products might be recommended to them. That is not necessarily improper, many free digital services worldwide run on some version of this trade but it is a materially different relationship than a purely public advisory service, and it is worth farmers, FPOs, and ICAR partners understanding clearly.

Where this Model Fits in the Bigger Picture

Feature	CropSync Kiosk Model	Public AI Advisory (e.g. Bharat-VISTAAR, Farmer.Chat)
Access point	Physical kiosk at FPO/village centre	Phone call, WhatsApp, app – no fixed location
Funding	Advertising, CSR sponsorship, B2B data	Government budget or philanthropic grant
Farmer identification	RFID/phone – always verified	Varies; often phone-linked but not ad-targeted
Commercial layer	Yes – targeted ads and sold analytics	No direct commercial layer
Underlying knowledge source	ICAR research	ICAR / CGIAR / national agri-research bodies
Scale (reported)	~2,000-2,100 farmers, 3 districts	Hundreds of thousands to millions of users

Conclusion

CropSync's kiosk network is still a small regional pilot roughly 2,000 farmers across three Telangana districts, a fraction of what national platforms claim. But its real significance isn't scale; it's a different funding philosophy for last-mile advisory, linking FPOs, ICAR institutes, CSR sponsors, and agri-input companies into one commercial loop, testing whether extension services can be self-sustaining rather than grant-dependent.

That question has no clean answer yet, and shouldn't be forced into one. The model's real worth will hinge on three quieter tests: whether farmers genuinely understand what consent they're giving, not just sign off on it; whether "anonymised" data stays that way as more parties gain access; and whether FPOs joining a COFO partnership know exactly what commercial rights they're extending. These aren't unique to CropSync every ad- or data-funded public-interest technology faces them. What makes agriculture different is the stakes: the person at that kiosk is often the most vulnerable link in the food chain, and the advice shapes an entire season's income.

For now, the kiosk works honestly for the farmers using it. But as it scales beyond three districts, that scrutiny shouldn't soften a good tool and a fair arrangement aren't automatically the same thing.

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Green Revolution in the Food Industry: Using ‘Bio-Films’ and ‘Smart Indicators’ for Plastic-Free Packaging

Article ID: 74544

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Abstract

Modern food processing and distribution chains face two problems that are growing to alarming proportions: environmental damage caused by plastic waste, and the enormous wastage of food. Conventional petroleum-based plastic wrappers persist in the environment for hundreds of years in the form of microplastics. At the same time, the fixed ‘Best Before’ date printed on packets cannot record temperature changes that occur during storage, so even perfectly safe food is often thrown away. To overcome these challenges, food technology has combined **Biodegradable Bio-Films** with **Smart Indicator Labels**. This article reviews in detail how both of these innovative technologies are made, the science behind how they work, their active ability to preserve food, and the challenges in commercialising them.

Introduction

In the food processing industry, packaging is a basic necessity for maintaining the quality, freshness and safety of food. However, the packaging methods in use today are not sustainable from the point of view of either the environment or food safety.

1. The plastic waste crisis: About 40% of all plastic waste generated globally comes from food and beverage packaging alone. This plastic destroys soil fertility and endangers marine life.

2. Global food wastage: According to a United Nations (UN) report, nearly one-third (1/3) of all food produced spoils either before it reaches consumers or in their homes. The main reasons are the lack of proper storage and the absence of an accurate system for judging freshness.

As an effective answer to these problems, a new concept has emerged: **Sustainable Active & Smart Packaging**. This system does not merely protect food from the outside; it also monitors the biochemical changes taking place inside the package and gives consumers direct information about the actual condition of the food.

Process and Technical Methods

1. Production of Bio-Films and Active Packaging: Bio-films are a highly capable alternative to conventional plastic cling films. They are made entirely from natural ingredients:

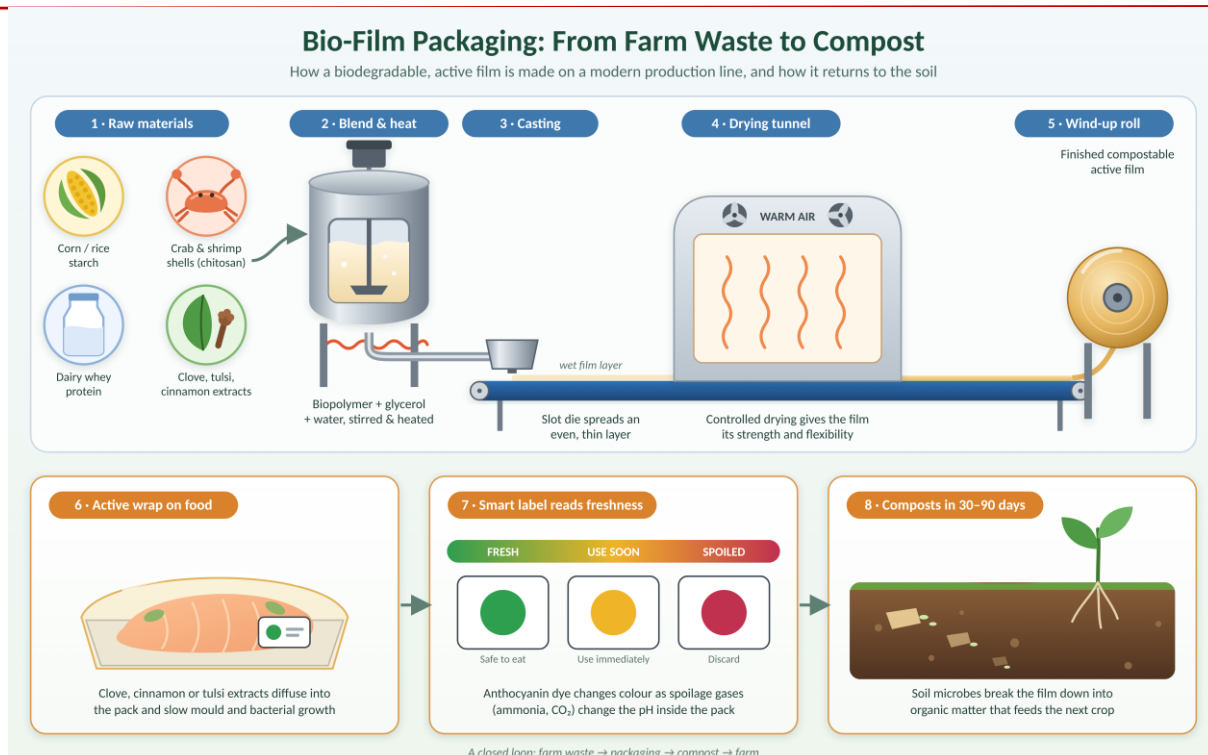
a. Sources of bio-polymers:

i. **Plant-based sources:** Corn starch (PLA - Polylactic Acid), rice flour, cellulose and pectin.

ii. **Animal-based and waste materials:** Chitosan, and waste whey protein from the dairy industry.

b. **Active components:** The wrapper does more than just cover the food. Natural ‘antimicrobial’ and ‘antioxidant’ ingredients are blended into it, for example extracts of clove, cinnamon, basil (tulsi) or ajwain (carom). These ingredients slowly diffuse into the package and prevent the growth of moulds and bacteria.

c. **Natural degradation:** After use, when these bio-films are put into soil or a home compost pit, microorganisms break them down within 30 to 90 days and they merge back into the soil, achieving zero plastic waste.



Modern production process for biodegradable bio-film packaging: from farm waste to compost

2. How Smart Indicator Labels Work: Smart labels keep a close watch on chemical changes in the atmosphere inside the package:

- a. Colorimetric (pH) Indicators:** When meat, fish or fruit begin to spoil, they release specific gases (e.g. ammonia, ethylene, sulphur compounds or carbon dioxide). These labels use **anthocyanins**, a natural pigment. On contact with these gases, the acidity (pH) around the pigment changes and the colour of the label changes:
 - i. Green:** The food is fresh and fit to eat.
 - ii. Yellow:** The food is moderately fresh (use immediately).
 - iii. Red/Purple:** The food has spoiled.
- b. Time-Temperature Indicators (TTIs):** These labels show whether the cold chain was broken during transport or in the shop. If the temperature rises, the polymer in the label changes colour, so one can immediately tell whether the food is safe, even if the 'Best Before' date has not yet passed.

Did you know? TTIs are already part of everyday life in India. The small square-in-a-circle 'Vaccine Vial Monitor' printed on many vaccine vials used in immunisation programmes is a time-temperature indicator: when the inner square turns as dark as the outer circle, the vaccine has been exposed to too much heat and should not be used. The same principle is now being applied to food packets.

Comparative Analysis

Technical parameter	Conventional plastic packaging	Modern bio-film + smart labels
Basic material	Petroleum products (Polyethylene/PP)	Agricultural waste, chitosan and bio-polymers
Environmental impact	Non-biodegradable waste that persists for 400-500 years	Converts into organic compost in 30-90 days
Freshness assessment	Depends on estimates and a fixed printed date	Direct information based on real-time chemical changes
Mode of protection	Only passive, physical protection	Active antibacterial and antioxidant protection
Microplastic risk	High risk of microplastics entering the food chain	Zero risk (completely natural and safe)

Making Active, Biodegradable Bio-Film Packaging

Three stages: produce the film, add natural active components, and deliver safer, plastic-free packaging

A Bio-Film Production

1 Raw material preparation



- Corn and rice starch
- Chitosan from crab and shrimp shells
- Agricultural waste, whey protein

2 Polymer blending



- Mixed with plasticisers such as glycerol
- Water and controlled heat

3 Film forming



- Solution casting
- Extrusion
- Coating

4 Drying and conditioning



- Controlled drying
- Gives the film flexibility and strength

B Adding Active Components

1 Encapsulating essential oils



- e.g. clove and thyme oil packed into nano-capsules

2 Incorporation methods



- Direct mixing into the polymer
- Coating the dried film
- Printing as indicator labels

3 Controlled release



- Actives migrate slowly into the space around the food

Fresh

Use soon

Spoiled

C What Active and Biodegradable Packaging Delivers



Antimicrobial protection

Slows mould and bacterial growth



Longer shelf life

Food stays fresh for more days



Direct freshness tracking

Colour change shows the real condition of food



Biodegradability

Breaks down in soil within 30–90 days

Stages of active bio-film packaging: production, active components and benefits

Why this Matters for India

For India, this technology is both a necessity and an opportunity:

- 1. Growing plastic waste:** According to the Central Pollution Control Board (CPCB), India generated about 4.1 million tonnes of plastic waste in 2020-21, up from about 3.4 million tonnes in 2018-19. A large share of this is single-use food packaging.
- 2. Policy push:** Since 1 July 2022, India has banned a range of identified single-use plastic items under the Plastic Waste Management (Amendment) Rules, 2021. This has created a strong demand for safe, biodegradable alternatives.
- 3. Household food waste:** The UNEP Food Waste Index Report 2024 estimates that Indian households waste about 55 kg of food per person every year, amounting to roughly 78 million tonnes annually. Smart labels can help families decide more accurately whether food is still safe to eat.
- 4. Ready raw material:** India's large agricultural, dairy and seafood-processing sectors produce abundant residues such as rice bran and husk, fruit peels, whey and crab and shrimp shells. These can serve as low-cost raw materials for bio-films, creating extra income for farmers and food processors.

Commercial Challenges and Future Directions

Although this technology is highly effective, a few challenges remain before it can be adopted widely:

- 1. Production cost:** At present, the production cost of bio-polymers is 30 to 40 percent higher than that of conventional plastics.
- 2. Mechanical strength:** The ability of bio-films to block water and air is slightly lower than that of plastic; the use of nano-particles is being explored to improve this.
- 3. Government policies and approvals:** These new bio-materials that come into contact with food need faster approval from food safety authorities (FSSAI / FDA).

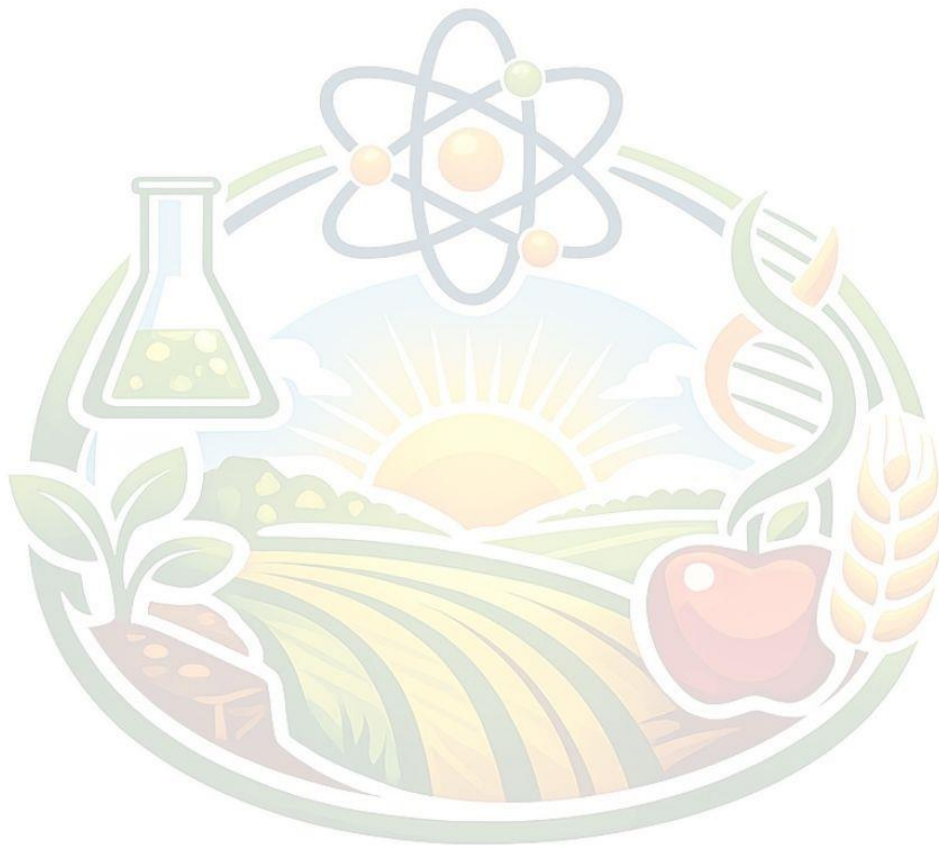
Key Takeaways

1. Bio-films made from starch, chitosan, whey and other natural materials can replace plastic cling films and break down in soil within 30 to 90 days.
2. Natural extracts such as clove, cinnamon and tulsi turn the wrapper into an 'active' package that slows spoilage.
3. Colour-changing smart labels show the real condition of food, instead of relying only on a printed date.

4. Lower costs, better barrier properties and faster regulatory approvals are the keys to large-scale adoption.

Conclusion

The integration of bio-films and smart indicator labels is an important milestone for the food processing and packaging industry. Along with bringing pollution from 'single-use' plastics down to zero, this technology also strengthens consumers' confidence in food safety. In the coming years, nanotechnology and large-scale production will bring its cost down. This green revolution will prove decisive in delivering safe, fresh and plastic-free food from farm to plate.

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Ultra-Processed foods, Gut Microbiota and Metabolic Health

Article ID: 74545

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Introduction

Nutrition is no longer viewed simply as the supply of calories, proteins, vitamins and minerals. Modern nutritional biochemistry increasingly focuses on how dietary components interact with metabolic pathways, hormones, cellular signalling and the trillions of microorganisms inhabiting the human gastrointestinal tract. One of the most important dietary changes of the current era is the rapid increase in the consumption of **ultra-processed foods (UPFs)**. These include many packaged snacks, sugar-sweetened beverages, processed meat products, instant foods, confectionery items and ready-to-eat meals.

UPFs are generally formulated using multiple ingredients and industrial processes designed to improve taste, convenience, texture, shelf life and affordability. Their increasing presence in modern diets has raised concerns about obesity, insulin resistance, cardiovascular disease and other metabolic disorders. From a nutritional biochemistry perspective, an important question is not only *what nutrients are present in these foods*, but also *how processing, food structure and additives influence metabolic responses and the gut microbiome*.

Nutritional Biochemistry of Ultra-processed Foods

The metabolic effects of a food depend on its macronutrient composition as well as its physical structure. Two foods containing similar amounts of carbohydrate, for example, may produce different post-meal glucose responses depending on processing, particle size, fibre content and the rate of digestion. Many UPFs contain relatively high amounts of refined carbohydrates, added sugars, sodium and fats while providing comparatively less dietary fibre and micronutrient density. Rapidly digestible carbohydrates can result in a rapid increase in blood glucose, followed by increased insulin secretion. Repeated exposure to high postprandial glucose and insulin concentrations may contribute to metabolic disturbances in susceptible individuals.

Dietary fibre provides a contrasting biochemical effect. Unlike many digestible carbohydrates, certain fibres escape digestion in the small intestine and reach the colon, where they are metabolized by intestinal microorganisms. The resulting fermentation products include **short-chain fatty acids (SCFAs)** such as acetate, propionate and butyrate. These metabolites participate in energy metabolism, intestinal barrier function and immune regulation. Thus, the nutritional quality of a diet cannot be determined solely by measuring calories. The biochemical consequences of food depend on the interaction between nutrients, food structure, digestion and microbial metabolism.

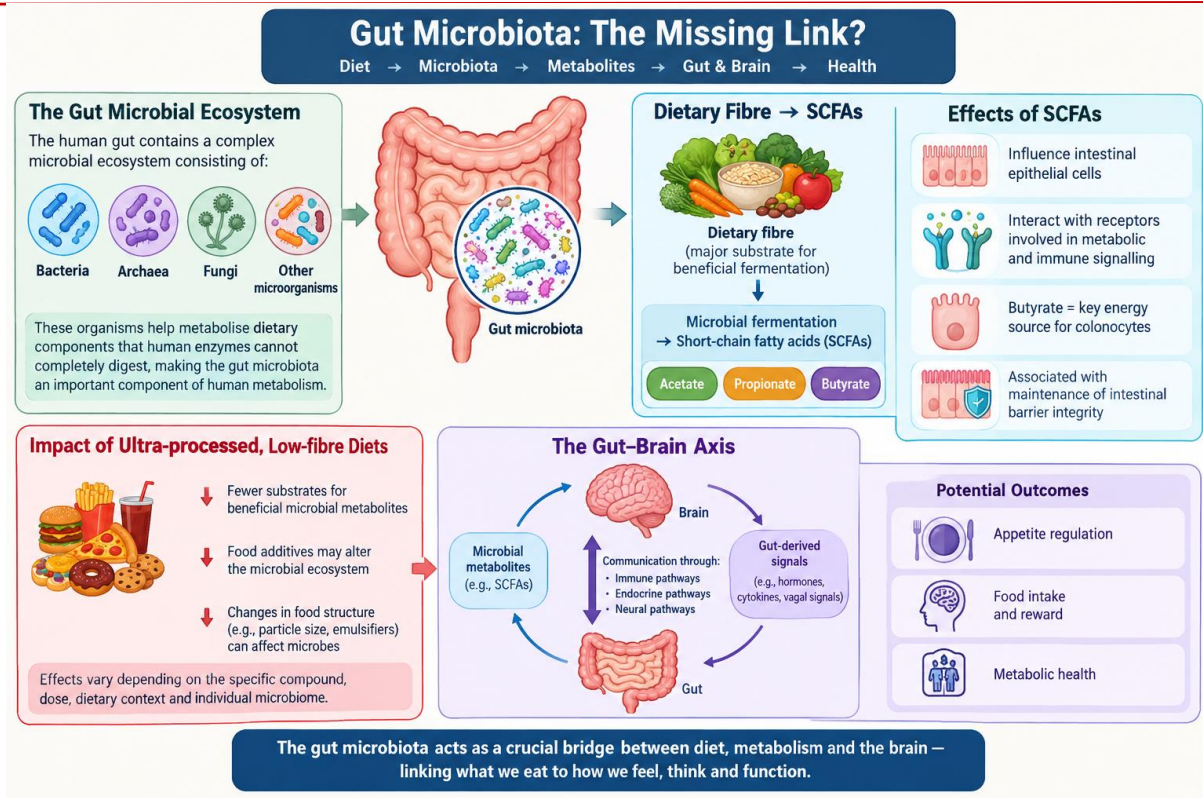
Gut Microbiota: The Missing Link?

The human gut contains a complex microbial ecosystem consisting of bacteria, archaea, fungi and other microorganisms. These organisms contribute to the metabolism of dietary components that human enzymes cannot completely digest. Consequently, the gut microbiota can be considered an important component of human metabolism.

Dietary fibre is one of the major substrates supporting beneficial microbial fermentation. SCFAs generated during fermentation can influence intestinal epithelial cells and interact with receptors involved in metabolic and immune signalling. Butyrate, for example, is an important energy source for colonocytes and is associated with maintenance of intestinal barrier integrity.

In contrast, diets dominated by highly processed, low-fibre foods may provide fewer substrates for the production of beneficial microbial metabolites. Food additives and changes in food structure may also influence the microbial ecosystem, although the effects can vary considerably depending on the specific compound, dose, dietary context and individual microbiome.

The concept of the **gut-brain axis** further expands this discussion. Microbial metabolites and gut-derived signals can communicate with the nervous system through immune, endocrine and neural pathways. This has generated considerable research interest in the relationship between diet, microbiota and appetite regulation.



Effects on Metabolic Health

One of the major concerns associated with high consumption of UPFs is its relationship with excess energy intake and weight gain. Foods that are highly palatable, energy dense and convenient may encourage rapid consumption and increased total energy intake. In addition, liquid calories from sugar-sweetened beverages may produce weaker satiety responses than solid foods. Excessive energy intake can promote expansion of adipose tissue and alterations in lipid metabolism. Persistent energy surplus may contribute to increased circulating triglycerides, ectopic lipid accumulation and impaired insulin signalling.

Insulin resistance is a central feature of metabolic syndrome and type 2 diabetes. Normally, insulin promotes glucose uptake and storage while suppressing excessive hepatic glucose production. In insulin-resistant states, these actions become impaired. Factors such as excess adiposity, chronic inflammation, oxidative stress and altered lipid metabolism can interfere with insulin signalling pathways.

It is important, however, to recognize that UPFs are a heterogeneous category. Not every processed food has the same nutritional or metabolic effects. Processing can also improve food safety, preservation and accessibility, and some processed foods can be important sources of essential nutrients. Therefore, the health impact depends on the overall dietary pattern, food composition and individual circumstances.

Personalised Nutrition and the Future

A particularly exciting development in nutritional biochemistry is the movement toward personalised nutrition. Individuals can show different glucose and metabolic responses to the same food. Differences in genetics, age, physical activity, sleep, gut microbiota and habitual diet may contribute to this variation.

Future nutritional interventions may therefore combine dietary assessment with information about an individual's metabolic profile and gut microbiome. Advances in metabolomics, microbiome sequencing and artificial intelligence could help researchers identify nutritional patterns associated with improved metabolic health.

However, personalised nutrition should complement rather than replace basic dietary principles. Increasing consumption of vegetables, fruits, legumes, whole grains, nuts and other minimally processed foods, while limiting excessive intake of highly processed foods rich in added sugars, sodium and unhealthy fats, remains a practical approach for improving overall diet quality.

Conclusion

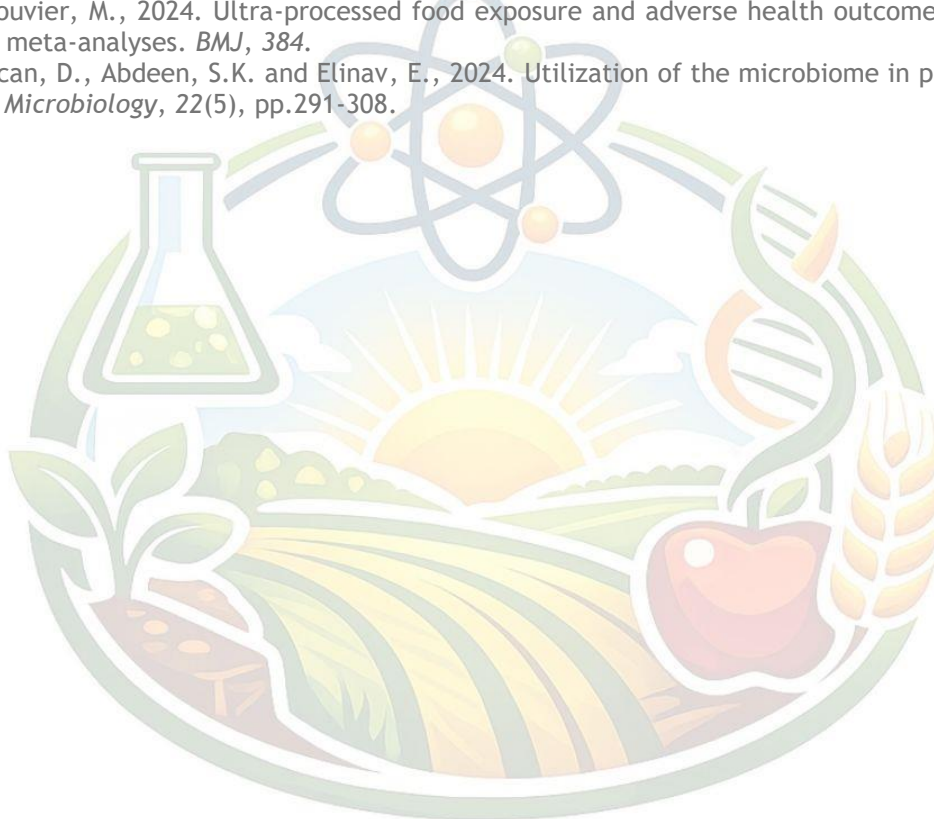
The growing consumption of ultra-processed foods represents an important nutritional challenge of the modern era. Nutritional biochemistry provides a framework for understanding how dietary patterns influence glucose metabolism, lipid metabolism, insulin signalling, inflammation and the gut microbiome. The emerging evidence suggests that food

should be considered as more than a collection of isolated nutrients. **Food structure, processing, fibre content, microbial fermentation and metabolic signalling interact to determine the physiological response to a meal.** Understanding these interactions may help develop more effective strategies for preventing metabolic diseases.

The future of nutritional science is therefore likely to move beyond the traditional question of “*How many calories or nutrients does this food contain?*” but, towards a broader question: “*How does this food interact with our metabolism and our microbial ecosystem?*” This systems-level approach could play an important role in addressing the nutritional and metabolic challenges of the current century.

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Seeds, Not Seedlings: The Rise of Direct-Seeded Rice

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Summary of Article

Direct-seeded rice (DSR) is emerging as an important alternative to conventional puddled transplanted rice under conditions of increasing labour scarcity, water constraints and the need for more resource-efficient crop production. In DSR, rice is established directly from seed in the main field, eliminating nursery raising and transplanting. The approach can reduce labour and water requirements and offers greater scope for mechanization. However, DSR also creates important challenges, particularly weed competition, uneven crop establishment and the need for varieties adapted to direct seeded environments. Recent breeding efforts are therefore focusing on early seedling vigour, rapid and uniform emergence, anaerobic germination tolerance, good root architecture, weed competitiveness and stable yield. The future of DSR lies in integrating improved genetics with precision sowing, efficient water and nutrient management, integrated weed control and digital agriculture. The transition from seedlings to seeds is therefore not merely a change in crop establishment, but a step towards reforming the rice production system for greater resource efficiency and climate resilience.

Introduction

Rice is traditionally grown through puddled transplanting. In this system, seed is first raised in a nursery, seedlings are uprooted and the main field is puddled before transplanting. Although this method has supported rice production for decades, it is labour-intensive and requires considerable water. Rising labour costs, shortages of farm workers, water scarcity and increasingly variable weather are encouraging farmers and researchers to reconsider conventional rice establishment. Direct-seeded rice refers to the establishment of rice directly from seed in the main field rather than from transplanted seedlings. Direct seeding has received increasing attention because it can reduce the labour associated with nursery raising and transplanting, improve opportunities for mechanization and potentially improve water productivity. However, these advantages are accompanied by greater weed competition and a stronger dependence on timely crop establishment and precise management.

From Nursery to Direct Sowing

The conventional rice production pathway contains several labour-demanding operations: nursery preparation, seedling raising, uprooting, puddling and transplanting. DSR removes the nursery and transplanting stages and places the seed directly in the field. This can shorten the establishment process and make large-scale mechanized sowing more practical. Dry DSR is generally suited to prepared, non-puddled seedbeds, while wet DSR uses pre-germinated seed in wet conditions. Water-seeded systems use pre-germinated seed under standing water. The appropriate method depends on soil type, rainfall, irrigation availability, machinery, sowing window and farmer management capacity. In transplanted rice, relatively large seedlings enter the field with an initial competitive advantage. In DSR, rice and weeds emerge together, making early crop vigour and weed management especially important.

Why is DSR Gaining Attention?

The major drivers of DSR are resource constraints. Eliminating nursery raising and transplanting can reduce labour requirements at a critical period of the rice-growing season. Direct sowing can also avoid or reduce water-intensive puddling and allows greater use of seed drills and other mechanized equipment. Earlier crop establishment may provide opportunities for timely harvest and establishment of subsequent crops in intensive cropping systems. However, water savings are influenced by soil, rainfall, irrigation practice, land levelling and crop management. Likewise, lower labour requirements do not mean that DSR is a low-management system. Instead, labour is partly replaced by greater requirements for timely sowing, field levelling, weed control and precision management.

The Weed Challenge: The Biggest Hurdle

Weed competition is one of the most important constraints to successful DSR. Because rice and weeds generally emerge at the same time, the crop has less initial size advantage than transplanted rice. The absence of prolonged standing water during early establishment in some DSR systems can also allow a wider range of weeds to emerge. Consequently, ineffective weed management can cause substantial yield loss. Integrated weed management is therefore central to DSR. Preventive measures, stale seedbed preparation, suitable crop establishment, competitive varieties, mechanical

weeding, water management and appropriately timed herbicide applications can be combined according to local conditions. Relying on a single herbicide is undesirable because repeated use of the same mode of action can select resistant weed populations. Sustainable DSR therefore requires a combination of preventive and curative tactics rather than a single intervention.

Breeding the Rice Plant for DSR

One of the most important long-term opportunities lies in plant breeding. Many rice varieties currently cultivated under DSR were originally developed for transplanted systems. Direct seeding creates a different selection environment in which rapid germination, strong early growth and competitive ability can influence final crop performance. Important breeding targets include rapid and uniform germination, early seedling vigor, rapid emergence, anaerobic germination tolerance, suitable root system architecture, drought tolerance, nutrient-use efficiency, weed competitiveness, lodging resistance and stable grain yield. Recently, researchers have identified traits such as mesocotyl elongation, early vigour, root architecture and weed competitiveness as important targets for improving DSR adaptation. Anaerobic germination is particularly relevant to wet DSR. When heavy rainfall or excess irrigation temporarily submerges freshly sown seed, oxygen availability around the seed becomes limited. Genotypes able to germinate and establish under low-oxygen conditions can maintain a more uniform stand and may also gain a competitive advantage over weeds. Breeding for these traits can therefore improve the reliability of direct crop establishment. The ideal DSR variety should establish rapidly, compete effectively with weeds, maintain suitable root and shoot growth under variable soil moisture, resist lodging and deliver stable grain yield under direct-seeded conditions.

DSR and Climate-Resilient Rice Production

The relevance of DSR extends beyond labour and water savings. Rice production is increasingly exposed to irregular rainfall, high temperatures and water scarcity. A production system that reduces dependence on labour-intensive establishment and allows more flexible water management can contribute to climate-resilient agriculture. DSR performance depends on appropriate sowing time, field preparation, water control, weed management, nutrient supply and variety choice. Poor crop establishment or severe weed infestation can offset the expected resource-saving advantages.

Why has DSR Not Completely Replaced Transplanting?

Despite its potential, DSR is not a universal replacement for transplanted rice. Successful direct seeding requires good land preparation and levelling, timely sowing, reliable crop establishment and effective weed control. Heavy rainfall immediately after sowing may cause establishment problems, while inadequate soil moisture can also reduce emergence. Farmers may additionally face constraints related to machinery availability, seed quality, herbicide access and technical knowledge. These factors explain why DSR adoption varies among regions. The most suitable establishment system should be selected according to soil, rainfall pattern, irrigation access, labour availability, machinery, variety and management capacity. A locally adapted DSR package is more important than simply replacing transplanting with direct sowing.

The Role of Integrated Research and Future Scope

The successful expansion of DSR requires multidisciplinary research. Plant breeders need to develop varieties with rapid establishment, early vigour, suitable root traits, stress tolerance and yield stability. Agronomists need to refine sowing dates, seed rates, nutrient management, irrigation schedules and weed-management strategies. Agricultural engineers need to improve seeders and other equipment for different field conditions, while plant protection scientists need to strengthen sustainable weed-management strategies.

Digital agriculture can add another layer by providing timely information on crop establishment, soil moisture and weed or stress hotspots. Farmers must remain central to this process because technologies developed under research conditions ultimately need to be practical, affordable and reliable at field scale.

The future of DSR will increasingly connect plant genetics with mechanization and digital agriculture. Precision seeders can improve seed placement, spacing and depth, while laser land levelling can help create a more uniform field. Sensors, drones and remote sensing can assist in identifying poor establishment, crop stress and weed hotspots. Decision-support tools can then help farmers respond to crop requirements in a timely manner.

This convergence of breeding, agronomy, engineering and digital technologies could transform DSR from a simple direct-sowing method into a precision rice production system. The most useful technologies will be those that are affordable, easy to operate and adapted to local farming conditions.



Figure 1: Comparison of transplanted rice and direct-seeded rice establishment methods

Conclusion

Direct-seeded rice represents an important opportunity to rethink how rice is established and managed. By eliminating nursery raising and transplanting, DSR can reduce labour requirements, improve the scope for mechanization and potentially reduce water use associated with crop establishment. However, the system also creates major challenges, particularly weed competition, uneven emergence and the need for varieties adapted to direct-seeded conditions. The future of DSR therefore lies not in a single technology, but in the integration of improved genetics, precision agronomy, mechanization and digital tools. Developing rice varieties specifically suited to direct-seeded environments will be particularly important for making the system more reliable. From nursery to seed and from transplanting to precision sowing, DSR represents a shift towards a more resource-efficient and climate-resilient approach to rice production.

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Bamboo as a Resource for Rural Livelihoods in Northeast India

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Introduction

The Northeast Eastern region constitutes of eight states is endowed with rich forest resources, biodiversity and cultural diversity. The states are inhabited by diverse tribal communities such as Apatani, Adi, Khasi, Garo, Bodo, Dimasa, Mizo Angami and Ao etc., whose livelihoods and traditional practices are through close interaction with the forests. Also, this region is one of the mega biodiversity hotspots of the world with rare and endemic flora and fauna. Among the different forest resources, bamboo occupies a significant place in the social, cultural and economic life of tribal communities in Northeast. Therefore, this region is also considered as ‘bamboo paradise of India’ (Basumatary et al., 2015).

Bamboo is a fast-growing, versatile and valuable resource that has been used for generations for household goods, agricultural implements, handicrafts, fuelwood, food and various cultural activities (Miao et al., 2020; Abebe et al., 2021). Its diverse uses make bamboo an important resource for the livelihoods and cultural identity of many tribal communities. A notable example is the Apatani tribe of Arunachal Pradesh, which has traditionally managed bamboo-cum-pine agroforestry systems. These systems provide essential materials for day-to-day needs and reflect the community’s indigenous knowledge and sustainable approach to natural resource management (Taka and Tangjang, 2015). This article highlights the diverse traditional uses of bamboo and its significant role in sustaining the rural livelihoods in Northeast India.

Bamboo Diversity in Northeast

The favourable climatic conditions, high rainfall, varied topography and extensive forest cover in northeast provide ideal conditions for the growth of bamboo. The distribution of bamboo is in natural forests, cultivated, agricultural fields and other disturbed areas. About 25% of the world’s bamboo species are reported to occur in India. The north eastern states are particularly rich in bamboo diversity, harbouring nearly 90 species, of which 41 are endemic to the region as well as rich in bamboo stock (Bisht et al., 2011; Sharma and Nirmala, 2015). The availability of bamboo close to settlements has historically made it an easily accessible and relatively inexpensive resource for rural households. Some of the common species reported from the region are *Melocanna baccifera*, *Dendrocalamus hamiltonii*, *Dendrocalamus giganteus*, *Bambusa tulda*, *Bambusa balcooa* and *Bambusa pallida*.

Uses of Bamboo

Bamboo is an integral part of the daily lives of tribal communities and has diverse applications that contribute significantly to their livelihoods. Young bamboo shoot are consumed fresh and are also preserved in the form of fermented, dried and pickled. In addition to their nutritional value, bamboo shoots provide an important source of income for rural communities. Fresh, dried, fermented and pickled bamboo shoots are sold in local markets, creating livelihood opportunities and supporting household income. Furthermore, bamboo has traditionally been an important construction material for tribal communities. It is used for walls, floors, ceilings, fencing, partitions and animal shelters.

For household and agricultural uses, bamboo is extensively used for making baskets, mats, storage containers, fishing equipment and other household articles. Farmers also use bamboo in fencing, supporting crops and constructing structures. Traditionally designed bamboo baskets are used for carrying agricultural produce, firewood and forest products.

Bamboo as a Source of Livelihood and Income

Bamboo contributes to the livelihoods of tribal live in rural area in several ways. Households can obtain bamboo directly from nearby resources for their own requirements, reducing expenditure on construction and household materials. Handicrafts provide opportunities for artisans and small-scale entrepreneurs, while bamboo shoot collection and processing provide seasonal income. The growing interest in sustainable and environmentally friendly products also provides opportunities for expanding bamboo-based enterprises. Furniture, decorative products, packaging materials, flooring and other value-added products can provide additional livelihood opportunities when supported by appropriate skills and market access.

Conclusion

Bamboo has played an important role in the livelihood, culture and everyday life of tribal communities in northeast for generations. It has provided material for houses, household articles, agricultural tools, handicrafts and food while also supporting traditional skills and local income generation.

Changing lifestyle is gradually changing this traditional knowledge of bamboo use with modern products. This transition presents a challenge for the preservation of traditional knowledge and bamboo-based livelihoods.

At the same time, bamboo offers significant opportunities for sustainable rural development. By combining traditional knowledge with modern technology, product design, value addition and improved market access, bamboo can continue to contribute to tribal livelihoods while adapting to changing lifestyles. Strengthening this connection between tradition, innovation and sustainability can help ensure that bamboo remains an important resource for the communities of northeast in the future.

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Kitchen Composting for Terrace Garden

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Introduction

Modern households generate substantial quantities of biodegradable waste, including vegetable peels, fruit residues, tea leaves, coffee grounds, spoiled vegetables and plant-based food scraps. Rather than treating these materials as waste, they can be viewed as a source of organic carbon, nitrogen and minerals that can be returned to the biological cycle through decomposition. Kitchen composting converts these residues into a stable organic amendment that can support plant growth and improve soil or growing media. It is particularly relevant to terrace gardens, where plants are often grown in containers with restricted soil volumes. In such systems, moisture, aeration, nutrient availability and organic matter (OM) can change rapidly. Composting is a controlled aerobic biological process in which diverse communities of microorganisms, including bacteria, fungi and other decomposers, decompose OM. During decomposition, microorganisms release heat, CO₂, water and mineral nutrients, transforming fresh residues into a more stable, biologically active material. The resulting compost is not merely decomposed kitchen waste, rather it is a biologically transformed material capable of contributing to soil fertility and improving the physical environment surrounding plant roots. Thus, kitchen composting represents a practical example of circular agriculture, in which nutrients removed from the food system are recovered and returned to production.

Kitchen Waste: A Hidden Resource

The suitability of kitchen waste for composting depends largely on its chemical composition and biodegradability. Fresh vegetable residues, fruit peels, leafy materials, tea leaves and coffee grounds are generally rich in readily decomposable organic compounds and contain appreciable amounts of nitrogen. In composting terminology, these materials are commonly described as “green” materials. They provide moisture and nitrogen (N) required for microbial growth and usually decompose relatively rapidly. However, a composting system cannot function efficiently on fresh kitchen waste alone. Excessive quantities of wet, N-rich material tend to compact easily, restrict air movement and create anaerobic microenvironments. This is why kitchen residues should be balanced with relatively dry, carbon (C)-rich materials. Dry leaves, shredded untreated cardboard, uncoated paper, dry grass and other plant residues serve as “brown” materials. They contribute C and, importantly, provide physical structure that allows oxygen to circulate through the composting mass.

A favourable starting carbon-to-nitrogen (C:N) ratio is approximately 25-30:1, although household gardeners generally do not need to measure it directly. Instead, the mixture can be adjusted by observing its moisture, structure and decomposition. The compost bin should not be treated as a general waste container. Plastics, glass, metals, synthetic fabrics and chemically treated materials should be excluded. A practical composting system should generally avoid meat, fish, bones, dairy products and large quantities of oily or heavily salted food. They can create problems in simple household composters because they may decompose slowly, generate unpleasant odours or attract rodents and other pests. For simple terrace composters, predominantly plant-based kitchen waste is easier to manage.

From Kitchen Waste to Compost

Efficient composting requires adequate aeration, moisture, drainage and structure. A simple ventilated container can be sufficient when the contents are properly managed. A practical approach (Fig. 1) is to:

1. Place a layer of dry, porous material such as leaves or shredded cardboard at the bottom.
2. Add moderate quantities of fresh kitchen residues.
3. Cover them with another layer of dry material.
4. Continue alternating wet and dry materials.
5. Chop larger residues into smaller pieces to increase their surface area and accelerate decomposition.

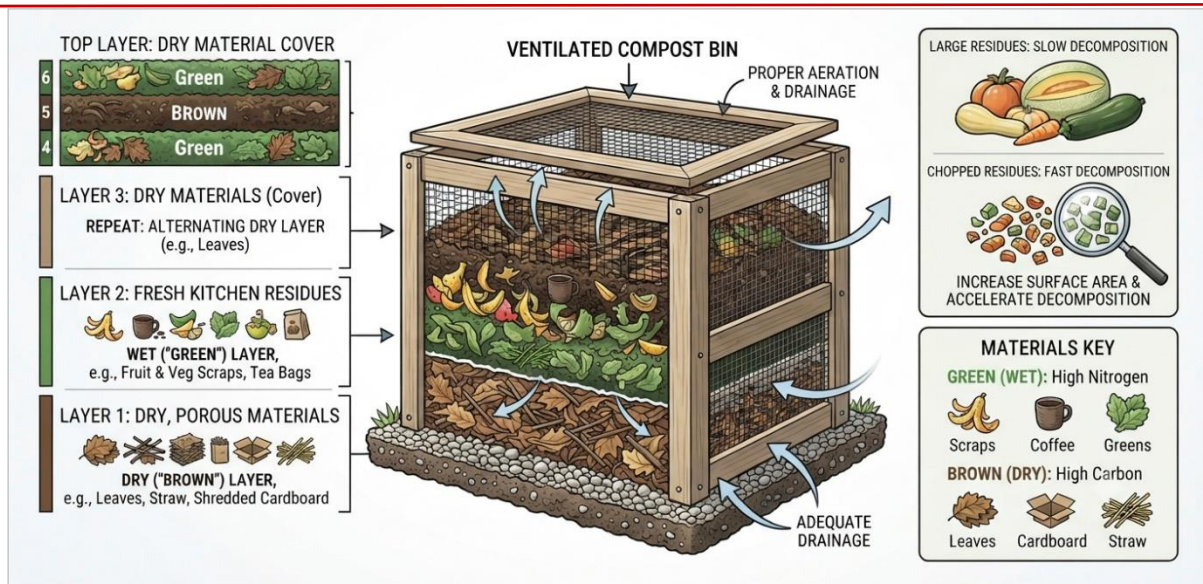


Fig. 1: A scientific illustration of kitchen composting

Microbial activity produces heat as microorganisms metabolise easily decomposable compounds. Large, well-managed compost piles may reach substantial temperatures, but small household composters may not consistently achieve such conditions. Therefore, appropriate feedstock selection and maturation are particularly important in terrace systems.

Moisture Management

Compost should remain approximately as moist as a wrung-out sponge. If the compost is excessively wet (characterised by a strong rotten smell), dry leaves, shredded cardboard or other C-rich materials should be added, whereas if it is too dry, a small quantity of water or N-rich materials should be added. Nevertheless, excess moisture should be avoided because it fills air spaces and can promote anaerobic conditions.

Aeration and Maturation

Periodic turning or mixing introduces oxygen, redistributes moisture and reduces compaction. As decomposition progresses, the material becomes darker and more homogeneous, crumbly in texture, less recognisable as the original kitchen residues, and it is characterised by a mild, earthy smell rather than a strong waste odour. Compost should be allowed to mature before extensive use around plants. Mature compost is more stable and less likely to cause temporary nutrient immobilisation or problems around plant roots. Mature compost is dark, crumbly and earthy-smelling, with little resemblance to the original waste.

Under well-managed conditions, household kitchen/organic waste generally takes about 6-12 weeks to transform into mature compost, although the duration may extend to 3-4 months depending on the type of waste, moisture, aeration, temperature and frequency of turning, so a fixed number of days should not be treated as universal.

Compost in the Terrace Garden

The principal value of mature kitchen compost is its contribution of OM and its effects on the growing environment. When incorporated into soil or growing media, compost can improve soil aggregation, porosity and aeration, moisture-holding properties, OM content and biological activity. These benefits are particularly relevant in containers exposed to repeated irrigation and drying cycles. Kitchen compost also contributes to nutrient cycling. Depending on its feedstock and production conditions, it may contain nitrogen, phosphorus, potassium, calcium, magnesium and micronutrients. However, compost is not a standardised fertiliser, so its nutrient content varies with feedstock, decomposition conditions, maturity and storage. Therefore, compost is often best viewed primarily as an organic amendment that improves the growing environment, rather than as a precise replacement for mineral fertilisers. The biological aspect is also important. Mature kitchen compost provides organic substrates and can support microbial activity, contributing to nutrient transformation and overall soil ecosystem functioning.

Limitations and Practical Constraints

Kitchen composting also presents several challenges (Fig. 2). Household organic waste varies considerably from day to day in terms of the proportion of kitchen scraps, dry leaves and other biodegradable materials, making it necessary to maintain an appropriate balance of carbon-rich and nitrogen-rich inputs during composting. Urban households may also face difficulties due to limited space for installing compost bins or pits, particularly where adequate ventilation, drainage and accessibility are required. Improper management, excessive moisture or inadequate aeration can encourage flies,

rodents and other pests while generating unpleasant odours and liquid seepage. The quality of the resulting compost may also vary in terms of nutrient concentration, pH, salt content and degree of decomposition, depending on the materials used and the efficiency of the composting process. Quality assessment becomes particularly important when compost is applied in large quantities or used as a major nutrient source, as laboratory analysis can help determine its nutrient content and agricultural suitability. Moreover, compost generally releases nutrients slowly and may not provide all essential nutrients in sufficient quantities to meet the high demand of intensively cultivated vegetable crops, making supplementary nutrient sources necessary in some situations.

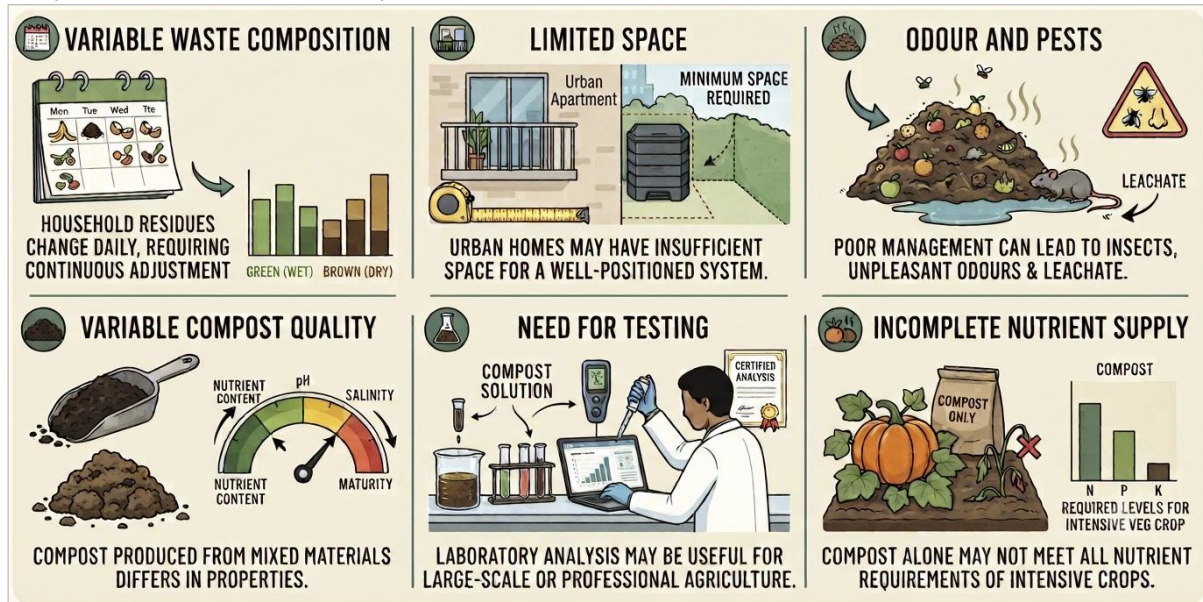


Fig. 2: Key challenges in producing quality kitchen compost

Conclusion

Kitchen composting is a simple application of ecological principles to everyday life. Vegetable residues and other biodegradable materials contain organic carbon and plant nutrients that can be returned to production through controlled biological decomposition. For terrace gardeners, composting provides a practical opportunity to reduce organic waste while producing a useful amendment for plant cultivation. Its success depends more on sound biological management than on sophisticated equipment. Kitchen compost demonstrates the importance of OM and nutrient recycling, microbial ecology, carbon transformation and circular resource management, and provides a direct connection between consumption and cultivation. A terrace composting system cannot solve every waste-management or soil-fertility problem. Its significance lies in closing a small but meaningful nutrient loop, i.e., food residues generated in the kitchen can return to the soil, support microbial life and contribute to the production of new plants. In an increasingly urbanised world, such decentralised cycles can contribute to sustainable agriculture, responsible waste management and resilient food systems.

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Floating Vegetable Cultivation: A New Hope for Farmers in Waterlogged and Flood-Prone Regions

Article ID: 74549

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Abstract

Floating vegetable cultivation is a traditional, climate-resilient production system for waterlogged and flood-prone regions. It involves growing vegetables on buoyant beds made from aquatic biomass such as water hyacinth, along with straw and other biodegradable materials. The system enables vegetable production during periods when conventional fields remain submerged while promoting food security, supplementary income and biomass recycling. Vegetables such as leafy greens, tomato, chilli, okra and cucumber can be cultivated depending on local conditions. With improved bed design, nutrient management and crop selection, floating cultivation offers a promising nature-based approach for sustainable horticulture and livelihood resilience under increasing flood and climate risks.

Introduction

Flooding and prolonged waterlogging are among the major constraints affecting agricultural productivity in several parts of India and South Asia. During the monsoon season, large areas of low-lying agricultural land may remain submerged for weeks or even months, making conventional crop production difficult. Prolonged inundation reduces soil aeration, damages roots, disrupts nutrient availability and frequently results in complete crop failure. For small and marginal farmers who depend heavily on seasonal agriculture, such losses can severely affect household income and food security. The situation is becoming more important in the context of climate variability and changing rainfall patterns. Conventional agricultural systems are generally designed around relatively stable land and water conditions, whereas flood-prone farmers need production systems capable of adapting to temporary changes in water levels. Floating vegetable cultivation provides an innovative solution by moving the growing medium above the water surface rather than attempting to cultivate directly in flooded soil. This approach converts waterlogged areas into productive spaces for vegetable cultivation and provides an opportunity to combine traditional ecological knowledge with modern climate-smart horticultural practices.

A Traditional Practice with Modern Relevance

Floating cultivation is an indigenous agricultural practice that has been used for generations in flood-prone areas, particularly in Bangladesh. The practice is locally associated with terms such as *baira*, *dhap* and floating gardening. Farmers traditionally construct floating beds using locally available aquatic plants, especially water hyacinth, along with grasses, straw and other biodegradable materials. The practice represents an important example of how farming communities have adapted agriculture to their surrounding environment. Instead of treating floodwater only as a constraint, farmers utilize the floating characteristics of organic biomass to create temporary growing platforms. The traditional knowledge behind floating agriculture has attracted increasing scientific interest because of its relevance to climate adaptation, food security and sustainable livelihoods. Studies have reported that floating gardens can provide vegetables and supplementary income during periods when conventional agricultural land remains submerged (Irfanullah et al., 2008; Chowdhury and Moore, 2017). The approach is particularly valuable because it does not necessarily require expensive infrastructure. Locally available biomass and simple construction techniques can form the foundation of the production system.



Fig: Construction of floating bed



Fig: Balls prepared for seedling raising

How it Works

Floating vegetable cultivation begins with the preparation of a buoyant organic growing bed that remains above the water surface even as water levels fluctuate. Aquatic vegetation, particularly water hyacinth, is collected and layered with straw, grasses and other biodegradable plant residues to form a compact, stable platform. Traditionally, beds may be prepared approximately 0.5-1.0 m thick and 1-2 m wide, depending on local water conditions and the intended crop. The biomass is compressed and allowed to undergo partial decomposition, producing a soft, organic growing medium. A thin layer of decomposed biomass, compost or suitable growing substrate can then be added to the upper surface to support seed germination and seedling establishment. Bamboo poles or locally available supports may be used to anchor the beds and prevent excessive movement due to wind and water currents. Vegetable seedlings can either be raised separately and transplanted onto the beds or established directly on them. Crops such as spinach, amaranthus, okra, chilli, tomato, cucumber, bottle gourd and other leafy vegetables can be cultivated depending on bed stability and local conditions. During crop growth, supplementary organic matter or nutrients may be applied according to crop requirements. The thickness, composition, buoyancy and stability of the floating bed are critical for successful production. As the organic materials gradually decompose, the bed becomes a nutrient-containing growing medium but may also lose thickness over time. Therefore, appropriate biomass selection and periodic maintenance are important. The beds can generally be used for several months and may be reconstructed or repositioned using locally available materials. Research has also shown that the type of aquatic vegetation used in bed preparation can influence bed stability and crop performance, highlighting the importance of scientifically evaluating locally available biomass before large-scale adoption.



Fig: Transplanting of seedlings



Fig: Harvest of crops on floating bed

Benefits and Sustainability

- 1. Productive use of waterlogged areas:** The most important advantage of floating cultivation is its ability to utilize land and water bodies that cannot support conventional agriculture during periods of flooding. Instead of abandoning production during the rainy season, farmers can use floating platforms to produce vegetables.
- 2. Climate-resilient vegetable production:** Floating beds rise and fall with changing water levels, allowing crops to remain above the surrounding floodwater. This makes the technology particularly relevant in regions experiencing recurrent seasonal flooding. Floating cultivation therefore represents an adaptation strategy rather than a flood-control strategy. It does not prevent floods, but it enables farmers to continue agricultural production under conditions in which conventional cultivation may fail.

3. Improved food and nutritional security: Vegetables are important sources of vitamins, minerals, dietary fibre and other essential nutrients. During flood periods, access to fresh vegetables may decline because roads, markets and conventional farms can be affected. Floating vegetable gardens can provide households with fresh produce close to their settlements while also generating surplus vegetables for local markets.

4. Additional income for farmers: Surplus vegetables produced on floating beds can be sold in local markets. For small and marginal farmers, this can provide an additional source of income during periods when conventional agricultural activities are restricted. The economic potential depends on production costs, labour availability, crop choice, market prices and transportation facilities. Therefore, market-oriented crop planning is essential for commercial success.

5. Recycling of aquatic biomass: Floating cultivation provides a productive use for aquatic plant biomass. Materials such as water hyacinth and other aquatic weeds can be incorporated into floating beds rather than being treated solely as waste. As the organic material decomposes, nutrients are gradually released into the growing medium. After the cultivation period, the decomposed biomass can potentially be incorporated into agricultural fields as organic matter.

6. Low-cost and locally adaptable technology: Unlike highly capital-intensive protected cultivation systems, traditional floating gardens can be constructed using locally available materials. This makes them particularly attractive for resource-constrained farming communities. However, low-cost does not mean zero-input. Labour, seed, plant protection, nutrient supplementation and transportation may still represent important costs.

Success Stories and Potential in India

This system has been successfully practiced in Bangladesh's southern deltaic regions for generations and has recently gained attention in India. States such as Assam, Bihar, Odisha, West Bengal, and parts of Uttar Pradesh and Kerala have begun piloting floating vegetable cultivation projects. In Assam's Dhemaji and Majuli districts, for instance, farmers have started producing vegetables during the monsoon months when traditional fields remain inundated. Such initiatives, supported by agricultural universities and NGOs, are showing promising results in enhancing productivity and farmer resilience.

Challenges and Future Prospects

Despite its advantages, floating cultivation faces challenges related to initial training, availability of suitable biomass materials, and pest management in humid conditions. However, with institutional support, capacity building, and the integration of modern agronomic practices, it can be scaled up effectively. Research on optimizing nutrient management, bed composition, and crop diversification will further enhance its sustainability and productivity.

Conclusion

Floating vegetable cultivation represents a simple yet transformative approach to address the challenges of climate-induced flooding and waterlogging. By making unproductive water bodies agriculturally useful, it offers new livelihood opportunities and promotes ecological balance. This innovative practice truly stands as a new hope for farmers in waterlogged and flood-prone regions, ensuring food security and sustainability in the face of changing climate realities.

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Wild Relatives as a Source of Genetic Diversity for Crop Improvement

Article ID: 74550

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Abstract

Crop wild relatives (CWRs) are wild species that are genetically related to cultivated crops and can provide valuable genes for crop improvement. During domestication and subsequent intensive selection, many cultivated crops have undergone a reduction in genetic diversity. In contrast, wild relatives have continued to evolve under natural selection and often possess valuable traits such as resistance to diseases and insects, tolerance to drought, salinity, heat and other environmental stresses, and improved nutritional or quality characteristics. These traits can be transferred into cultivated crops through conventional hybridization, introgression, backcrossing and modern molecular breeding approaches. Examples include the use of wild relatives in wheat, rice, tomato and potato. With climate change and increasing pressure on agricultural resources, CWRs have become increasingly important for developing resilient and productive crop varieties. However, their utilization is often complicated by cross-incompatibility, linkage drag and undesirable traits. Conservation through both in situ and ex situ approaches is therefore essential.

Keywords: Crop wild relatives, genetic diversity, plant breeding, introgression, pre-breeding, genetic resources, stress tolerance, disease resistance.

Introduction

Plant breeding depends fundamentally on genetic variation. Breeders select, recombine and evaluate genetic variation to develop crop varieties with desirable characteristics. However, modern cultivated crops often possess a narrower genetic base than their wild relatives because domestication and intensive selection have favoured a limited number of desirable characteristics.

Crop wild relatives (CWRs) are wild plant species that are genetically related to cultivated crops. They include wild ancestors of crops as well as other closely related species that can potentially be used in breeding programmes. These species constitute an important reservoir of genetic diversity and may contain alleles that are absent or rare in modern cultivars. The Food and Agriculture Organization recognizes crop wild relatives as important sources of novel traits for developing productive, nutritious and resilient crop varieties.

Wild relatives are particularly important because they have evolved under diverse and often harsh environmental conditions. Consequently, they may possess adaptations to drought, heat, salinity, pests, diseases and other stresses. Modern genomics and molecular breeding are making it easier to identify and transfer these useful genetic resources into cultivated crops.

Importance of Genetic Diversity in Crop Improvement

Genetic diversity refers to variation in genetic composition among individuals, populations and species. It provides the raw material required for selection and genetic improvement.

A crop with a broad genetic base has greater potential to respond to changing environmental conditions and emerging pests and diseases. In contrast, a genetically narrow crop population can be more vulnerable when a new disease, insect pest or environmental stress occurs.

Wild relatives can broaden the genetic base of cultivated crops by introducing new alleles and gene combinations. Their contribution is particularly valuable for traits that have become limited in cultivated germplasm.

Important traits obtained from wild relatives include disease resistance, insect and pest resistance, drought tolerance, heat tolerance, salinity tolerance, waterlogging tolerance, cold tolerance, improved nutritional quality, improved grain, fruit or seed quality, adaptation to marginal environments and improved yield stability.

Why Wild Relatives Are Valuable to Plant Breeders

During domestication, humans selected plants with desirable characteristics such as larger seeds, higher yield, uniform maturity, reduced seed shattering and improved quality. Although these changes made crops more suitable for agriculture, they also resulted in the loss or reduction of some naturally occurring genetic variation.

Wild relatives have not undergone the same degree of artificial selection. Therefore, they may retain alleles associated with adaptation to environmental stresses and biological threats. For example, wild relatives of tomato have been investigated as sources of drought and salt tolerance. Species such as *Solanum pennellii*, *S. habrochaites*, *S. pimpinellifolium* and *S. chilense* possess useful stress-tolerance traits.

Wild Relatives as Sources of Resistance to Biotic Stresses

1. Disease Resistance: Disease resistance is one of the most extensively exploited characteristics of wild relatives. Wild relatives of wheat have provided resistance to several diseases. *Oryza nivara* has been used as a source of resistance to grassy stunt virus in rice, while *Solanum demissum* has contributed resistance to important diseases of cultivated potato. Wild relatives have also contributed resistance genes in several other crops.

2. Insect and Pest Resistance: Wild species may possess natural mechanisms that reduce insect damage. These can include physical barriers such as hairs and thick cuticles, production of defensive chemicals, antibiosis, antixenosis and tolerance to insect feeding. Such traits can potentially be incorporated into cultivated varieties through breeding.

Wild Relatives as Sources of Abiotic Stress Tolerance

Abiotic stresses are non-living environmental factors that adversely affect crop growth and productivity. Major abiotic stresses include drought, heat, salinity, cold and waterlogging. Climate variability has increased the importance of breeding crops capable of producing stable yields under stressful conditions.

1. Drought Tolerance: Wild relatives can possess adaptations such as efficient water-use mechanisms, deep or extensive root systems, osmotic adjustment, improved stomatal regulation and maintenance of photosynthesis under water deficit.

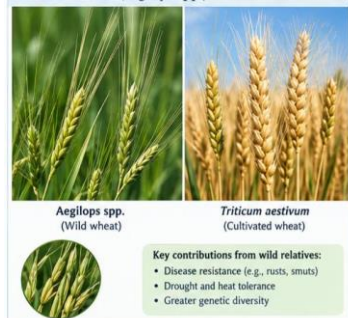
2. Salinity Tolerance: Salinity affects plant growth by causing osmotic stress and ionic imbalance. Wild relatives can possess mechanisms for maintaining growth under saline conditions. Genetic resources from wild relatives have contributed to the development of salt-tolerant breeding materials.

3. Heat Tolerance: Increasing temperatures can affect pollen viability, flowering, seed formation and grain filling. Wild relatives adapted to hot environments may provide useful alleles for improving heat tolerance. This makes CWRs particularly relevant to breeding programmes aimed at developing climate-resilient crops.

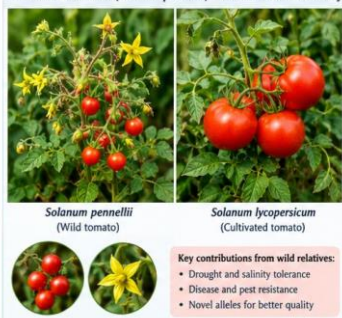
Important Examples of Wild Relatives Used in Crop Improvement

Crop	Wild relative	Important contribution
Wheat	<i>Aegilops</i> spp.	Disease and stress resistance
Rice	<i>Oryza nivara</i>	Resistance to grassy stunt virus
Rice	<i>Oryza officinalis</i>	Brown planthopper resistance
Potato	<i>Solanum demissum</i>	Disease and nematode resistance
Tomato	<i>Solanum pennellii</i>	Drought and salt tolerance
Wheat	<i>Triticum dicoccoides</i>	Stress tolerance and useful agronomic traits
Wheat	<i>Aegilops ventricosa</i>	Eyespot resistance
Barley	Wild <i>Hordeum</i> relatives	Stress-adaptation traits

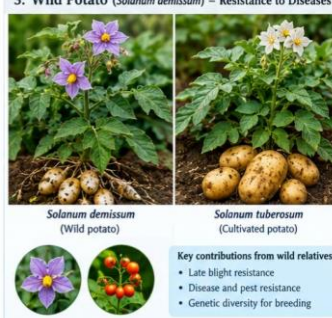
1. Wild Wheat (*Aegilops* spp.) – A Source of Useful Genes



2. Wild Tomato (*Solanum pennellii*) – Tolerance and Diversity



3. Wild Potato (*Solanum demissum*) – Resistance to Diseases



4. Wild Rice (*Oryza nivara*) – Resilience and Diversity



Methods for Utilizing Wild Relatives in Plant Breeding

1. Germplasm Collection and Evaluation: Wild populations are collected from different geographical regions and maintained in germplasm collections. The material is evaluated for useful characteristics such as resistance, stress tolerance and quality.

2. Pre-breeding: Pre-breeding is an important step in utilizing CWRs. The objective is to identify useful genetic variation and transfer it into material that can be more readily used by breeders.

3. Hybridization and Introgression: A wild relative is crossed with a cultivated variety, and the resulting progeny are selected for the desired trait. Repeated backcrossing may then be used to recover most of the desirable characteristics of the cultivated parent while retaining the target allele from the wild parent.

4. Marker-Assisted Selection: Molecular markers can be used to identify plants carrying desirable genes or genomic regions. This can make selection more efficient, particularly for traits that are difficult to evaluate visually.

5. Genomic Selection and Genomics: Genomic information can help breeders evaluate the contribution of wild genetic diversity across the genome. Genome sequencing and high-throughput genotyping have greatly expanded the ability to characterize CWRs and identify potentially useful alleles.

6. Gene Editing: Modern gene-editing technologies may provide another approach for utilizing genetic information discovered in wild relatives. Genomic studies can identify useful genes or alleles, while targeted technologies can help investigate or modify specific genomic regions.

Challenges in Using Wild Relatives

Despite their enormous potential, the use of CWRs is not always straightforward.

1. Cross-incompatibility: Some wild relatives cannot readily cross with cultivated species because of differences in chromosome number, genome constitution or reproductive biology.

2. Linkage drag: A desirable gene may be genetically linked with undesirable genes. When the wild segment is transferred into a cultivated crop, unwanted characteristics may also be introduced.

3. Undesirable agronomic traits: Wild plants may have low yield, small fruits or seeds, poor plant architecture, late maturity, seed shattering or poor quality.

4. Limited characterization: A large amount of wild germplasm remains insufficiently characterized. Identifying useful accessions requires systematic phenotyping and genotyping.

5. Conservation threats: Habitat destruction, urbanization, environmental degradation and climate change threaten many wild plant populations.

Conservation of Crop Wild Relatives

1. In Situ Conservation: In situ conservation means conserving wild relatives in their natural habitats. This allows natural populations to continue evolving under environmental pressures. Protected areas and conservation reserves can play an important role.

2. Ex Situ Conservation: Ex situ conservation involves maintaining genetic material outside its natural habitat, particularly in seed banks, gene banks, field gene banks, botanical gardens and in vitro collections. Ex situ conservation provides breeders with accessible genetic material while acting as a backup for natural populations.

Future Prospects

The importance of crop wild relatives is expected to increase as agriculture faces climate change, emerging diseases, declining natural resources and the need for sustainable production.

Future breeding programmes will increasingly combine wild genetic diversity with conventional breeding, molecular markers, genomics, phenotyping, speed breeding and gene editing. Such integration can make it possible to identify useful alleles more rapidly and incorporate them into elite breeding populations.

The development of climate-resilient crops is an especially important area. CWRs contain valuable genetic variation for drought, heat, pest and other stress responses, while modern genomic approaches are improving their utilization. The conservation of CWRs should therefore be considered an investment in future food and nutritional security rather than merely a biodiversity-conservation activity.

Conclusion

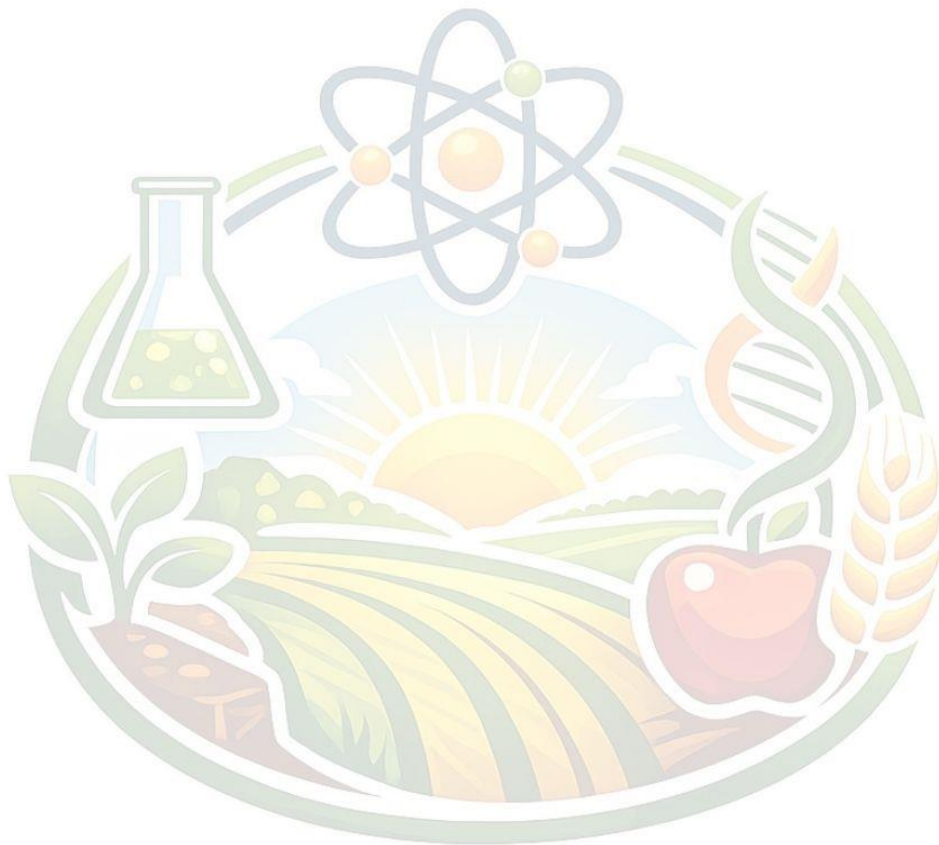
Crop wild relatives represent one of the most valuable reservoirs of genetic diversity available to plant breeders. They contain genetic variation that can contribute to disease resistance, insect resistance, drought tolerance, salinity tolerance, heat tolerance, quality improvement and adaptation to changing environments.

Their utilization requires careful evaluation, pre-breeding, hybridization, introgression and selection. Molecular markers, genomics and modern breeding technologies are increasingly improving the efficiency with which useful genes can be identified and transferred.

At the same time, conservation of these resources is essential. In situ conservation protects the evolutionary diversity of wild populations, while ex situ conservation provides secure and accessible genetic material for research and breeding. Integrating the genetic diversity of wild relatives with modern plant-breeding technologies can play an important role in developing crop varieties capable of meeting future agricultural challenges.

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When Rice Goes Underwater: The Sub1 Story

Article ID: 74551

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Summary of Article

Rice is a water-loving crop, but complete submergence can still destroy a crop within days. An exceptional example is the traditional rice cultivar FR13A, which can withstand prolonged flooding due to presence of the SUB1 locus. SUB1 enables rice to adopt a 'quiescence strategy' by limiting excessive shoot elongation and conserving carbohydrate reserves during flooding and breeders have harnessed this trait through marker-assisted breeding to develop flood-tolerant varieties. The journey from FR13A to SUB1 rice highlights how genetic diversity, plant physiological mechanisms and molecular breeding can work together to improve rice adaptation to flood-prone environments.

Introduction

Rice is commonly grown under waterlogged conditions but complete and prolonged submergence can cause severe plant injury and yield loss. Rice possesses adaptations like aerenchyma that facilitate internal gas movement, enabling it to tolerate waterlogged conditions better than many terrestrial crops. However, when the entire plant is submerged, leaves and growing tissues lose direct contact with the atmosphere, while underwater photosynthesis is often insufficient to meet energy requirements of plants. At the same time, restricted oxygen availability limits aerobic respiration, increasing dependence on stored carbohydrates for survival. The rate at which these reserves are produced and consumed can therefore strongly influence the plant's ability to survive and recover after the flood recedes (Singh *et al.*, 2017). Flooding is not a single environmental condition: a few days of complete submergence during the vegetative stage differs physiologically from prolonged deep-water or partial-submergence environments. These contrasting conditions trigger different plant responses and require distinct adaptive mechanisms. Therefore, an effective breeding strategy should focus not simply on developing rice varieties that tolerate flooding, but on identifying and deploying the appropriate tolerance mechanism for a specific flooding regime (Singh *et al.*, 2017).

FR13A: A Valuable Donor for Submergence Tolerance

The traditional rice cultivar FR13A became a landmark donor in flood-tolerance research because of its ability to survive temporary complete submergence. Earlier flood-adapted landraces often carried useful tolerance but were not ideal directly as modern cultivars because of limitations such as low yield, poor grain quality, lodging and other agronomic characteristics. FR13A provided a particularly valuable source of genetic tolerance that could be transferred into other backgrounds. Gradually, genetic analysis of FR13A-derived material led to the identification and fine mapping of the Submergence 1 (SUB1) quantitative trait locus on chromosome 9. The region contains three ethylene response factor-like genes viz., SUB1A, SUB1B and SUB1C. Among them, SUB1A was identified as a major determinant of the strong tolerance phenotype associated with complete submergence. (Panda and Barik, 2021).

SUB1A and the Quiescence Response

The presence of SUB1A induces an energy management response in plants. Submergence induces changes in hormone signalling, particularly pathways involving ethylene and gibberellin responsiveness. In SUB1 containing plants, these responses help suppress excessive shoot elongation. Reduced elongation limits the amount of carbohydrate required for new growth and allows more of the stored reserve to remain available for maintenance and subsequent recovery. Restrained elongation, slower carbohydrate consumption and better preservation of chlorophyll and photosynthetic capacity are SUB1 response. The overall outcome is a plant that enters a low-growth state during the period of complete submergence and resumes growth after the flood recedes. This is the basis of the quiescence strategy.

The quiescence response should not be interpreted as a universal response to every flooding condition. Deep-water rice provides a useful contrast. When water rises gradually and remains for long periods, rapid elongation can be beneficial because it helps leaves approach the water surface. Genes such as SNORKEL1 and SNORKEL2 have been associated with this escape response. Thus, conserving resources is advantageous when a temporary flood is expected to recede, whereas elongation can be advantageous when water continues to rise (Singh *et al.*, 2017; Oladosu *et al.*, 2020).

From Gene Discovery to Marker-Assisted Breeding

The discovery of SUB1 became particularly valuable when it was combined with molecular breeding. Conventional transfer of a trait from a traditional landrace into an elite cultivar can require repeated generations of selection and may inadvertently introduce undesirable donor characteristics. Marker-assisted backcross breeding provides a more

precise route for transferring a target genomic region while recovering the genetic background of the preferred recurrent parent.

In SUB1 breeding programmes, markers linked to or within the target region are used for foreground selection, allowing breeders to identify plants carrying the desired SUB1 segment. Recombinant selection can help reduce the size of the donor segment around the target region, while genome-wide background markers can accelerate recovery of the recurrent parent genome. This combination makes it possible to introduce submergence tolerance without replacing the agronomic identity of the popular variety. The success of this approach is illustrated by the transfer of SUB1 into several widely cultivated varieties, including Swarna, IR64, Samba Mahsuri, BR11, CR1009 and many more. Swarna-Sub1 was released in India in 2009 following evaluation in farmers' fields and that it can withstand approximately two weeks of flash flooding and recover after floodwater recedes. Other SUB1-introgressed varieties have been developed for different rice-growing regions of South and South-East Asia. These examples demonstrate how a gene identified in a traditional donor can be converted into a useful breeding product when the donor allele is combined with a suitable elite genetic background.

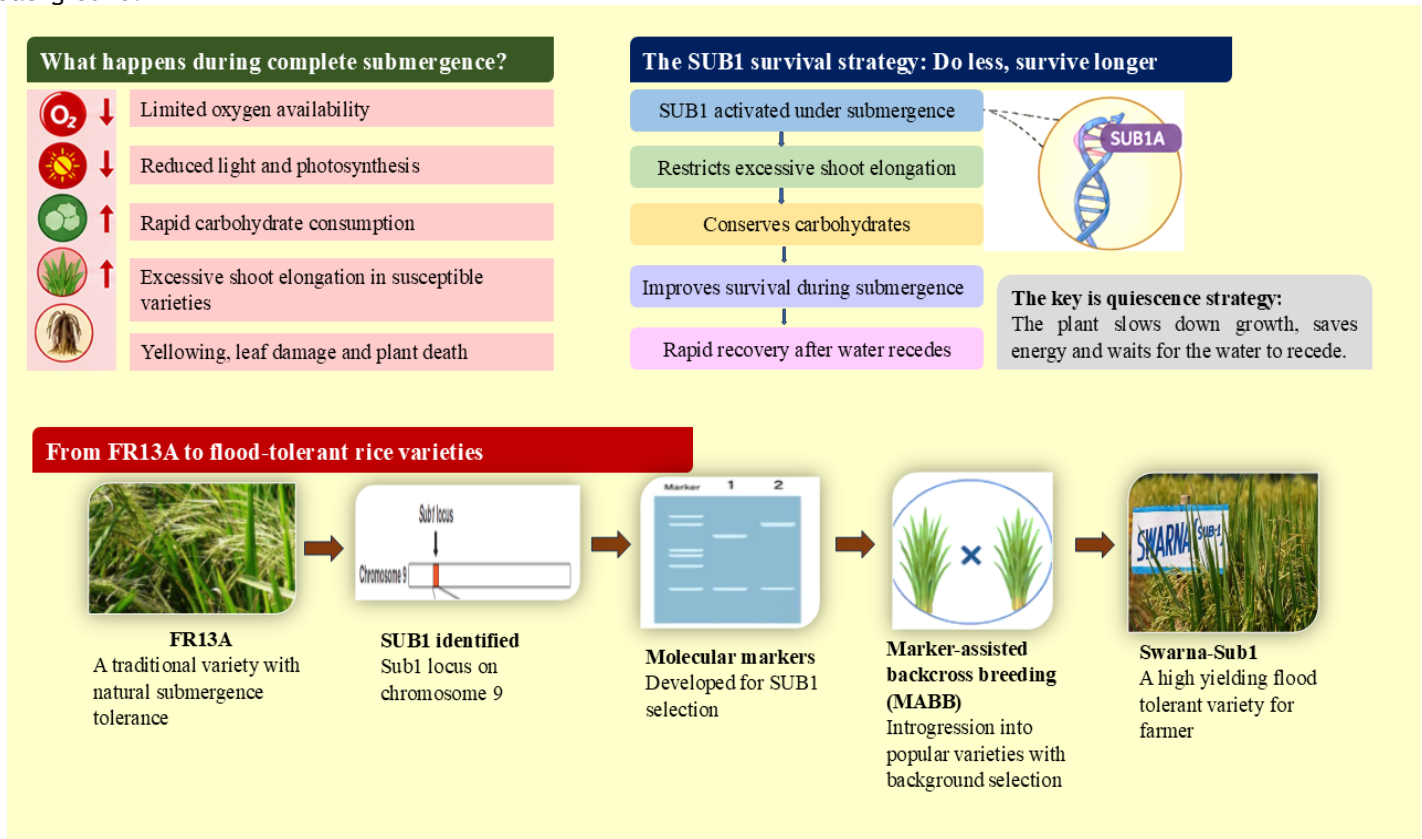


Figure 1. SUB1-mediated submergence tolerance and its deployment through marker-assisted breeding in rice

Beyond Sub1: Future Directions for Flood-Resilient Rice

Future breeding may combine submergence tolerance with drought tolerance, salinity tolerance, disease resistance and improved nutrient-use efficiency. Marker-assisted gene pyramiding, genomic selection, high-throughput phenotyping and genome editing can provide complementary tools for developing varieties with broader resilience. The objective is not simply to produce a rice plant that survives underwater, but one that survives the flood, recovers quickly and still produces an economically useful harvest.

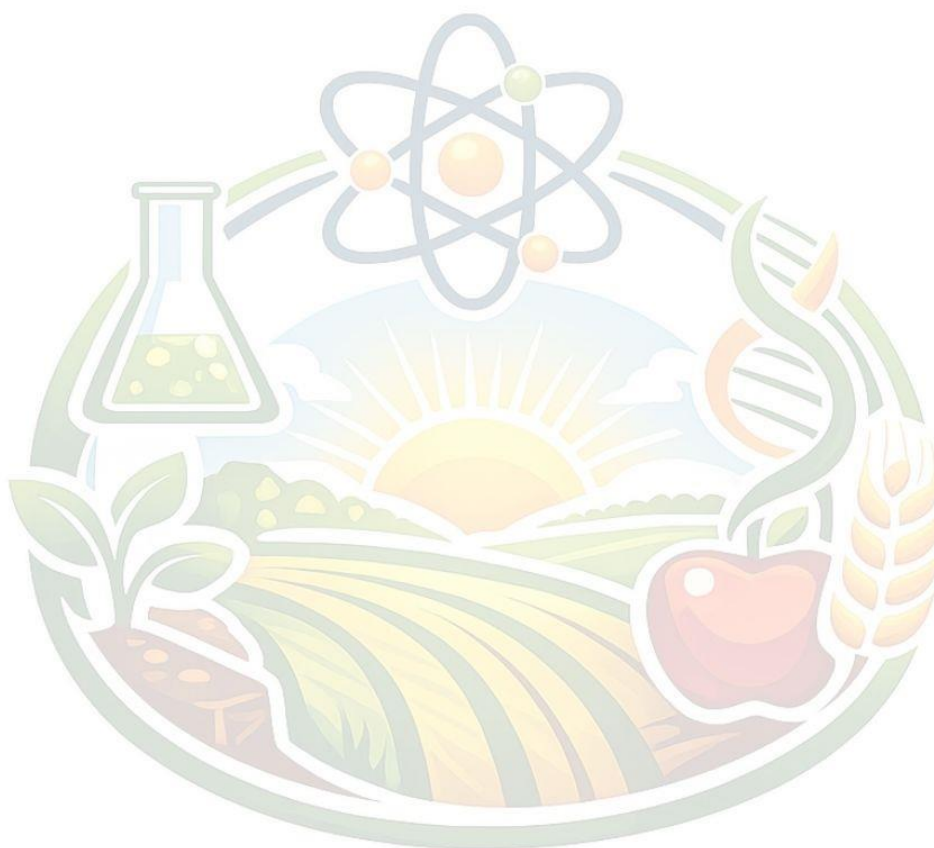
Conclusion

Complete submergence challenges rice through oxygen and energy limitations, but FR13A and the SUB1A-mediated quiescence strategy show how genetic variation can provide effective survival mechanisms. The discovery of SUB1 and its transfer into popular varieties through marker-assisted breeding demonstrate how plant physiology, genetic resources and molecular breeding can be combined to develop flood-resilient rice. Future breeding efforts can build on this success by combining submergence tolerance with other stress-adaptive traits for broader and more stable crop resilience.

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EUCALYPTUS: From the Australian Bush to a Global Medicinal and Industrial Resource

Article ID: 74552

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Abstract

Eucalyptus, a diverse genus of aromatic evergreen trees and shrubs belonging to the family **Myrtaceae**, represents one of the world's most economically and pharmacologically important plant resources. Although strongly associated with Australia, where the genus evolved and diversified extensively, eucalyptus species are now cultivated across many parts of the world for timber, pulp, fuelwood, essential oils and a wide range of pharmaceutical, cosmetic, agricultural and food-related applications. The extraordinary importance of eucalyptus arises from the chemical diversity of its leaves, bark, wood and essential oils. Eucalyptus essential oils are particularly rich in monoterpenes with **1,8-cineole (eucalyptol)** being the characteristic constituent. Other important compounds include α -pinene, limonene, p-cymene, γ -terpinene, citronellal, terpineol and various phenolic compounds. The concentration and composition of these constituents vary substantially with species, genotype, geographical location, climate, plant part, maturity and extraction method. Scientific investigations have reported antimicrobial, antifungal, antioxidant, anti-inflammatory, analgesic, insecticidal, repellent and other biological activities of eucalyptus-derived preparations. Particular research attention has focused on respiratory health, oral health, wound-related applications, microbial control and pharmaceutical formulations. Eucalyptus also possesses considerable potential for food preservation because its essential oils can inhibit selected bacteria, fungi and spoilage organisms. However, the strong volatility, intense aroma, limited water solubility and chemical instability of essential oils present challenges for their direct application, creating opportunities for microencapsulation, nano-emulsions, edible coatings and other advanced delivery systems. Beyond its medicinal and food-related applications, eucalyptus remains an important forestry and industrial resource, contributing to pulp, paper, biomass, timber, cosmetics and agricultural products. Overall, eucalyptus represents a versatile plant resource at the interface of phytochemistry, pharmacology, food science, forestry and biotechnology.

Keywords: Eucalyptus; eucalyptol; 1,8-cineole; essential oil; phytochemicals; pharmacology; food preservation; antimicrobial activity; pharmaceutical industry; medicinal plants.

Introduction

When we hear the word **eucalyptus**, the first association is often eucalyptus oil, its characteristic penetrating aroma or perhaps the Australian landscape. It encompasses hundreds of species with remarkable variation in growth habit, leaf chemistry, wood characteristics, ecological adaptation and economic value. Eucalyptus belongs to the **Myrtaceae** family. The genus contains a large diversity of trees and shrubs and Kew's Plants of the World Online currently recognizes the genus as native across a range extending from the Philippines and New Guinea through Australia and nearby regions. The genus became particularly famous because of its ability to grow rapidly, produce substantial woody biomass and survive under diverse environmental conditions. These characteristics made eucalyptus attractive to foresters, while its aromatic leaves made certain species valuable sources of essential oil. But perhaps the most fascinating aspect of eucalyptus is that the same plant can simultaneously be viewed as a forest resource, essential-oil crop, medicinal plant, pharmaceutical raw material, food-preservation candidate and industrial biomass source.

Origin

Eucalyptus is fundamentally an **Australian genus** and became dominant components of many Australian ecosystems and developed adaptations allowing them to persist under drought, fire and nutrient limitations. The genus is therefore not simply a collection of commercially planted trees; it represents a major component of Australia's botanical heritage.



Image showing Eucalyptus oil and Eucalyptus plant.

How did the Name "Eucalyptus" Originate?

The genus *Eucalyptus* was formally established by the French botanist Charles Louis L'Héritier de Brutelle in the late eighteenth century. The genus was published in *Sertum Anglicum* in 1789, with *Eucalyptus obliqua* serving as the type species. The name **Eucalyptus** originates from Greek roots associated with the idea of being “well-covered” or “well-hidden,” referring to the cap-like structure covering the developing flower. This botanical feature is particularly characteristic of eucalyptus flowers: the developing stamens are enclosed by an operculum or cap, which later falls away when the flower opens.

Eucalyptus Globulus - The Famous Blue Gum

Among the numerous eucalyptus species, *Eucalyptus globulus* is one that is most historically and commercially significant. It is commonly known as the **Tasmanian blue gum** and is native to southeastern Australia and Tasmania. Its importance comes from several characteristics: rapid growth, valuable timber, high biomass production, adaptability to many introduced environments, aromatic foliage, suitability for essential-oil production and particularly, its relatively high **1,8-cineole content**.

Eucalyptus was introduced into India as early as approximately **1790**, when eucalyptus species were reportedly planted around Nandi Hills near present-day Bengaluru. Later, *Eucalyptus globulus* was introduced into the Nilgiri region in the nineteenth century. Regular plantations were established there from the 1840s onward, initially to address fuelwood requirements. This eventually transformed eucalyptus into an important plantation crop in India. The species and hybrids subsequently became important sources of: fuelwood, pulpwood, paper raw material, timber, essential oils and products viz., eucalyptus oil, eucalyptol, pharmaceutical ingredients, cosmetic ingredients, agricultural applications such as insect repellents, botanical pesticides, antifungal preparations, herbicidal research, plant-pathogen management, biomass, poles and other wood products.

The most important chemical compound: **1,8-Cineole** also known as **Eucalyptol**. It is a cyclic monoterpene ether and is responsible for much of the characteristic fresh, penetrating aroma associated with eucalyptus oil. A recent study of *E. globulus* essential oil found: **1,8-cineole - 86.1%**, p-cymene - 4.9%, α -pinene - 3.8%, γ -terpinene - 2.2%, α -terpinene - 1.6% in the particular oil investigated. This illustrates that there is no single universal “eucalyptus oil” composition. The chemical profile changes according to species, chemotype, geography, season, plant part and extraction conditions.

Important Phytochemicals of Eucalyptus

Although 1,8-cineole is the star compound, eucalyptus chemistry is considerably more complex. Important constituents reported across eucalyptus species include:

Compound/group	Importance
1,8-Cineole (eucalyptol)	Characteristic medicinal oil constituent
α -Pinene	Aroma and biological activity
Limonene	Aroma, antioxidant/antimicrobial research
p-Cymene	Monoterpene associated with antimicrobial activity
γ -Terpinene	Volatile monoterpene
Citronellal	Aroma and insect-repellent relevance
Terpineol	Fragrance and antimicrobial research
Phenolic compounds	Antioxidant and biological activity
Flavonoids	Antioxidant and pharmacological research
Tannins	Astringent and biological properties

Essential Oil - The Liquid Treasure of Eucalyptus

The oil is commonly obtained through **Steam distillation**. Fresh or partially dried leaves are exposed to steam, which carries volatile compounds away from the plant material. The vapour is subsequently condensed, allowing the essential oil to be separated from the aqueous phase. This process provides a concentrated mixture of volatile phytochemicals.

Medicinal Importance of Eucalyptus

Eucalyptus has a long history of traditional medicinal preparations have included leaves, infusions, vapours and oils for conditions involving: cough; common cold; nasal congestion; respiratory discomfort; minor wounds; muscle discomfort; inflammation and microbial infections. Modern scientific research has subsequently investigated many of these traditional claims and reported evidence for several biological activities, including antimicrobial activity against different: gram-positive bacteria; gram-negative bacteria; fungi; yeasts; and biofilm-forming microorganisms, anti-inflammatory, antioxidant, antiviral, analgesic and other pharmacological effects.

Respiratory Health: Eucalyptol has been investigated for providing relief against: mucus-related respiratory symptoms; airway inflammation; sinus-related symptoms; bronchial conditions; common cold-associated symptoms and respiratory tract inflammation.

Important caution: Oral ingestion of concentrated eucalyptus oil can be toxic and inappropriate exposure can be dangerous, particularly in children.

Aromatherapy: Eucalyptus holds an important place in aromatherapy because of its distinctive fresh, camphoraceous and penetrating aroma, which is largely attributed to eucalyptol. Eucalyptus essential oil is commonly used in diffusers, steam inhalation, massage oils, bath preparations, balms and personal-care products, where its invigorating fragrance creates a refreshing and cooling sensory experience. Its aroma is traditionally associated with a feeling of clearer breathing, reduced nasal stuffiness, relaxation and mental freshness, making it particularly popular during periods of seasonal congestion and fatigue.

Oral and Dental Applications: Research has investigated eucalyptus-derived preparations against: oral bacteria; dental plaque-associated organisms; biofilms and microorganisms associated with oral disease. This creates opportunities for: mouthwash formulations; toothpaste ingredients; oral-care products; antimicrobial gels and biofilm-control systems.

Antioxidant Potential: Eucalyptus contains both volatile and non-volatile phytochemicals. Phenolic compounds, flavonoids and terpenoid constituents have demonstrated antioxidant activity. Antioxidants are important because oxidative stress can contribute to cellular damage and numerous pathological processes. The antioxidant activity of eucalyptus therefore represents another important area of: pharmaceutical research; food preservation; cosmetics, nutraceutical research.

Advanced drug delivery: One particularly exciting area is **nano-formulation**. Nano-emulsions and other delivery systems can potentially improve: dispersion; stability; controlled release; bioavailability and practical application of hydrophobic essential-oil constituents.

Natural food preservative: Research has demonstrated that eucalyptus essential oil can inhibit selected food-spoilage microorganisms. This suggests possible applications in: fruit preservation; vegetable preservation; beverages; fresh produce; edible coatings; active packaging and antimicrobial food-contact systems.

There is an Interesting Paradox

The same chemical properties that make eucalyptus oil biologically active can make it difficult to use in foods. Essential oils are often: highly volatile; strongly aromatic; chemically unstable; poorly water-soluble and capable of producing undesirable flavours at effective antimicrobial concentrations. Researchers therefore investigate: Microencapsulation, Nano-emulsions, Edible coatings, Active packaging, Controlled-release systems. These technologies can potentially deliver antimicrobial compounds at lower effective concentrations while reducing undesirable sensory effects. This is a major frontier in food science.

Eucalyptus in Cosmetics and Personal Care: The characteristic aroma of eucalyptus has made it valuable in: soaps; shampoos; creams; lotions; deodorants; perfumes; massage products; oral-care products and personal-hygiene formulations.

Eucalyptus as a Forestry and Industrial Crop: Its wood is used for: pulp; paper; poles; fuelwood; charcoal; construction; engineered wood; biomass energy and other wood products. This makes eucalyptus a classic example of a multipurpose industrial plant.

Eucalyptus and the Paper Industry: One of eucalyptus's greatest industrial contributions is pulp production. Its relatively rapid growth and suitable fibre characteristics have made eucalyptus important for: kraft pulp; writing paper; tissue

products; packaging materials; printing paper and cellulose-based products. This has transformed eucalyptus from a botanical curiosity into an important component of the global forest-products economy.

Environmental Importance and the Debate

Eucalyptus can provide: rapid biomass production; carbon storage in biomass; fuelwood; erosion-control benefits in appropriate settings; industrial raw materials and livelihood opportunities. But poorly planned eucalyptus plantations can also raise concerns about: water availability; soil nutrient dynamics; biodiversity; fire behaviour; invasive potential in some ecosystems and displacement of native vegetation. The environmental effect therefore depends strongly on: species × genotype × climate × soil × plantation density × management × landscape context.

Research Methodologies Used to Study Eucalyptus are

1. Gas Chromatography-Mass Spectrometry (GC-MS)-To identify volatile compounds in essential oils.
2. High-Performance Liquid Chromatography (HPLC)-To analyse non-volatile phytochemicals.
3. FTIR spectroscopy-To characterize chemical functional groups.
4. Antimicrobial assays-To determine inhibition against bacteria and fungi.
5. MIC and MBC testing-To determine minimum inhibitory and bactericidal concentrations.
6. Antibiofilm assays-To investigate the ability to prevent or disrupt microbial biofilms.
7. Antioxidant assays -DPPH; ABTS; FRAP.
8. Cell culture studies used to investigate: inflammation; cytotoxicity; molecular pathways & cellular responses.

Conclusion

Eucalyptus represents one of the most remarkable examples of how a plant can bridge traditional knowledge, modern science and industrial biotechnology. The extraordinary versatility of eucalyptus is fundamentally rooted in its chemistry. Among its numerous phytochemicals, 1,8-cineole (eucalyptol) stands out as one of the most commercially and pharmacologically significant constituents. Together with α -pinene, limonene, p-cymene, terpinene, terpineol and various phenolic compounds, it contributes to the biological and sensory properties of eucalyptus-derived products. The medicinal potential of eucalyptus is particularly notable in the areas of aromatherapy, respiratory health, antimicrobial activity, inflammation, oral health, wound-related research and topical applications. At the same time, eucalyptus essential oils are increasingly being investigated for food preservation, active packaging, cosmetics, agricultural pest management and advanced pharmaceutical delivery systems. It is a chemically sophisticated, economically valuable and biologically active plant resource whose full potential lies at the intersection of forestry, phytochemistry, pharmacology, food science, biotechnology and sustainable agriculture. **“Eucalyptus is not merely a tree of the forest; it is nature’s chemistry written in leaves, distilled into possibility, and carried forward by science.”**

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Masters of Adaptation: How Plant Pathogens Change Strategies to Survive

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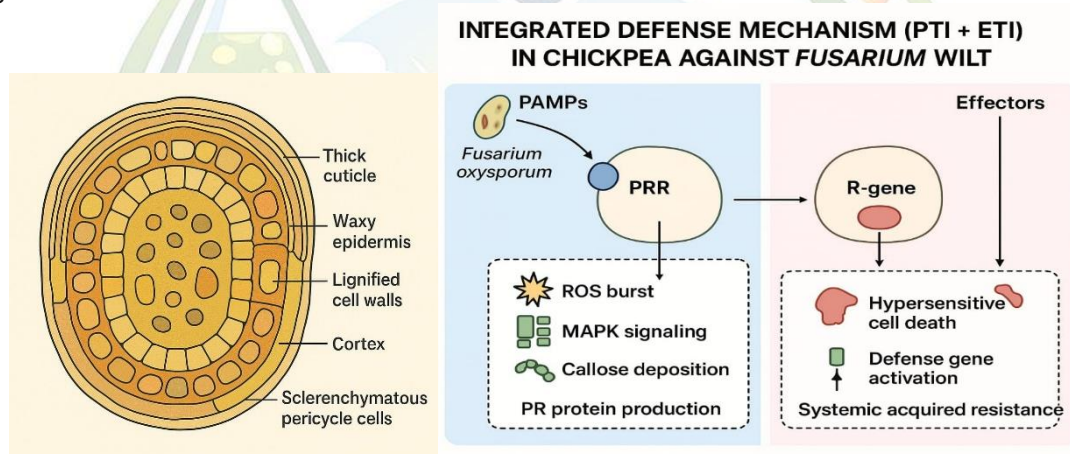
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Introduction

Every day, in gardens, fields and woods, there's an unseen conflict where plants and the diseases that infect them go back and forth. Even though plants are rooted in the ground, they still carry complex immune systems, chemical tricks and physical defences, wrapped in layers. Meanwhile the pathogens, bacteria, viruses, fungi and oomycetes have built remarkable strategies to outperform these barriers.

Plants and their First Line of Defense

Plants aren't just passive hosts. Their first line of defence includes physical barriers such as the waxy cuticle, rigid cell walls, and regulated stomatal openings. These are supported by antimicrobial compounds as well as an innate immune system that can detect invading microbes. Pattern-triggered immunity or PTI, is the part that recognizes conserved microbial signatures, but then effector-triggered immunity ETI provides a more specific response against pathogen-derived molecules. Together, these mechanisms form a dynamic interaction often described the “zig-zag” model of plant immunity.



Pathogens: Masters of Molecular Manipulation

To overcome plant immunity, pathogens send out effector like molecules that interfere with the host defences and other cell routines. Fungal pathogens hide certain molecules that should've triggered plant recognition, while bacterial pathogens can inject effectors directly into plant cells using specialised secretion systems. Oomycetes also seem to send effectors that interfere with host cellular functions. These strategies enable pathogens suppress immunity leading to an infection. Pathogens can further **reprogram the host from within**. They achieve this by manipulating plant hormones, including salicylic acid, jasmonic acid, and auxin, so defence reactions change, nutrient allocation shifts and cellular processes follow. Some pathogens take advantage of programmed cell death to obtain resources, whereas others suppress it to maintain living host tissue. Certain fungi can shift between biotrophic and necrotrophic lifestyles during an infection, which indicates flexibility range of pathogens.

The Viral Strategy for Survival

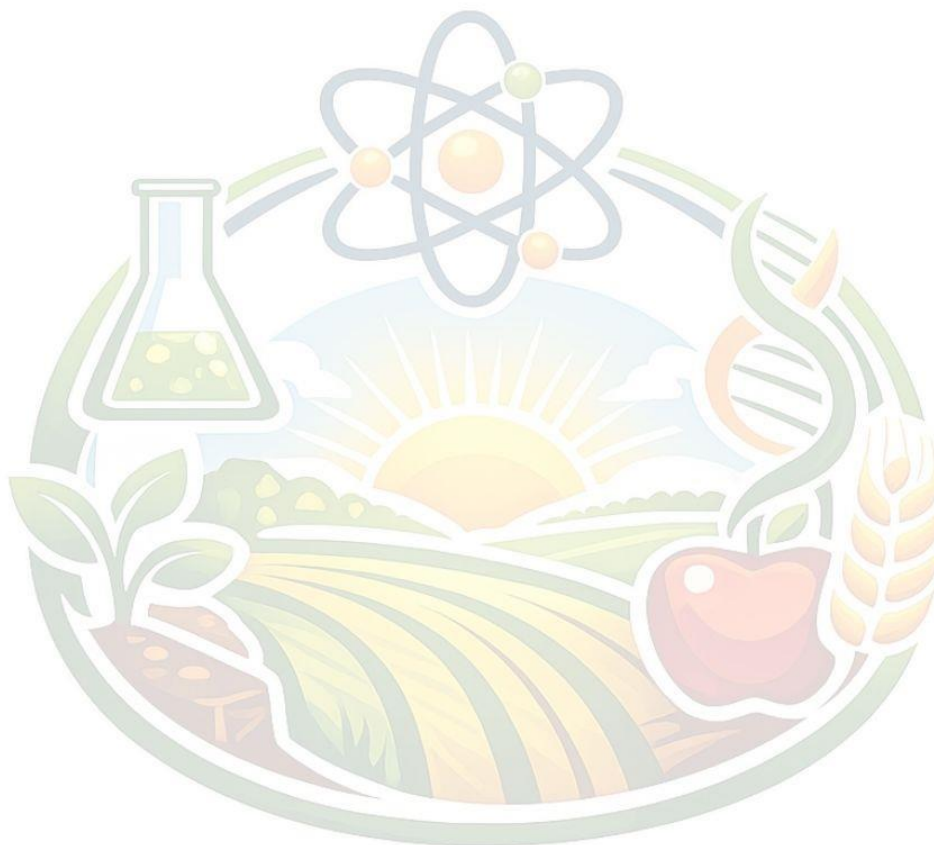
Plant viruses have a simple structure but employ highly effective mechanisms to evade host defence. The major target is the plant's RNA silencing system. It basically recognises and then degrades outside foreign genetic material. Hereafter, the viruses produce suppressor proteins which interfere with the pathway, triggering the evolution of new plant defense mechanisms at the molecular level.

Adapting to Change: The Continuing Struggle Between Plants and Pathogens

Pathogen adaptation is influenced not only by host resistance but also by environmental conditions. Temperature, humidity, drought and salinity can influence pathogen development, reproduction and even the disease severity. Climate

change alters pathogen distribution and their interactions with susceptible crops may change, which may end up exposing plants to disease pressures. Because pathogens adapt so well, it becomes a big hurdle for sustainable crop protection. Resistance based on a single gene can be defeated when pathogen populations evolve or lose the matching target. This has contributed to the famous **“boom and bust”** pattern of resistance in several crop diseases.

The key lies not in achieving permanent control, but in developing durable and adaptable management strategies. Combining multiple resistance genes, quantitative resistance, biological control, cultural routines and careful chemical use, can make it difficult for pathogens to overcome plant defences. For example, RNA based disease management, may hold considerable potential. Ultimately, the plant-pathogen relationship is an ongoing negotiation. Pathogens survive by altering their strategies, while plants keep strengthening their defences. Understanding pathogen adaption and evolution is fundamental to developing durable crop protection strategies capable of maintaining their effectiveness overtime.

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“Madhuvan” Success: Transforming a Coconut Plantation into a Profitable Beekeeping Enterprise

Article ID: 74554

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Mr. Ram Jethabhai Mulubhai, 38 year old farmer belongs to Chamoda village of Gir Somnath district. After completing his education, including graduation in Drawing from Ahmedabad, he returned to his native village and joined his family occupation of agriculture. His 15-vigha farm was entirely covered with a mature coconut plantation that was more than two decades old. Although the plantation generated an annual income of approximately ₹60,000-70,000, limited space and dense canopy restricted the cultivation of additional crops, creating a need for an alternative source of income.



Recognizing the untapped potential of his coconut orchard, he explored the possibility of integrating beekeeping with horticulture. In 2021, he participated in a scientific beekeeping training program organized by Krishi Vigyan Kendra, Ambuja Foundation, Kodinar, under the sponsorship of the National Bee Board, New Delhi. The training inspired him to adopt beekeeping as a commercial enterprise. Thereafter, he visited several successful apiaries, gained practical exposure, and built confidence to start his own venture.

Enterprise Development

Beginning with 40 honeybee colonies, Ram Jethabhai established a commercial beekeeping unit within his coconut orchard. With the active support of his wife, Mrs. Dhrutiben, and other family members, the enterprise gradually expanded and now comprises 100 bee boxes. The family is involved in all operations including colony management, honey extraction, packaging, labelling, and marketing.

With technical guidance from KVK, Ambuja Foundation, he launched his own honey brand, “Madhuvan”, enabling direct marketing and value addition. The brand has gained recognition in the local market for its quality raw honey.

Financial Performance

Year wise comparative Economic				Revenue Composition for year 2025-26		
Year	Investment (₹)	Gross Income (₹)	Net Income (₹)	Source of Income	Amount (₹)	Share (%)
2023-24	1,80,000	9,30,000	7,50,000	Honey Sale (750 kg)	4,50,000	58.1
2024-25	1,20,000	7,40,000	6,20,000	Bee Box Sale (46 Nos.)	1,84,000	23.8
2025-26	1,50,000	7,74,000	6,24,000	Colony Division (35 Nos.)	1,40,000	18.1
Total	4,50,000	24,44,000	19,94,000	Total Revenue	7,74,000	100

Highlights of the Year 2025-26

1. Maintains approximately 100 honey bee colonies.
2. Produced and self-marketed 750 kg of raw honey.
3. Sold 46 bee colonies/boxes.
4. Generated 35 colony divisions (splits) for further sale and expansion.
5. Provides technical guidance and practical demonstrations to aspiring beekeepers.
6. More than 350 farmers visit his apiary annually to learn scientific beekeeping practices.

His success has transformed him from a farmer into a local resource person and rural entrepreneur, promoting livelihood diversification and sustainable agriculture in the region.

Knowledge Sharing and Capacity Building

Mr. Ram Jethabhai actively promotes scientific beekeeping among rural youth and farmers in collaboration with Krishi Vigyan Kendra, Ambujanagar. His farm has emerged as a practical learning centre where KVK's trainees is being observe colony management, honey extraction, and value addition practices. Through regular field visits and farmer interactions, he has inspired several individuals to adopt beekeeping as an additional source of income.



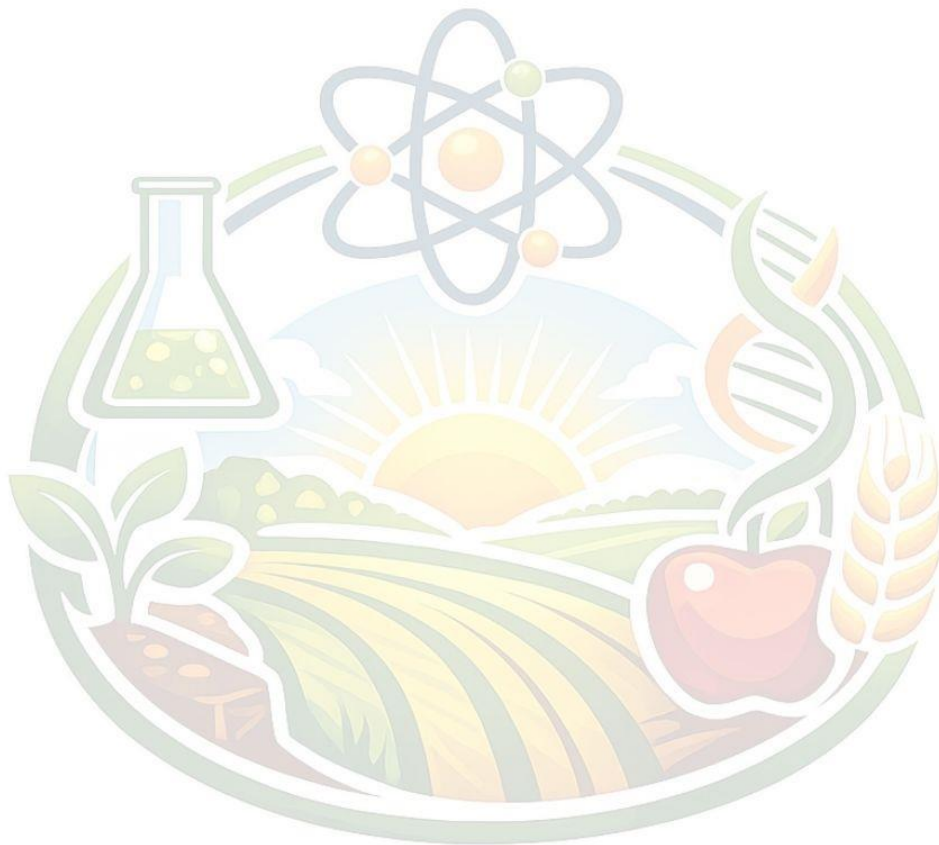
Recognition & Awards

The success of the Madhuvan Honey enterprise has received attention from farmers and local media, highlighting the potential of integrating beekeeping with horticultural crops for enhanced farm income and entrepreneurship.



Conclusion

The journey of Ram Jethabhai Mulubhai demonstrates how scientific training, entrepreneurial vision, and family participation can convert an underutilized coconut orchard into a profitable beekeeping enterprise. Through strategic integration of beekeeping with horticulture, value addition under the Madhuvan brand, and continuous knowledge sharing, he has achieved annual earnings exceeding ₹6 lakh net income while becoming a role model for farmers across Gir Somnath district. His success underscores the immense potential of apiculture as a sustainable livelihood option for small and medium farmers.

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From SHG Leader to Rural Entrepreneur: Empowering Women through Value Addition and Natural Farming

Article ID: 74555

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Mrs. Kantaben Nagajibhai Singala, a 63-year-old progressive farm woman from Hadmatiya (Gir) village of Talala taluka in Gir Somnath district, is a remarkable example of determination, leadership, and entrepreneurship. Despite receiving formal education only up to Standard 2, she successfully manages 42 bigha of irrigated farmland, a 7-bigha mango orchard comprising 130 mango trees, livestock, and natural farming activities. She cultivates sugarcane, groundnut, soybean, wheat, sorghum, bajra, and fodder crops while actively promoting sustainable agricultural practices. Her hardworking nature, strong social connect, and passion for helping others have enabled her to emerge as a respected leader among rural women. Recognizing the importance of collective action, Mrs. Kantaben joined the Krishna Lok Shakti Self-Help Group (SHG) in 2014 and was subsequently elected as its President. Through her leadership and dedication, the SHG movement expanded significantly in the village, resulting in the formation of 10 Self-Help Groups involving nearly 100 women members. She further established the Javantri Cluster Sakhi Sangh and initiated a Food Processing Producer Group to encourage women-led enterprises. Today, she serves as President of the cluster-level cooperative society and continues to motivate women towards financial independence and self-reliance.



KVK Intervention and Enterprise Development

A major turning point in Mrs. Kantaben's journey came in 2019 when Krishi Vigyan Kendra (KVK), Kodinar organized a Value Addition Training Programme at Hadmatiya village, attended by 37 farm women. The training focused on scientific methods of processing agricultural produce, value addition, packaging, labeling, quality maintenance, storage, branding, and marketing strategies. The programme created awareness among rural women about converting farm produce into high-value products, thereby generating additional income and reducing post-harvest losses.

Inspired by the training and encouraged by KVK scientists, Mrs. Kantaben recognized the immense potential of utilizing produce from her own natural farming system for value addition. Equipped with newly acquired skills, she initiated small-scale processing activities using raw materials available on her farm. The technical knowledge imparted through KVK training enabled her to prepare quality products, maintain hygiene standards, adopt attractive packaging, and

improve marketability. With continuous guidance and motivation from KVK, she gradually established a farm-based value addition enterprise and started manufacturing a wide range of products, including Drumstick Powder, Chiku Chips, Kasuri Methi, Amla Candy, Mango Powder, Amchur Powder, and various traditional Kachari products prepared from wild cucumber, sponge gourd, radish, tomato, cucumber, and okra.

In addition, she markets naturally grown fenugreek, white and black sesame, garlic, organic mangoes, and other farm produce.

The uniqueness of her enterprise lies in the fact that most of the raw materials are sourced directly from her own farm. This farm-to-market approach not only reduces production costs but also ensures freshness, quality, traceability, and consumer confidence. Her products, particularly Drumstick Powder and Mango Powder, have received excellent market response owing to their nutritional value and natural processing methods. To strengthen her enterprise, Mrs. Kantaben utilized financial support through Self-Help Groups and government schemes such as Mahila Utkarsh Yojana. She actively participated in agricultural fairs, exhibitions, and marketing events, where her products received wide appreciation. Participation in Saras Mela at Somnath, exhibitions at Talala, and trade fairs in Ahmedabad provided valuable market exposure and helped establish direct connections with consumers. Through these events, she earned approximately ₹25,000 at Somnath, ₹14,000 at Talala, and ₹40,000 at Ahmedabad, demonstrating the commercial viability of value-added agricultural products.



Impact

The intervention of KVK Kodinar not only enhanced Mrs. Kantaben's technical knowledge but also transformed her from a farm woman into a successful entrepreneur and community leader. By adopting value addition technologies and utilizing produce from her natural farming system, she successfully converted low-value agricultural produce into premium market-ready products, thereby increasing profitability and creating a sustainable supplementary source of income. Today, her enterprise generates an annual net profit of approximately ₹52,000, contributing significantly to household income and livelihood security.

Beyond economic gains, her achievements have created a far-reaching impact across the community. As the leader of 10 SHGs comprising nearly 100 women members, she has become a role model for rural women aspiring to become self-reliant. Her enterprise serves as a practical demonstration unit where women learn about value addition, food processing, packaging, and entrepreneurship. Through regular interaction and mentoring, she actively encourages SHG members to initiate income-generating activities based on locally available agricultural resources.

Her success has strengthened women's participation in economic activities, enhanced confidence among SHG members, and promoted collective entrepreneurship within the village. Participation in fairs and exhibitions has not only expanded market access for her products but has also showcased the entrepreneurial capabilities of rural women at district and state levels. The visibility created through these events has inspired many farm women to explore value addition as a viable pathway for livelihood enhancement.

In addition to generating income, her efforts have contributed to the promotion of natural farming, reduction of post-harvest losses, utilization of local resources, and development of a self-reliant rural economy. Her journey exemplifies how rural women can successfully integrate agriculture, value addition, leadership, and entrepreneurship to improve their socio-economic status while contributing to community development.

Key Achievements

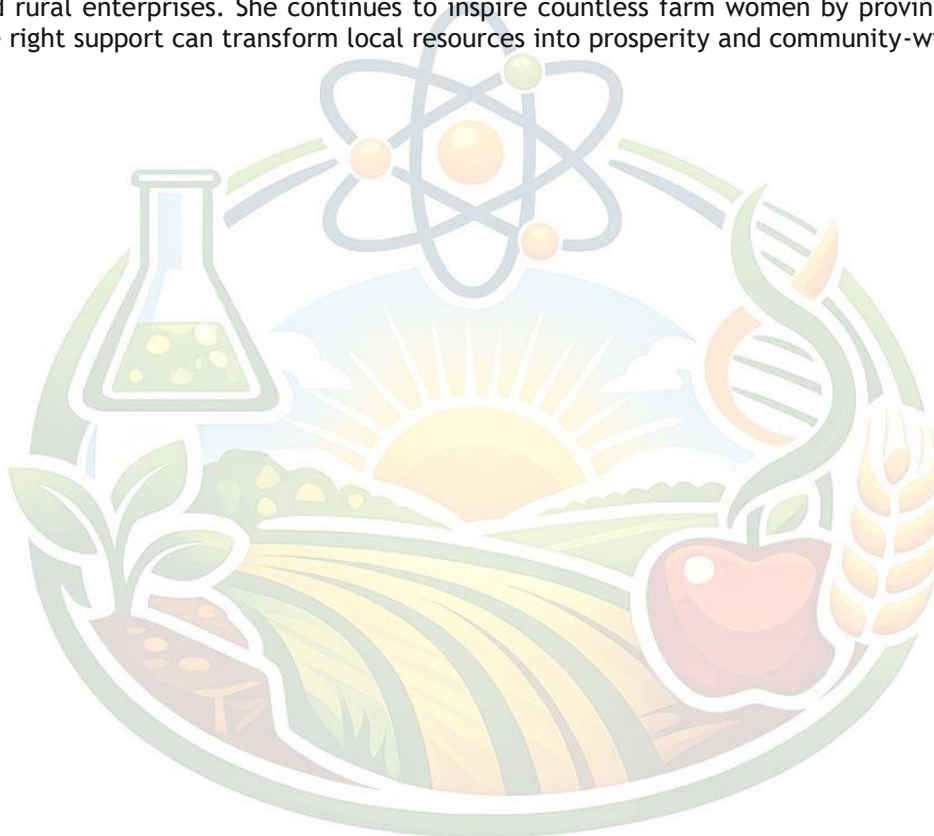
1. Successfully established a farm-based value addition enterprise.
2. Leads 10 Self-Help Groups with nearly 100 women members.
3. Promotes natural farming and value addition using farm-grown produce.
4. Generated additional annual income of approximately ₹52,000.
5. Strengthened women's entrepreneurship and financial inclusion.
6. Established market linkages through fairs and exhibitions across Gujarat.
7. Inspired rural women to adopt income-generating enterprises and collective development initiatives.

Conclusion

Mrs. Kantaben Nagajibhai Singala's journey from a village farm woman to a successful entrepreneur and community leader is a powerful example of the transformative impact of knowledge, collective action, and institutional support. Despite limited formal education, she successfully leveraged opportunities provided through Self-Help Groups, government support schemes, and capacity-building programmes organized by Krishi Vigyan Kendra, Kodinar. Through perseverance, innovation, and visionary leadership, she transformed locally available agricultural resources into a thriving value-addition enterprise that generates income and creates opportunities for others.

More importantly, her achievements extend far beyond personal success. Through her leadership of 10 SHGs and nearly 100 women members, she has fostered a culture of entrepreneurship, savings, cooperation, and self-reliance among rural women. Her efforts demonstrate that when technical guidance, financial inclusion, and community participation come together, rural women can emerge as powerful agents of socio-economic transformation.

Today, Mrs. Kantaben stands as an ambassador of natural farming, value addition, women's empowerment, and grassroots leadership. Her success story highlights how KVK interventions can catalyze sustainable livelihood opportunities and promote women-led rural enterprises. She continues to inspire countless farm women by proving that determination, confidence, and the right support can transform local resources into prosperity and community-wide development.

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Milk Fermentation: Emerging Technologies and Future Perspectives

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Abstract

Milk fermentation has progressed from a conventional preservation practice to a precisely managed biotechnological process supported by modern analytical and microbial technologies. Recent developments in starter-culture selection, probiotic combinations, metagenomic and metabolomic approaches have improved understanding of microbial interactions, fermentation metabolites and product characteristics. Traditional fermented milks continue to provide important sources of diverse microorganisms that may possess useful technological properties. At the same time, postbiotics, plant-derived bioactive compounds and precision fermentation are creating new opportunities for innovation in fermented dairy products. Precision fermentation enables microorganisms to be utilized for the targeted production of specific dairy proteins and other functional ingredients. Furthermore, artificial intelligence and data-driven methods have potential applications in monitoring, predicting and optimizing fermentation processes. This article summarizes recent technological developments in milk fermentation and discusses their relevance to the production of dairy foods with reproducible quality, desirable sensory attributes and potential functional value. Future innovation will require simultaneous consideration of microbial safety, regulatory frameworks, consumer acceptance and scientifically substantiated health claims.

Keywords: Milk fermentation; Starter cultures; Probiotic cultures; Metabolomics; Metagenomics; Postbiotics; Precision fermentation; Fermented dairy foods; Artificial intelligence.

Introduction

Milk fermentation is one of the oldest methods used to improve the preservation, flavour, texture and digestibility of milk. Products such as dahi, yoghurt, kefir and cultured buttermilk have traditionally been produced using naturally occurring microorganisms or previously fermented milk as inoculum. Today, milk fermentation has evolved from an empirical practice into a controlled biotechnological process through advances in microbial genomics, metabolomics, probiotic technology, starter-culture development and precision fermentation.

The fundamental principle remains the microbial conversion of lactose and other milk constituents into organic acids and other metabolites. However, modern research focuses on identifying specific microorganisms, understanding microbial interactions and controlling fermentation to obtain predictable sensory, nutritional and functional properties. The transition from spontaneous and back-slopping fermentation to defined starter cultures has greatly improved process consistency and industrial reproducibility (Bintsis and Papademas, 2022).

Recent developments include advanced starter cultures, probiotic and multi-strain fermentation, metagenomics, metabolomics, postbiotics, natural bioactive ingredients and precision fermentation. These technologies are transforming fermented milk from a traditional food into a platform for developing innovative functional dairy products.

From Traditional to Controlled Fermentation

Traditional fermented milk is commonly produced through spontaneous fermentation or back-slopping, where a portion of previously fermented milk is used to inoculate fresh milk. Although this method can produce distinctive sensory characteristics, microbial composition may vary with milk quality, temperature, utensils, environment and starter material.

Modern dairy processing generally uses defined starter cultures to obtain consistent fermentation. Yoghurt production, for example, primarily uses *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*. Current research is moving beyond conventional starters toward selected probiotic strains, adjunct cultures and deliberately designed microbial combinations.

Modern starter selection considers not only acidification ability but also growth behaviour, safety, metabolite production, flavour development and technological performance. Genomic and metabolic approaches are therefore helping researchers select microorganisms according to specific functions rather than relying only on traditional screening methods (Gänzle et al., 2024).

Advanced Starter and Probiotic Cultures

The incorporation of probiotic microorganisms is one of the major developments in fermented dairy technology. Probiotics can contribute potential functional properties while also influencing fermentation behaviour, flavour and metabolite formation.

Zhang et al. (2020) studied *Lactobacillus plantarum* K25 in fermented milk containing conventional yoghurt starters. The probiotic remained viable during refrigerated storage and altered the metabolic profile of the product, including an increase in γ -aminobutyric acid (GABA). This demonstrated that probiotic cultures could influence the biochemical characteristics of fermented milk in addition to providing viable microorganisms.

Research has subsequently moved toward multi-strain fermentation. Wang et al. (2021) compared *Lactocaseibacillus casei* Zhang, *Bifidobacterium animalis* subsp. *lactis* Probio-M8 and their combination in yoghurt. Metabolomic analysis showed differences in volatile and non-volatile metabolites, indicating that interactions between microorganisms can influence flavour and biochemical characteristics.

Similarly, Peng et al. (2022) evaluated *L. casei* Zhang and *B. lactis* V9 individually and in combination. The binary culture influenced microbial growth and the production of several organic acids during fermentation and storage. These findings indicate that starter cultures should increasingly be considered as interacting microbial communities rather than simply acid-producing organisms.

Probiotic cultures may also improve fermentation performance. Recent research has investigated *B. animalis* subsp. *lactis* Probio-M8 as an additional starter culture, with reported effects on fermentation time, texture, stability and metabolite formation. Such findings support the use of selected probiotic strains as active fermentation partners rather than merely as post-fermentation additions.

Metabolomics: Understanding Fermentation Chemistry

Metabolomics has become an important tool for understanding the biochemical changes occurring during milk fermentation. Conventional studies generally focus on pH, titratable acidity, microbial counts and a limited number of flavour compounds. Metabolomics provides a broader picture by simultaneously examining organic acids, amino acids, peptides, sugars, fatty acids and volatile compounds.

These metabolites form a biochemical fingerprint of fermentation and can help explain differences between products produced using apparently similar cultures. Peng et al. (2022), for example, demonstrated that different probiotic combinations produced distinct metabolic profiles during yoghurt fermentation and storage.

Metabolomics can also improve starter selection. Cultures can be screened for their ability to produce desirable aroma compounds, bioactive metabolites and flavour precursors, allowing fermentation to be designed according to specific product characteristics.

Metagenomics and the Microbial Diversity of Traditional Fermented Milk

Molecular techniques such as 16S rRNA sequencing and shotgun metagenomics have revealed the complex microbial communities present in traditional fermented milks. Traditional dahi is an important example because household and artisanal products often use undefined starter cultures.

Tigga et al. (2025) used 16S metagenomics and untargeted GC-MS metabolomics to study traditional Indian dahi produced by back-slopping. Firmicutes and Proteobacteria were among the dominant bacterial phyla, while *Lactobacillus* and *Streptococcus* were prominent genera. The researchers identified 62 metabolites, including amino acids, fatty acids, sugars and other metabolic intermediates. Differences among samples were associated with milk type, heating conditions, containers and inoculation practices.

These findings demonstrate that traditional fermented milk is microbiologically diverse rather than uniform. Such products can therefore serve as valuable sources of indigenous microorganisms with potentially useful technological properties. Selected microorganisms may eventually be used to develop defined starter cultures that retain desirable characteristics of traditional products while improving manufacturing consistency.

Shotgun metagenomics provides even deeper information about microbial communities and their functional potential. Wang et al. (2024) investigated microbial changes during nine months of continuous back-slopping fermentation of traditional fermented milk and identified 186 high-quality metagenome-assembled genomes representing seven genera and 13 species. *Lactobacillus helveticus* was dominant, followed by *Enterococcus durans* and *Limosilactobacillus fermentum*. Changes in microbial diversity and carbohydrate-metabolism genes demonstrated how microbial communities adapt during repeated fermentation.

Postbiotics and Next-Generation Probiotics

The development of fermented dairy products is increasingly extending beyond conventional live probiotics toward postbiotics, paraprobiotics and next-generation probiotics. Maintaining probiotic viability throughout processing, storage

and gastrointestinal passage can be challenging. Consequently, microbial metabolites, cellular components and other microbial-derived preparations are receiving increasing attention.

Taşkoparan et al. (2025) highlighted the growing interest in postbiotics and next-generation probiotic cultures in dairy-based beverages. These approaches may provide opportunities for developing products with improved stability and targeted functionality.

However, the presence of a bioactive microbial component does not automatically establish a clinical health benefit. The biological effects of postbiotic preparations depend on their composition, concentration, dose and demonstrated physiological activity. Therefore, health-related claims should be supported by appropriate scientific and clinical evidence.

Natural Bioactive Ingredients in Fermented Milk

Another important trend is the incorporation of fruits, vegetables, herbs, cereals and other plant-derived ingredients into fermented milk. This approach combines microbial transformation with the nutritional and bioactive properties of plant materials.

Prestes et al. (2022) reviewed the incorporation of fruit-derived bioactive compounds into fermented milk and reported effects on nutritional composition, texture, sensory characteristics and oxidative stability. Berries, pomegranate, citrus fruits, cereals and spices are among the ingredients being explored.

However, formulation requires careful optimization. Plant compounds may influence microbial growth, acidity, flavour and probiotic survival. Therefore, successful product development requires a balance between microbial viability, sensory acceptance, nutritional value and functional properties.

Kefir: A Complex Microbial Fermentation System

Kefir represents a distinctive form of milk fermentation because it contains a complex community of lactic acid bacteria, acetic acid bacteria and yeasts associated with kefir grains. Interactions among these microorganisms contribute to its characteristic acidity, aroma, flavour and slight carbonation.

Alvarez et al. (2022) reviewed the microbiota of milk kefir and described the antimicrobial interactions associated with its complex microbial community. Modern sequencing technologies are providing greater insight into these microbial interactions and may eventually support the development of defined kefir starter systems with improved industrial consistency while retaining selected characteristics of traditional kefir.

Precision Fermentation: A New Frontier in Dairy Biotechnology

Precision fermentation represents a major expansion of the concept of fermentation. Instead of using microorganisms primarily to transform milk, precision fermentation employs selected microorganisms as biological production systems for specific target molecules.

Microbial systems can be designed to produce particular proteins and other food ingredients. This has attracted considerable interest for producing milk proteins traditionally obtained from animals (Nielsen et al., 2024). For dairy applications, caseins and whey proteins are particularly important because they contribute nutritional quality as well as functional properties such as emulsification, gel formation and foaming. Precision fermentation may therefore provide new approaches for producing specific dairy proteins with controlled characteristics.

Hilgendorf et al. (2024) described precision fermentation as an expanding food biotechnology with potential applications related to quality, flavour, safety and sustainability. Thus, fermentation technology is moving beyond simply fermenting milk toward using microorganisms as biological factories for selected dairy ingredients.

Artificial Intelligence and Data-Driven Fermentation

The future of milk fermentation is likely to become increasingly data-driven. Modern fermentation systems can generate large datasets involving temperature, pH, acidity, microbial growth, metabolite production and storage behaviour.

Combining these data with machine-learning approaches may help identify relationships that are difficult to detect using conventional methods. Genomic, phenotypic and metabolic information can also be integrated to identify microorganisms with desirable technological characteristics (Gänzle et al., 2024). In dairy processing, such approaches may assist in predicting fermentation endpoints, optimizing processing conditions and detecting abnormal fermentation. Nevertheless, experimental validation remains essential because fermentation behaviour depends on milk composition, microbial strains, culture combinations and processing conditions.

Fermentation for Improved Functionality

Fermentation can generate or release compounds with potential biological activity, including bioactive peptides, GABA, exopolysaccharides, organic acids and certain vitamins. Lactic acid bacteria are particularly important because their metabolic activities modify milk proteins and carbohydrates.

Leroy et al. (2022) highlighted the technological and functional potential of lactic acid bacteria in dairy processing, including their ability to produce bioactive peptides, GABA, conjugated linoleic acid, exopolysaccharides and vitamins. However, biochemical activity should not automatically be interpreted as a demonstrated health benefit. Laboratory findings must be distinguished from effects confirmed in human studies. Therefore, functional claims for fermented dairy products should be supported by appropriate scientific evidence.

Future Perspectives

The future of fermented dairy technology will involve increasing precision in the selection of microorganisms, metabolites and processing conditions. Products may be developed using specific probiotic strains, postbiotic preparations, bioactive peptides, plant-derived compounds or optimized nutritional profiles.

The objective is shifting from simply producing fermented milk with viable microorganisms toward designing products around defined microbial functions, metabolite profiles, sensory characteristics and nutritional objectives. The growing interest in multi-strain cultures, metagenomics, metabolomics, postbiotics, precision fermentation and data-driven processing illustrates this transition (Taşkoparan et al., 2025).

Conclusion

Milk fermentation is undergoing a major technological transformation. Traditional fermented milks remain valuable sources of microbial diversity and cultural knowledge, while modern analytical technologies are revealing their microbial and metabolic complexity.

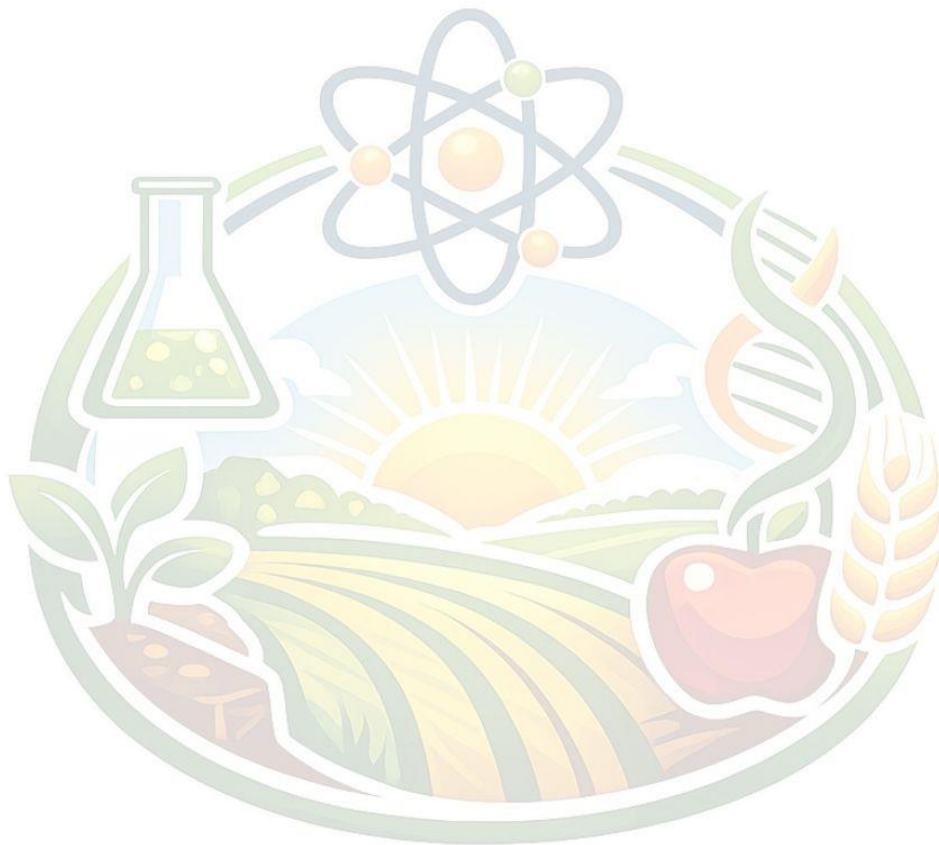
Advanced starter cultures, probiotics, multi-strain fermentation, metabolomics, metagenomics, postbiotics, natural bioactive ingredients and precision fermentation are expanding the possibilities of fermented dairy technology. Recent research demonstrates that microbial combinations can influence fermentation performance and metabolite production, while genomic approaches can identify microorganisms and functional traits that were previously difficult to characterize.

The future of milk fermentation will therefore depend on integrating traditional knowledge with modern biotechnology. The focus is moving from simple preservation toward the controlled development of fermented dairy foods with predictable quality, desirable sensory characteristics, improved functionality and appropriate safety. At the same time, food safety, regulatory requirements, consumer acceptance and evidence-based health claims must remain central to product development.

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Crop Rotation and Its Importance in Soil Health

Article ID: 74557

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Abstract

Crop rotation is a sustainable agricultural practice in which different crops are grown in a planned sequence on the same field over successive seasons. It is an important component of soil and crop management because different crops have different nutrient requirements, rooting patterns, residue characteristics and interactions with soil microorganisms. A well-designed rotation can improve soil fertility, increase soil organic matter, enhance microbial activity, improve soil structure and water infiltration, and reduce the build-up of weeds, insect pests and soil-borne diseases. Inclusion of legumes can contribute biologically fixed nitrogen and reduce dependence on external nitrogen inputs. Crop residues returned to the soil also contribute carbon and support nutrient cycling. Thus, crop rotation can improve both the biological and physical condition of soil while supporting stable crop productivity. This review discusses the concept of crop rotation, its role in maintaining soil health, major agronomic benefits, challenges to adoption and its importance in sustainable agricultural systems.

Keywords: Crop rotation, Soil health, Sustainable agriculture, Soil fertility, Nutrient cycling, Soil organic matter, Agronomy.

Introduction

Soil is a fundamental natural resource for agricultural production and provides plants with nutrients, water, air and physical support. In addition to supporting crop growth, soil performs important ecological functions such as nutrient cycling, water regulation, carbon storage and maintenance of biological diversity. However, intensive cultivation, repeated growing of the same crop, excessive tillage, imbalanced fertilizer use and inadequate residue management can gradually reduce soil quality. Continuous monocropping may accelerate the depletion of particular nutrients and can favour the accumulation of crop-specific weeds, insect pests and soil-borne pathogens. Declining soil organic matter and deterioration of soil structure can further reduce water infiltration, nutrient-use efficiency and crop productivity. Therefore, management practices that maintain soil functions while sustaining crop production are essential for long-term agricultural sustainability. Crop rotation is a planned sequence in which two or more crops are cultivated on the same field in a defined order over successive seasons or years. It differs from monocropping because crops with contrasting nutrient requirements, root architectures, residue qualities and pest associations are deliberately alternated. A suitable rotation can distribute nutrient extraction among soil layers, improve nutrient cycling and create more favourable conditions for soil biological activity. Rotations that include cereals, legumes, oilseeds and other crops can therefore provide complementary effects on soil properties and crop performance. Legumes such as chickpea, lentil, pea and mung bean are particularly valuable components of many rotations. Through symbiotic associations with nitrogen-fixing bacteria, legumes convert atmospheric nitrogen into biologically available forms, part of which can benefit subsequent crops after residues and roots decompose. Crop residues also return organic carbon to soil and can contribute to aggregation, moisture retention and microbial activity. Deep-rooted crops may improve soil porosity and explore nutrients from deeper layers, whereas crops with dense surface cover can protect soil from erosion and reduce the impact of rainfall and wind. Crop rotation is also an important cultural method of integrated weed, pest and disease management. Changing the crop environment can interrupt the life cycles of organisms associated with a particular host crop and reduce their population build-up. This can lower the need for chemical pesticides and help delay the development of resistance. Similarly, varying sowing dates, crop canopies and cultivation practices across a rotation can improve weed suppression. In the context of climate change, increasing pressure on land and water resources, and the need to produce food while conserving soil, crop rotation has renewed importance. When combined with conservation agriculture, integrated nutrient management, residue management and efficient water use, it can contribute to resilient and resource-efficient farming systems. Therefore, scientifically planned crop rotations are an important agronomic strategy for maintaining soil health, improving resource-use efficiency and supporting sustainable crop production.

Concept of Crop Rotation

Crop rotation is the practice of growing different crops on the same land in a planned and recurring sequence. The sequence is selected according to soil type, climate, crop duration, nutrient demand, root system, water requirement and local market conditions. Examples include Rice Wheat Mung Bean and Maize Mustard Chickpea. A successful rotation aims to obtain complementary benefits from successive crops rather than repeatedly exposing the soil to the same nutrient and biological pressures.

Importance of Crop Rotation in Soil Health

- 1. Improvement of Soil Fertility:** Rotating crops with different nutrient requirements helps prevent excessive depletion of particular nutrients. Legumes can add biologically fixed nitrogen to the system and may reduce the nitrogen requirement of following crops when managed properly.
- 2. Increase in Soil Organic Matter:** Roots, fallen leaves and crop residues add organic carbon to soil. Their decomposition contributes to soil organic matter, which supports aggregation, nutrient retention, moisture storage and biological activity.
- 3. Enhancement of Soil Biological Activity:** Different crops provide different root exudates and residues, creating varied habitats and food sources for microorganisms. Greater biological diversity can improve decomposition and nutrient cycling and may contribute to suppression of some soil-borne pathogens.
- 4. Improvement of Soil Structure:** Crops with different rooting depths and architectures influence soil aggregation, pore distribution and penetration resistance. Deep-rooted crops can help explore compacted layers, while residue cover protects the surface.
- 5. Nutrient Cycling and Use Efficiency:** Alternating crops with different nutrient requirements and rooting depths improves the capture and recycling of nutrients. Residues from one crop can supply nutrients to the next crop after decomposition.
- 6. Weed, Pest and Disease Management:** Changing the crop species and production environment can interrupt pest and pathogen life cycles and alter weed competition. This cultural approach can reduce dependence on pesticides when integrated with other management methods.

Erosion and Water Management

Crop residues and ground cover protect soil against raindrop impact and wind erosion. Improved aggregation and root activity can enhance infiltration and water-holding capacity.

Advantages of Crop Rotation

1. Maintains and improves soil fertility.
2. Supports soil organic matter and microbial activity.
3. Improves nutrient-use efficiency.
4. Reduces weed, pest and disease pressure.
5. Can reduce dependence on synthetic inputs.
6. Improves resilience of farming systems.
7. May stabilize or increase crop productivity over time.

Challenges and Limitations

Crop rotation requires careful planning and knowledge of crop compatibility, soil conditions, water availability and market demand. Small and fragmented holdings can limit diversification. Farmers may also prefer a single profitable crop because of established markets, machinery availability or perceived economic risk. In some situations, suitable seed, irrigation or technical guidance may be limited. Therefore, extension support, locally adapted rotation schedules, access to markets and economic incentives can encourage adoption.

Future Prospects

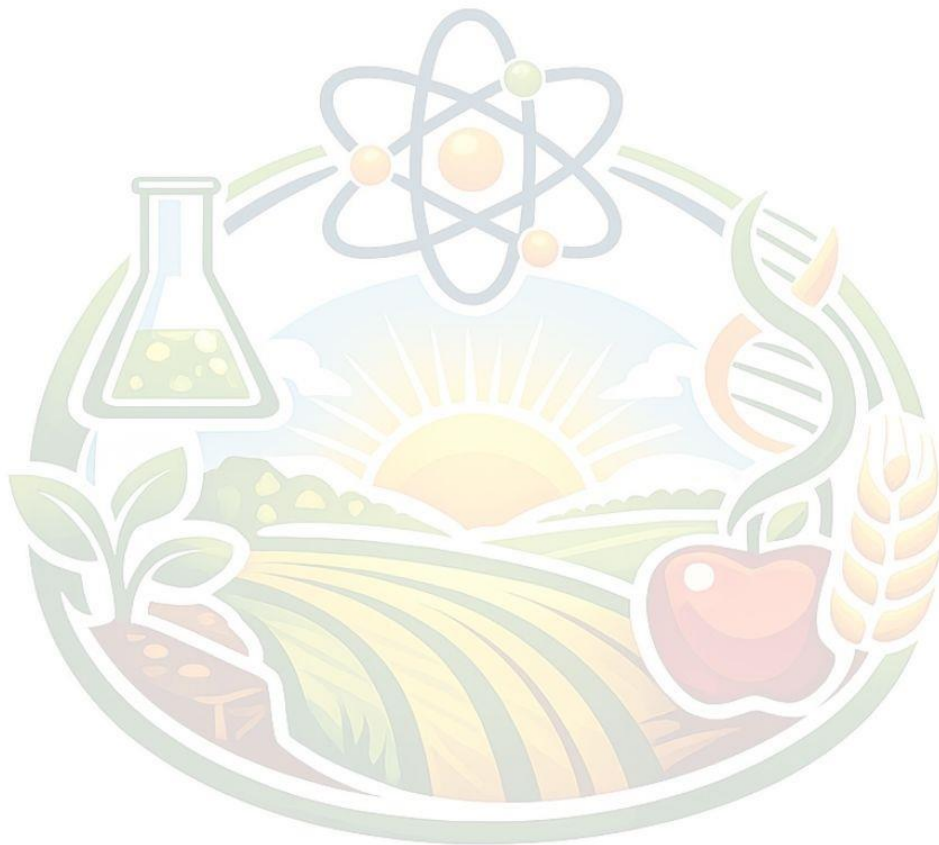
Crop rotation has strong potential as a component of climate-resilient and sustainable agriculture. Future systems can integrate legumes, cover crops, conservation tillage, precision nutrient management, residue retention and improved irrigation. Soil testing and site-specific planning can help farmers select rotations that match nutrient demand and water availability. Research on soil microbiomes, carbon sequestration and long-term rotation effects can further improve recommendations for different agro-ecological regions.

Conclusion

Crop rotation is a practical and environmentally sound agronomic practice for maintaining soil health and sustaining crop production. By alternating crops with contrasting characteristics, it can improve soil fertility, organic matter, structure, biological activity and nutrient cycling while reducing the pressure of weeds, pests and diseases. The inclusion of legumes and appropriate residue management can further strengthen these benefits. Although economic and management constraints may limit adoption, locally suitable and scientifically planned rotations can provide long-term benefits to farmers and the environment. Integrating crop rotation with other soil and crop management practices is therefore essential for sustainable agricultural production and long-term soil conservation.

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Sustainable Management and Collaborative Governance of Inland Reservoir Fisheries for Inclusive Growth

Article ID: 74558

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Abstract

Inland reservoir fisheries constitute a critical component of India's rural economy, providing food security, nutritional sustenance, and employment opportunities to thousands of local communities. Despite vast aquatic resources, optimal production in reservoir ecosystems remains constrained by open-access challenges, ecological degradation, inadequate infrastructure, and fragmented administration. This article evaluates the policy framework, ecological foundations, and governance models required to advance reservoir fisheries through co-management practices and sustainable development strategies. By transitioning from top-down regulatory frameworks toward community-centric co-management models—supported by technological interventions like cage culture and stocking management—reservoir fisheries can drive inclusive growth, climate resilience, and long-term socio-economic progress.

Introduction

India possesses extensive inland water resources, including major, medium, and small reservoirs created through river-valley projects and irrigation infrastructure. While these aquatic ecosystems are primarily planned for irrigation, power generation, and flood control, their biological potential for fish production represents a vital frontier for rural income generation.

The primary challenge in managing reservoir fisheries lies in balancing intensive exploitation with biological conservation. Historical top-down administration often led to conflicts, over-exploitation of natural stocks, and marginalization of local fishing communities. Transitioning to sustainable co-management models—where state governance partners directly with local primary fisheries cooperative societies (PFCS), community groups, and primary stakeholders—offers an equitable path toward resource conservation, stock enhancement, and sustainable development.

Theoretical Foundations of Fisheries Co-Management

Co-management represents a dynamic partnership arrangement in which government agencies, local fishers, scientific institutions, and community organizations share responsibility and authority for resource governance.

Core Components of Institutional Co-Management

- 1. Shared Decision-Making:** Fisher communities participate directly in setting seasonal mesh-size regulations, total allowable catch (TAC) limits, and fishing bans during breeding periods.
- 2. Resource Rights and Security:** Formal tenure security granted to local primary fisher cooperatives deters open-access exploitation and encourages long-term stewardship.
- 3. Conflict Resolution Mechanisms:** Structured local governance committees provide accessible avenues to resolve conflicts between primary stakeholders, migratory fishers, and commercial contractors.

Sustainable Growth Strategies for Reservoir Fisheries

Governance Domain	Traditional Practice	Management	Sustainable Model	Co-Management	Key Socio-Economic Impact
Stock Enhancement	Unplanned/Irregular fingerling stocking		Scientific stocking based on carrying capacity & limnology		Higher yields, predictable harvest cycles, optimized ecological balance
Infrastructure & Tech	Standard harvesting	open-water	Integrated cage culture, pen culture, & cold-chain access		Diversified income, reduced post-harvest losses, higher market value
Resource Rights	Auction systems to commercial middlemen		Long-term leases to Primary Fishery Cooperative Societies (PFCS)		Retention of profits within local communities, poverty alleviation
Ecological Governance	Unregulated harvesting	seasonal	Strict enforcement of breeding-season closures & mesh size rules		Protection of auto-spawning stocks and aquatic biodiversity

Key Technical Interventions

- 1. Culture-Based Capture Fisheries:** Regular, scientific stocking of fast-growing, non-invasive species (such as Indian Major Carps) matched to reservoir limnology and primary productivity levels.
- 2. Enclosure Systems (Cage and Pen Culture):** Deployment of floating cages in deep-water zones to rear advanced fingerlings and table fish without disturbing benthic habitats.
- 3. Ecosystem-Based Monitoring:** Systematic tracking of physical, biological, and chemical parameters (pH, dissolved oxygen, water level fluctuations) to prevent habitat degradation and disease outbreaks.

Policy Integration, Administrative Relevance, and Public Policy

Effective co-management requires an enabling administrative environment that intersects with public policy, rural development, and environmental conservation:

- 1. Blue Economy & Governance:** Aligning reservoir management with broader national growth frameworks (such as the *Pradhan Mantri Matsya Sampada Yojana - PMMSY*) ensures targeted funding for seed production, cold-chain infrastructure, and cooperative capacity building.
- 2. Inter-Departmental Coordination:** Synchronizing operations across Irrigation/Water Resource Departments, State Fisheries Departments, and Rural Development agencies prevents water-level drawdowns during critical fish breeding windows.
- 3. Socio-Economic Safety Nets:** Establishing institutional credit, micro-finance, insurance coverage against climate events, and safety equipment for traditional fishers.

Strategic Roadmap for Sustainable Reservoir Development

- 1. Tenure Reform and Formalization:** Streamline long-term leasing policies favoring local Primary Fishery Cooperative Societies (PFCS) with mandatory inclusion of women and marginalized groups.
- 2. Capacity Building & Institutional Training:** Provide technical training on seed nursery maintenance, feed management, post-harvest handling, and financial management through State Extension Systems and ICAR institutes.
- 3. Digital & Infrastructure Upgradation:** Implement real-time digital monitoring for water quality and catch registration while upgrading landing centers with solar-powered cold storage units.
- 4. Adaptive Eco-Governance:** Re-evaluate biological stocks every 3-5 years to adjust stocking densities and yield estimates based on changing hydrological patterns and climate variables.

Conclusion

Reservoir fisheries offer significant potential to enhance rural livelihoods, bolster protein supply, and advance the blue economy. Transitioning from legacy administrative models toward participatory co-management enables sustainable resource utilization while empowering traditional fishing communities. Integrating scientific stocking protocols, modern enclosure culture, robust institutional frameworks, and climate-resilient policies will ensure inland reservoirs serve as enduring engines for inclusive growth and sustainable development.

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Fisheries Science in the UPSC Civil Services Examination: Rationale, Scope and Policy Perspectives: A Case for Recognizing Fisheries Science as a Dedicated Academic Subject in Civil Services Education and Examination

Article ID: 74559

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Abstract

Fisheries and aquaculture are strategically important to India's food and nutritional security, employment, rural livelihoods, coastal and inland economies, exports and blue-economy development. The sector is also closely linked with biodiversity conservation, aquatic ecosystem management, climate resilience, rural development, technology, public administration and inclusive growth. Despite this broad significance, Fisheries Science is not currently offered as a dedicated optional subject in the Union Public Service Commission (UPSC) Civil Services Main Examination. The present article examines the rationale for considering Fisheries Science as a dedicated optional subject and, more broadly, for strengthening fisheries content within civil-services education and capacity building. It reviews the multidisciplinary character of Fisheries Science, its relevance to governance and public policy, the existing position of fisheries-related topics within the Civil Services Examination, possible academic scope, institutional requirements and challenges. The article argues that any consideration of a new subject should be based on transparent syllabus development, availability of qualified academic expertise, adequate question-setting and evaluation capacity, and consistency with UPSC's examination framework.

Keywords: Fisheries Science, UPSC, Civil Services Examination, aquaculture, fisheries governance, blue economy, public administration, optional subject, human resource development.

Introduction

The fisheries sector is a multidimensional component of India's economy and natural-resource governance. It includes marine and inland capture fisheries, aquaculture, ornamental fisheries, fish seed production, fish nutrition, aquatic animal health, processing, cold-chain, marketing, fisheries economics, extension and aquatic environmental management. Consequently, effective governance of fisheries requires administrative officers to understand biological resources as well as socioeconomic, technological, environmental and regulatory dimensions.

The Union Public Service Commission (UPSC) conducts the Civil Services Examination (CSE) for recruitment to services and posts of the Government of India. The examination includes General Studies papers and an optional-subject component in the Main Examination. The UPSC's current examination material lists Agriculture and Animal Husbandry & Veterinary Science among the optional subjects, but Fisheries Science is not listed as a separate optional subject.

This situation provides a basis for a policy and academic discussion: whether Fisheries Science, as a distinct multidisciplinary professional field, merits recognition as a dedicated optional subject in the Civil Services Main Examination and whether fisheries-related content should receive greater systematic attention in civil-service training.

Current Position of Fisheries in the Civil Services Examination

Fisheries-related issues can be relevant to several areas of the Civil Services syllabus, including agriculture and allied activities, environmental conservation, biodiversity, food security, rural development, science and technology, economics, disaster management and governance. However, the absence of a dedicated Fisheries Science optional means that candidates with specialized academic training in fisheries do not have an optional subject directly aligned with their professional discipline. The current UPSC examination framework demonstrates that specialized scientific and professional subjects are already accommodated as optional disciplines. The official UPSC previous-question-paper repository for 2026, for example, includes Agriculture and Animal Husbandry & Veterinary Science among the optional subjects. The proposal to consider Fisheries Science therefore needs to be examined not as a preference for one profession over another, but as a question of academic representation, administrative relevance, syllabus feasibility and examination integrity.

Why is Fisheries Science Is Important for Public Administration?

1. Food and Nutritional Security: Fish is an important source of high-quality animal protein and micronutrients. Public administrators working in agriculture, rural development, food systems and social-sector programmes benefit from understanding fisheries production, distribution, food safety and access.

2. Livelihoods and Rural Development: Millions of people participate directly or indirectly in fisheries and allied activities. Fisheries governance therefore involves livelihood support, infrastructure, market access, social protection, cooperative development and community institutions.

3. Blue Economy: Fisheries are a major component of the blue economy. Governance of marine resources increasingly requires integration of economic development with ecosystem conservation, maritime interests, coastal livelihoods and sustainable resource use.

4. Environmental Governance: Aquatic ecosystems face pressures from pollution, habitat alteration, overexploitation, invasive species, climate change and other factors. Fisheries Science provides scientific foundations for resource assessment, ecosystem management and biodiversity conservation.

5. Aquaculture Development: India's aquaculture sector involves hatcheries, nursery systems, ponds, reservoirs, cages, feed, aquatic health, processing and marketing. Administrators involved in agricultural and rural development require an understanding of these interconnected systems.

6. Climate Change and Disaster Resilience: Cyclones, floods, droughts, heat stress, changing rainfall and other climate-related risks can affect fishers, aquaculture farms and aquatic ecosystems. Fisheries knowledge can strengthen planning for adaptation, disaster preparedness and resilient livelihoods.

Multidisciplinary Nature of Fisheries Science

Fisheries Science is not limited to fish biology. It integrates multiple scientific and social disciplines, making it relevant to the broad analytical requirements of civil services.

1. Fisheries biology, taxonomy and ecology
2. Aquaculture and hatchery management
3. Fish genetics, breeding and biotechnology
4. Fish nutrition and feed technology
5. Aquatic animal health and disease management
6. Fisheries oceanography and limnology
7. Fishing technology and fisheries engineering
8. Fish processing, preservation and food safety
9. Fisheries economics and marketing
10. Fisheries extension and rural development
11. Fisheries resource management and conservation
12. Climate change, aquatic environment and sustainability

Rationale for a Dedicated Fisheries Science Optional Subject

1. Academic Recognition: Fisheries Science has developed into a specialized professional discipline with undergraduate, postgraduate and doctoral education, research institutions, universities and a specialized workforce. Recognition as an optional subject could provide a formal examination pathway for candidates trained in this field.

2. Administrative Relevance: Civil servants may work in departments and programmes concerned with agriculture, fisheries, rural development, environment, food processing, coastal development and blue economy initiatives. A structured fisheries syllabus could test knowledge directly relevant to these administrative responsibilities.

3. Balanced Representation of Allied Sectors: The present optional-subject framework includes several specialized scientific disciplines. Consideration of Fisheries Science could be examined within the broader principle of whether important professional disciplines with substantial academic infrastructure and public-policy relevance are adequately represented.

4. Strengthening Fisheries Governance: A dedicated academic subject could encourage deeper understanding of fisheries policies, resource management, aquaculture development, community institutions, technology adoption and sustainability among aspirants who choose the discipline.

Proposed Scope of a Fisheries Science Syllabus

If UPSC were to consider Fisheries Science as an optional subject, a balanced syllabus could be developed around the following broad areas:

1. Fisheries biology, biodiversity and aquatic ecology.
2. Marine and inland fisheries resources, stock assessment and sustainable management.

3. Aquaculture systems, hatchery management, seed production and farm management.
4. Fish genetics, selective breeding, biotechnology and emerging technologies.
5. Fish nutrition, feed formulation and feed management.
6. Aquatic animal health, fish pathology, biosecurity and disease prevention.
7. Fishing craft, gear technology and responsible fishing practices.
8. Fish processing, preservation, value addition, food safety and quality assurance.
9. Fisheries economics, marketing, entrepreneurship and value-chain management.
10. Fisheries extension, fisher institutions, cooperatives and livelihood development.
11. Fisheries policies, legislation, governance and institutional framework.
12. Climate change, aquatic pollution, conservation and ecosystem-based fisheries management.
13. Blue economy, marine spatial planning and emerging opportunities.
14. Case studies involving Indian fisheries and aquaculture development.

Relationship with General Studies

Recognition of Fisheries Science as an optional subject would not eliminate the need for fisheries-related issues in General Studies. Fisheries intersects with several general-policy themes and can be incorporated through current affairs, agriculture and allied sectors, environment, biodiversity, science and technology, economy, rural development and disaster management.

A dedicated optional subject and appropriate General Studies coverage would serve different purposes. General Studies could assess broad awareness and policy understanding, while an optional subject could assess deeper scientific, technical and analytical knowledge.

Potential Benefits for Civil Services and Governance

1. Improved availability of candidates with specialized fisheries knowledge for public-sector administration.
2. Greater scientific understanding of fisheries and aquaculture policy issues.
3. Improved capacity to interpret technical reports, research findings and fisheries statistics.
4. Better appreciation of the livelihood dimensions of fisheries-dependent communities.
5. Stronger understanding of aquatic environmental management and conservation.
6. Greater integration of fisheries with agriculture, rural development and blue-economy planning.
7. Encouragement of fisheries graduates to consider civil services as a career pathway.
8. Potential strengthening of interdisciplinary policymaking involving fisheries, environment, food systems and rural development.

Academic and Institutional Requirements

The introduction of any new UPSC optional subject requires careful institutional preparation. A Fisheries Science syllabus should be developed through consultation with experienced fisheries academics, researchers, administrators and subject experts.

1. Constitute an expert committee representing major fisheries disciplines.
2. Develop a comprehensive but manageable syllabus with clearly defined learning outcomes.
3. Ensure adequate academic depth while avoiding excessive specialization.
4. Establish transparent standards for question-paper setting and evaluation.
5. Prepare model question papers and examiner guidelines.
6. Ensure availability of qualified evaluators across the major sub-disciplines.
7. Review the syllabus periodically to incorporate advances in fisheries science and policy.
8. Maintain parity in examination standards, analytical demand and workload with existing optional subjects.

Challenges and Considerations

1. **Institutional Capacity:** A new optional subject requires sustained capacity for question setting, moderation, evaluation and syllabus review. Adequate availability of qualified subject experts would therefore be essential.
2. **Syllabus Breadth:** Fisheries Science covers a large number of disciplines. A syllabus that is too broad could become difficult to prepare, while excessive specialization could reduce accessibility and create an imbalance between sub-disciplines.

3. Candidate Base: The likely number of candidates choosing a new subject would need to be considered as part of the Commission's assessment. However, the size of a discipline alone should not determine its academic value; examination feasibility and administrative relevance are also important considerations.

4. Maintaining Examination Neutrality: Any new subject should be designed and evaluated according to the same principles of fairness, comparability and academic rigor applied to other optional subjects.

5. Periodic Review: Fisheries technologies and policy priorities change rapidly. Areas such as precision aquaculture, genomics, artificial intelligence, climate-resilient aquaculture and blue-economy governance may require periodic syllabus revision.

Fisheries Education and Civil-Service Capacity Building

Even if Fisheries Science is not immediately introduced as a dedicated optional subject, fisheries education can be strengthened within civil-service capacity building. Foundation and professional training programmes can provide administrators with introductory knowledge of fisheries policy, aquaculture, aquatic conservation, fisheries economics and livelihood development.

Universities, ICAR fisheries institutes, State fisheries departments and civil-service training institutions can collaborate to develop short courses, policy modules, case studies and field-based learning programmes. Such collaboration can improve the ability of administrators to translate fisheries science into effective public policy.

Way Forward

1. Undertake an academic and administrative feasibility study on Fisheries Science as a potential UPSC optional subject. Map existing fisheries content across the Civil Services syllabus and identify areas requiring stronger representation.
2. Consult ICAR institutes, fisheries universities, subject experts, administrators and professional bodies.
3. Develop a draft syllabus covering fundamental science, applied fisheries, economics, governance, environment and contemporary issues.
4. Assess the availability of qualified question setters, moderators and evaluators.
5. Prepare sample papers and conduct an academic review before any formal introduction.
6. Strengthen fisheries-related modules in civil-service foundation and in-service training regardless of the decision on an optional subject.
7. Promote interdisciplinary understanding of fisheries within agriculture, environment, rural development and blue-economy policy.

Conclusion

Fisheries Science has developed into a comprehensive professional discipline with direct relevance to food security, livelihoods, environmental conservation, aquaculture, rural development, exports and the blue economy. The current UPSC Civil Services Examination offers several specialized optional subjects, including Agriculture and Animal Husbandry & Veterinary Science, while Fisheries Science is not presently available as a separate optional subject.

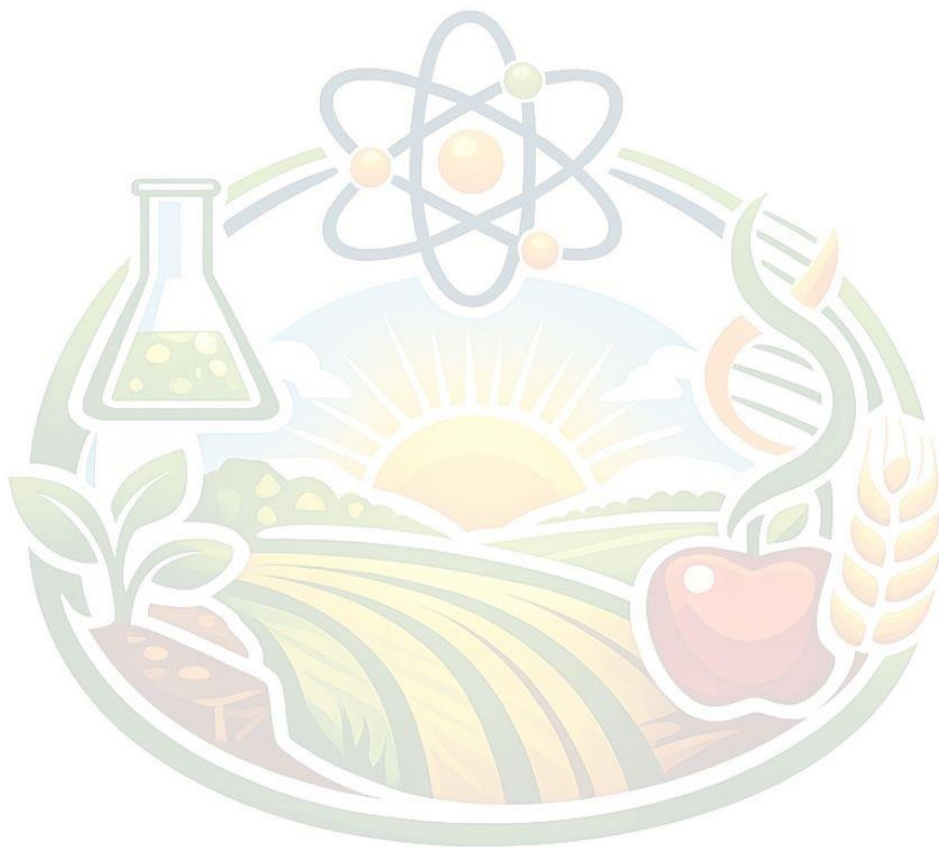
The proposal to consider Fisheries Science as a dedicated optional subject can therefore be examined on the basis of academic maturity, multidisciplinary scope, administrative relevance, availability of expertise and examination feasibility. Such consideration should be undertaken through an objective and transparent process rather than through sectoral preference alone.

Whether or not a dedicated optional subject is ultimately introduced, greater fisheries literacy among civil servants would be valuable. Strengthening fisheries content in General Studies, civil-service training and public-policy education can help administrators understand aquatic resources, fisher livelihoods, aquaculture, environmental sustainability and the emerging blue economy. A systematic interface between fisheries education and civil-service capacity building could consequently contribute to more scientifically informed and context-sensitive fisheries governance in India.

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Sona Masoori and Samba Mahsuri: The Rice on Every South Indian Plate

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Introduction

Rice is the heart of every South Indian meal: idli and dosa in the morning, rice with sambar and rasam at lunch, and curd rice at night. When a family in Hyderabad, Guntur or Bengaluru buys rice, the bag most often says **Sona Masoori** or **Samba Mahsuri**.

Many people think these are old, traditional rices. In fact, they are modern varieties bred by Indian scientists only about 40 years ago. Their story shows how good plant breeding quietly reaches every kitchen. In this article we look at where these rices came from, why everyone likes them, and how scientists are making them even better.

Where did they Come from?

The story begins with **Mahsuri**, a slender-grained rice from Malaysia. It grew well in India, and Indian breeders began using it as a parent to develop new varieties.

At the Agricultural Research Station, Bapatla (Guntur district, Andhra Pradesh), scientists crossed Mahsuri with two other varieties, GEB 24 and TN1. The best plant from this cross was released in 1986 as **BPT 5204**, which farmers and traders named **Samba Mahsuri**. A related variety, **BPT 3291**, came from a cross of Sona and Mahsuri and is sold as **Sona Mahsuri**. Fig. 1 shows how these varieties are related.

One Malaysian parent gave South India its favourite rices

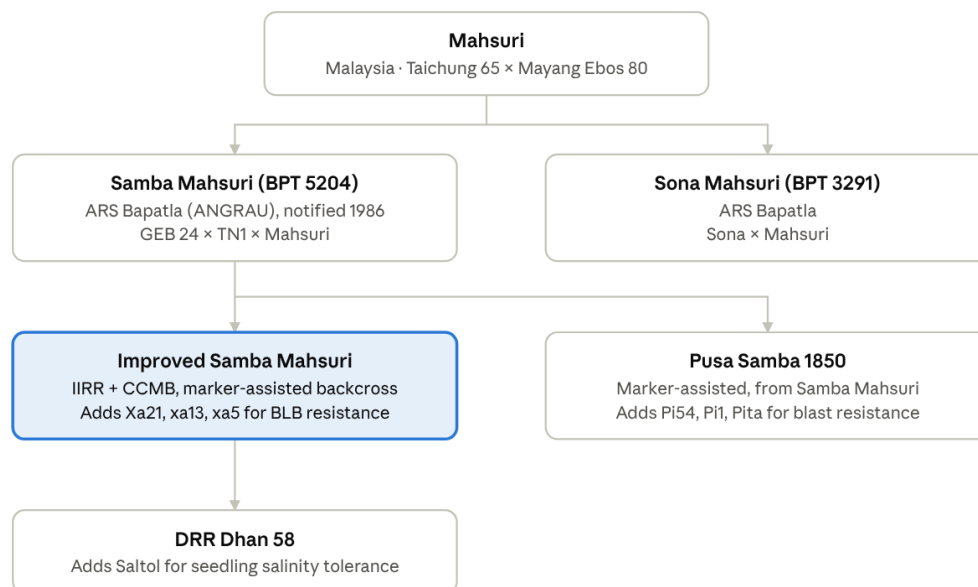


Fig. 1. Family tree of Samba Mahsuri and its improved versions

In the market, the names are often mixed up. BPT 5204 and other similar fine rices are usually sold under one common name, "Sona Masoori".

What makes the Grain Special?

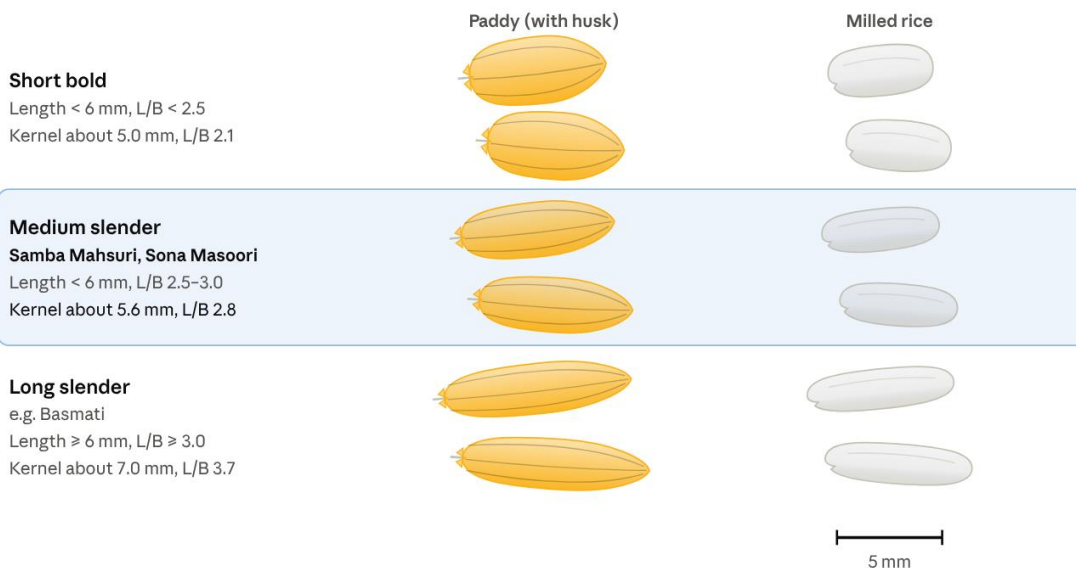
People choose rice by how it looks and how it cooks. Samba Mahsuri does well on both.

Grain shape: Rice grains are grouped by their length and by how long they are compared with their width. Samba Mahsuri grains are **medium slender**: shorter than basmati, but thin and neat (Fig. 2A). They are also clear and glassy, with very little chalky white portion. Chalky grains look dull and break easily in the mill, so fewer broken grains means better-looking rice in the bag.

Amylose content: Rice starch has a part called amylose, and the amount of amylose decides how the cooked rice feels (Fig. 2B). Samba Mahsuri has a **medium amylose content** (about 21-22%). So the cooked grains are soft, but they do not stick together.

Samba Mahsuri: medium-slender grain, intermediate amylose

A. Grain size classes (all grains drawn to the same scale)



B. Amylose content and cooking behaviour

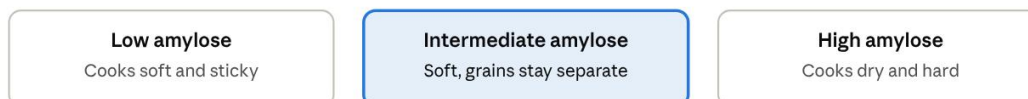


Fig. 2. (A) Grain types of rice with husk (paddy) and after milling, drawn to the same scale; (B) Effect of amylose content on the texture of cooked rice

In the kitchen: The rice cooks quickly, is light on the stomach and has a mild aroma. It suits plain rice with sambar, lemon rice, pulihora and curd rice, where each grain should stay separate. It is also used for idli and dosa batter. No wonder many families simply call it their "daily rice".

Why is Everyone Happy with it?

A variety spreads only when every person in the chain gains from it, and Samba Mahsuri pleases them all. Farmers get a good, steady yield and a better price for their paddy; millers get more whole grains; traders get a premium rice that sells well in India and abroad; and consumers get fine, soft, tasty rice at a fair price.

Because of this, Samba Mahsuri became a "**mega-variety**". It was first released for Andhra Pradesh. Today it is grown on about **15 lakh hectares** across Andhra Pradesh, Telangana, Karnataka, Tamil Nadu, Odisha, Bihar and Uttar Pradesh. Breeders like it too: it passes its good qualities to its offspring, so it is widely used as a parent for new varieties.

Its Weak Spot: Bacterial Leaf Blight

Samba Mahsuri has one big problem. It is easily attacked by **bacterial leaf blight (BLB)**, a disease caused by the bacterium *Xanthomonas oryzae* pv. *oryzae*. Farmers can spot it by these signs (Fig. 3):

1. Yellow, water-soaked streaks that start at the tip of the leaf.
2. The yellow patch spreads down along the leaf edges, with a wavy border.
3. The leaf later dries up and turns straw-coloured or grey.
4. In severe cases, young plants wilt completely (called **kresek**).

BLB starts at the leaf tip and spreads down the margins

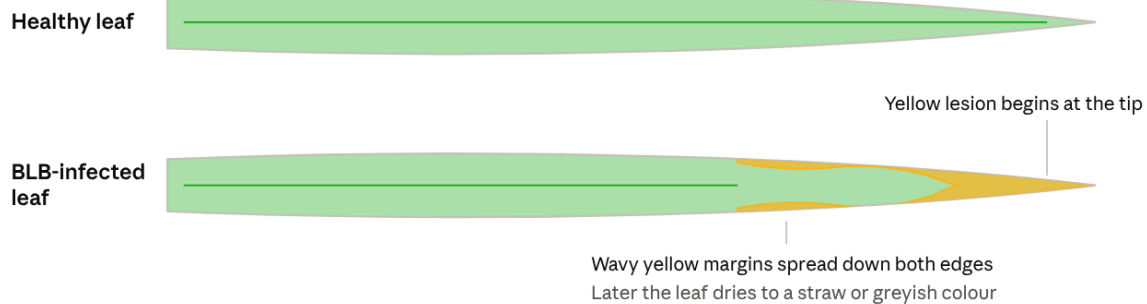


Fig. 3. Symptoms of bacterial leaf blight on a rice leaf (illustration)

The disease spreads fast after heavy rain and strong winds, and sprays do not control it well. More than **20 lakh hectares** of rice in India are prone to BLB, and fine rices like Samba Mahsuri are grown in many of these areas. Farmers badly needed a version of Samba Mahsuri that could resist this disease.

Improved Samba Mahsuri: Same Rice, Now Disease-Resistant

Scientists at two Hyderabad institutes, ICAR-Indian Institute of Rice Research (IIRR) and CSIR-Centre for Cellular and Molecular Biology (CCMB), found a smart solution. They added three BLB resistance genes, *Xa21*, *xa13* and *xa5*, into Samba Mahsuri using a method called **marker-assisted breeding** (Fig. 4). In simple steps:

1. Samba Mahsuri was crossed with a rice line that carried the three resistance genes.
2. The young plants were crossed back to Samba Mahsuri again and again, so they became more and more like the original variety.
3. In every generation, a small leaf piece was tested with **DNA markers**, which work like a genetic barcode, to pick only the plants that carried all three genes.
4. Finally, plants with all three genes and the same grain as Samba Mahsuri were selected.

Markers move three BLB genes into Samba Mahsuri

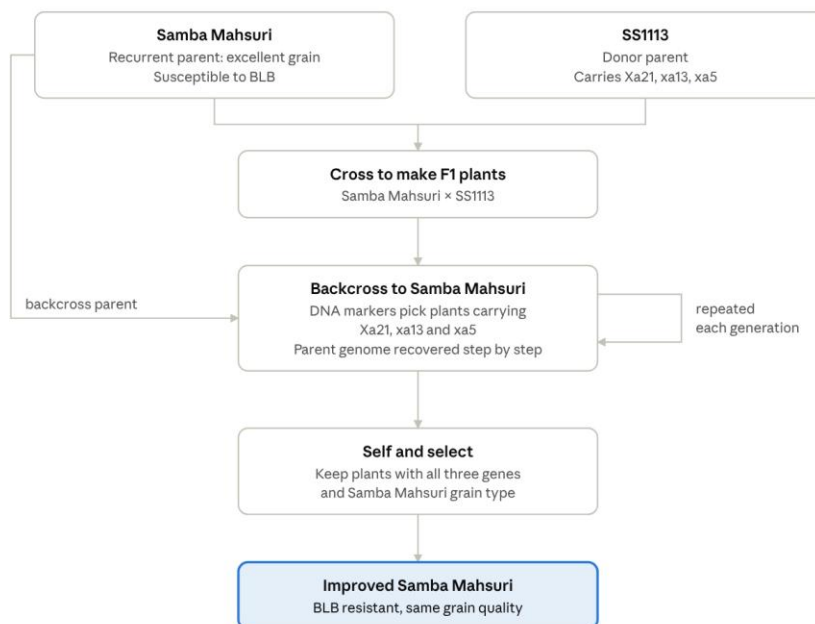


Fig. 4. Development of Improved Samba Mahsuri using DNA markers

The result was **Improved Samba Mahsuri (ISM)**, one of India's first rice varieties developed with the help of DNA markers.

Table 1. Key features of Improved Samba Mahsuri:

Feature	Details
Resistance genes	<i>Xa21</i> , <i>xa13</i> and <i>xa5</i>
Reaction to BLB	Highly resistant
Duration	135-140 days
Grain	Medium slender, same cooking quality as Samba Mahsuri
Yield potential	47-50 q/ha
Glycaemic index	About 51 (low)

Is it GM rice? No. No foreign gene was inserted. All three genes come from rice itself and were moved by normal crossing. DNA markers were used only to pick the right plants. A study by ICMR-National Institute of Nutrition, Hyderabad, found that ISM has a low glycaemic index. This means it releases sugar into the blood slowly, which makes it a better choice for people with diabetes.

The Next Generation of Samba Mahsuri

Because it is so popular, scientists keep adding new useful genes to Samba Mahsuri, one trait at a time. The grain stays the same, but the plant becomes stronger (Table 2).

Table 2. New versions of Samba Mahsuri:

Variety / line	Gene(s) added	Benefit
DRR Dhan 58	<i>Saltol</i> + three BLB genes	Grows well in salty coastal soils; about 24% more yield than ISM in such areas
Pusa Samba 1850	<i>Pi54</i> , <i>Pi1</i> and <i>Pita</i>	Resistant to blast disease
ISM with <i>Xa38</i> (research stage)	<i>Xa38</i>	Extra protection against BLB
ISM with <i>Pup1</i> (research stage)	<i>Pup1</i>	Grows better in soils low in phosphorus

The *Pup1* work is especially useful. Phosphorus fertilizers like DAP are costly, and many Indian soils are low in phosphorus. A Samba Mahsuri that needs less phosphorus would save money for farmers.

Conclusion

Sona Masoori and Samba Mahsuri rule South Indian plates because they keep everyone happy. Cooks get soft, separate, easy-to-digest grains. Millers get more whole grains, traders get a premium product, and farmers get a reliable crop with a ready market. Their one big weakness, bacterial leaf blight, has now been solved through marker-assisted breeding without changing the grain that people love. The same method is now adding tolerance to salty soils, blast and low phosphorus. The rice on our plate is the result of 40 years of Indian plant breeding, and its story is still growing.

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