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Pollinator-Dependent Vegetable Cultivation and Its Influence on Nutritional Security in Rural Communities

Article ID: 72000

Vusolla Anisha Preethi¹, M. Jahnavi², Kadiyala Prathima³

¹M.Sc. Research Scholar, Department of Food and Nutrition, College of Community Science, PJTAU, Hyderabad, Telangana--500030, India.

²M. Sc (Entomology), Scientist Entomology, Agricultural Research Station, Rekulakunta, Anantapur, Andhra Pradesh-515701, India.

³M. Sc scholar, Department of Vegetable Science, Dr. YSRHU-College of Horticulture, Anantharajupeta, Andhra Pradesh-516105. India.

Abstract

Pollinator-dependent vegetable cultivation is vital for global food security and nutrition, especially for rural agricultural communities. Pollinators like bees and butterflies boost yields and quality of nutrient-rich crops such as fruits, vegetables and spices. However, their populations are rapidly declining due to habitat loss, pesticides and climate change, threatening agricultural productivity. Protecting pollinators through sustainable farming, habitat conservation and supportive policies it is essential to maintain crop yields, improve dietary diversity and strengthen rural livelihoods. Prioritizing pollinator health helps build resilient food systems for a sustainable future.

Keywords: Pollinator-dependent crops, Vegetable Cultivation, Sustainable agriculture, Ecosystem health, Rural livelihoods.

Introduction

Agricultural sustainability and biodiversity preservation have become urgent global priorities. Climate change and declining pollinator populations threaten food security, especially since many fruit, vegetable and berry crops depend on pollinators. These crops support balanced diets and rural livelihoods, highlighting the critical link between agricultural practices, ecosystem health and nutritional security. Understanding this interplay is vital for developing resilient food systems that ensure nutritious food access amid environmental challenges.

1. The Global Decline of Pollinators and Its Implications: Pollinators, including bees, butterflies, moths and flies, are essential for 87 crop types and support over 90% of vitamin C production globally. Their populations are declining due to habitat loss, pesticide overuse, climate change and landscape fragmentation, risking a 3–8% decrease in global crop yields and threatening food security and nutrition. Understanding and protecting the spatial overlap between crops and pollinators is critical to maintaining effective pollination services.

2. Crops and Pollinator Dependency in India: India's diverse crops, including 50 out of 61 major crops, show varying reliance on pollinators, with small and marginal farmers growing nutrient-rich vegetables and seed spices that depend heavily on insect pollination. Although India produces over 7.5 million tonnes of vegetables annually, it maintains only 1.2 million bee colonies against a need for 150 million, highlighting a significant pollination deficit. The decline of pollinators due to environmental threats jeopardizes crop yields, food security, and rural livelihoods, stressing the urgent need for sustainable pollinator management and conservation strategies.

3. Importance of Pollinators: Pollinators are critical for food production, directly benefiting about 35% of global crops and supporting biodiversity and ecosystem health. They promote genetic diversity, aid crop improvement and prevent soil erosion, underpinning sustainable agriculture.

Table 1. Pollinators on which different crops depend:

S. No.	Insect pollinators	Crops
1	Honeybees	Tomato, Watermelon, Pumpkin, Squash, Coriander, lettuce, Asparagus, Okra, Onion, Peppers, Cole crops, Beans, Fennel

2	Wild bees	Tomato, Pumpkin and squash, Lettuce, cole crops
3	Bumble bees	Lima beans, Cowpes, field bean , scarlet runner bean , Okra
4	Beetles	Pumpkin, Squash, Parnish
5	Butterfly	Lettuce
6	Flies and moths	Pumpkin and squash, Onion, Lettuce, Coles, Dill
7	Drone flies	Onion
8	Thrips	Lima beans, Beet, Muskmelon
9	Ants	Muskmelon

Evolution of Food and Nutritional Security

Food security evolved as a global concern after the World Wars, shaped by international cooperation and now encompassing availability, access, utilization, stability and food preferences. It addresses complex challenges such as socioeconomic inequalities and climate change impacts. Nutritional security complements this by emphasizing adequate intake of essential nutrients and dietary diversity, with pollinator-dependent vegetables like tomatoes, brinjal and leafy greens playing a crucial role in supplying vitamins, minerals and dietary fiber to vulnerable populations.

Role of Pollinators in Food Systems and Economy: Pollinators are essential for healthy food systems by enhancing agricultural productivity, crop diversity and environmental resilience, thereby supporting global food and nutrition security. Pollinator-dependent crops also help reduce chronic disease risks, combat malnutrition and strengthen immunity. Additionally, wild pollinators economically benefit farmers by increasing yields without costly inputs, with their annual contribution valued between \$224 billion and \$577 billion, underscoring their critical role in sustainable agriculture.

Conclusion

Pollinator-dependent vegetable cultivation is fundamental for nutritional security and rural livelihoods worldwide. Despite a global decline in pollinators driven by habitat loss, pesticides and climate change, protecting pollinators through sustainable farming, habitat conservation and policies is critical. Prioritizing pollinator health ensures crop yields, improves nutrition and strengthens rural economies, fostering resilient and equitable food systems for the future.

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Production Technology of Calla Lily (*Zantedeschia spp.*)

Article ID: 72001

Aakanksha Tiwari¹, Tikam Das Vaishnav¹

¹Assistant Professor, Department of Horticulture, RNT College of Agriculture, Kapasan (Dist.- Chittorgarh), MPUAT – UDAIPUR.

Abstract

Calla lily (*Zantedeschia spp.*), a bulbous ornamental plant native to Southern Africa, is globally valued for its striking spathes, long stems, and wide utility as cut flowers, potted ornamentals, and landscaping plants. With its long vase life, symbolic significance, and growing international demand, the crop has emerged as a profitable choice for commercial floriculture. Successful cultivation requires well-drained sandy loam soils, moderate temperature (18–24°C), and balanced nutrient management with adequate irrigation. Propagation is mainly through rhizomes, although tissue culture has revolutionized large-scale production of disease-free planting material. Protected cultivation, fertigation, and integrated pest-disease management further enhance flower quality and yield. In India, its commercial potential is expanding in hilly regions such as Himachal Pradesh, Uttarakhand, and Sikkim. This review highlights the production technology, post-harvest handling, and commercial prospects of calla lily, emphasizing its role as a high-value export-oriented cut flower.

Introduction

Calla lily (*Zantedeschia spp.*), belonging to the family **Araceae**, is a bulbous perennial ornamental plant native to Southern Africa. It is popularly cultivated worldwide for its elegant spathes and long stalks that are highly valued in the cut flower industry. The name "calla" comes from the Greek word *Kallos*, meaning beauty. Although commonly referred to as lilies, calla lilies are not true lilies; they are herbaceous perennials grown from rhizomes or tubers.

Calla lily has gained popularity in **New Zealand, Netherlands, Kenya, Mexico, and USA**, which are leading producers and exporters. In India, it is gradually becoming popular in hilly states like Himachal Pradesh, Uttarakhand, Sikkim, and parts of the North-East, where the climate favors its growth.

The crop is not only significant for cut flowers but also as potted ornamentals, border plants, and for landscaping. The aesthetic appeal, combined with high market demand and good returns, makes it a promising flower crop for commercial cultivation.

Uses of *Zantedeschia*

1. Cut Flowers:

- Long vase life (7–14 days) makes it a premium export flower.
- Elegant spathes with sturdy stems are highly demanded for bouquets, floral decorations, and events.

2. Potted Plants:

- Dwarf and compact hybrids are popular for indoor decoration.
- Sold in nurseries and florist shops.

3. Landscaping:

- Suitable for bedding, borders, and water gardens.
- Its lush foliage and bright spathes provide aesthetic appeal.

4. Symbolic Uses:

- White calla lilies symbolize purity and innocence.
- Colored callas are associated with elegance, rebirth, and celebration.

5. Commercial Bulb Production: Bulbs are exported to several countries, with New Zealand leading in global trade.

Suitable Soil and Growing Media

1. **Soil type:** Well-drained sandy loam or loamy soils rich in organic matter are ideal.
2. **Drainage:** Essential to prevent rhizome rot. Raised beds improve aeration and drainage.
3. **pH:** Slightly acidic to neutral soils (pH 6.0–6.5) are preferred.
4. **Organic amendments:** Application of FYM (20–25 t/ha) or compost before planting improves soil fertility.
5. **Growing media for pots:** A mixture of peat moss, cocopeat, perlite, and well-decomposed compost in equal proportions ensures good root aeration and water retention.

Climate Conditions

1. **Temperature:**
 - a. Optimum: 18–24°C (day), 12–18°C (night).
 - b. Below 10°C → dormancy.
 - c. Above 30°C → poor flowering.
2. **Light:**
 - a. Bright indirect light or partial shade is ideal.
 - b. Dense shade → poor flowering; strong afternoon sun → leaf scorching.
3. **Humidity:** Prefers moderate to high humidity (60–80%).
4. **Rainfall:** Moderate rainfall is beneficial, but waterlogging must be avoided.
5. **Blooming Season:** Flowers appear 8–12 weeks after planting and continue for 2–3 months.

Multiplication Methods

1. **Rhizomes/Tubers (Commercial method):**
 - a. Tubers are divided into small pieces, each with at least one growing bud.
 - b. Treated with fungicides (e.g., carbendazim 0.1%) before planting.
2. **Seeds:**
 - a. Used for breeding and hybridization.
 - b. Seedlings take 2–3 years to flower, hence not practical for commercial use.
3. **Tissue Culture:**
 - a. Widely used for mass multiplication of disease-free plants.
 - b. Ensures uniformity and faster propagation.

Sowing Time and Method

1. **Planting time in India:** February–March (spring) or September–October (autumn) depending on region.
2. **Planting depth:** Rhizomes are planted 5–8 cm deep with buds facing upward.
3. **Bed preparation:** Raised beds of 1 m width are ideal for drainage.

Required Spacing

1. **Field planting:** 30 × 30 cm spacing ensures optimum plant growth.
2. **Pot planting:** 1–3 rhizomes per pot depending on pot size.
3. **Greenhouse planting:** Plants can be spaced at 25 × 25 cm for higher density.

Nutrient Management

1. **Basal dose:**
 - a. FYM: 20–25 t/ha before planting.
 - b. Fertilizers: NPK (200:150:200 kg/ha).
2. **Top dressing:**
 - a. Apply nitrogen in 2–3 split doses.

b. Foliar sprays of 0.2% urea + 0.1% potassium nitrate improve growth and flowering.

3. Micronutrients: Foliar spray of ZnSO_4 (0.5%) and MgSO_4 (0.2%) enhances flower colour and quality.

4. Precaution: Avoid excessive nitrogen which promotes leaf growth but reduces flower production.

Irrigation

1. Water requirement: Moisture-loving but not waterlogged conditions.

2. Frequency: Light irrigation at 4-to-5-day intervals depending on season.

3. Critical stages: Sprouting, flowering, and rhizome development.

4. Method: Drip irrigation with fertigation is most efficient for maintaining uniform soil moisture.

Pests and Diseases

1. Diseases:

- Bacterial soft rot (*Erwinia carotovora*)
- Botrytis blight (*Botrytis cinerea*)
- Powdery mildew
- Leaf spots
- Dasheen mosaic virus.

2. Pests: Aphids, thrips, spider mites, slugs, and beetles.

Management

1. Use disease-free planting material.

2. Crop rotation and proper drainage.

3. Fungicidal sprays (mancozeb, carbendazim).

4. Insecticides like neem oil or imidacloprid for sucking pests.

Winter and Dormancy Care

1. In frost-prone areas, rhizomes should be lifted and stored.

2. Procedure:

- Cut back foliage after yellowing.
- Lift rhizomes, clean, and treat with fungicides.
- Store in dry peat or sand at 10–15°C until replanting.

Flower Harvesting and Post-Harvest Handling

1. Stage of harvest: Half to fully open spathes.

2. Method: Cut with a sharp knife, leaving part of the stalk to encourage new shoots.

3. Post-harvest care:

- Place in clean water with preservatives (8-hydroxyquinoline citrate or sucrose solution).
- Keep at 2–4°C for prolonged vase life (7–14 days).

Conclusion

Calla lily is an aesthetically superior and commercially rewarding flower crop with vast global demand, especially in the cut flower and potted plant markets. Its successful cultivation hinges on adopting improved production practices including quality planting material, soil enrichment, fertigation, and efficient irrigation systems. Protected cultivation and tissue culture propagation provide opportunities for round-the-year, disease-free production, ensuring higher profitability for growers. With increasing domestic and international demand, calla lily cultivation holds immense potential for diversification and income generation in the floriculture sector, making it an ideal crop for progressive farmers and entrepreneurs.

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Radish Microgreens: A Simple Green with Extraordinary Health Benefits

Article ID: 72002

Jayadevi S¹, Geethanjali S², Yogasri T³

¹Project Associate, Department of Crop Physiology & Biochemistry,

²Assistant Professor (Biochemistry), Department of Crop Physiology & Biochemistry,

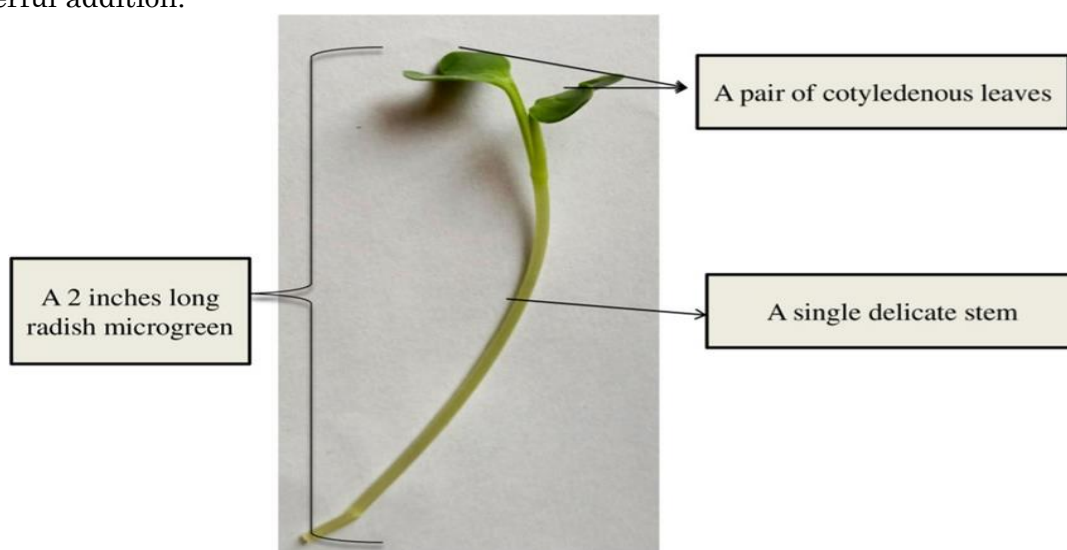
³IV BSc (Hons) Agriculture,

Anbil Dharmalingam Agricultural College and Research Institute, TNAU, Tiruchirappalli, Tamil Nadu – 27.

Introduction



Microgreens have taken the culinary world by storm, and among them, radish microgreens stand out for their bold flavour, vibrant appearance, and amazing nutritional profile. Whether you're a health enthusiast, a home cook, or someone looking to add fresh greenery to your plate, radish microgreens are a tiny yet powerful addition.



Radish microgreens are the young seedlings of radish plants, harvested 7–14 days after germination when the first true leaves appear. Unlike mature radishes, these tiny greens are delicate, tender, and full of flavour. Their stems are crisp, and the leaves carry a distinctive peppery and slightly spicy taste. They are not only aesthetically pleasing but also add texture, taste, and nutrition to a variety of dishes from salads and sandwiches to soups and smoothies.



The Nutritional Power of Radish Microgreens

Despite their small size, radish microgreens are nutrient-dense, offering concentrated amounts of vitamins, minerals, and antioxidants. Some of the key nutrients include:

Vitamin C – Boosts immunity, fights infections, and supports healthy skin.

Vitamin A – Supports vision, skin health, and immune function.

Vitamin K – Helps with bone strength and blood clotting.

Iron and Calcium – Supports energy, muscle function, and bone health.

Antioxidants – Protects cells from free radicals and reduces inflammation.

Studies suggest that microgreens can contain up to 40 times more nutrients than their fully grown counterparts, making them a superfood in miniature form.



Health Benefits of Radish Microgreens

One of the most notable benefits of radish microgreens is their high vitamin C content. This essential nutrient plays a crucial role in strengthening the immune system, helping the body fight off infections and recover faster from illnesses. Consuming radish microgreens regularly can support natural defenses, making them especially valuable during cold and flu seasons. In addition to immunity, these microgreens are excellent for digestive health. They contain dietary fiber, which promotes smooth digestion and helps maintain a healthy gut. Fiber also aids in preventing constipation and contributes to a feeling of fullness, which can be beneficial for weight management. For people who struggle with irregular digestion, incorporating radish microgreens can be an easy, natural solution. Heart health is another area where radish microgreens shine. They contain antioxidants that help neutralize harmful free radicals in the body, reducing oxidative stress that can damage blood vessels. Additionally, their potassium content helps regulate blood pressure, supporting healthy cardiovascular function. Regular consumption may contribute

to a lower risk of heart-related issues over time. Bone strength and overall skeletal health can also benefit from radish microgreens. They are rich in vitamin K and calcium, both essential nutrients for maintaining strong bones. Including these microgreens in your diet can help prevent bone density loss and support healthy growth, making them a good choice for people of all ages. Weight management is made easier with radish microgreens due to their low-calorie yet nutrient-dense nature. They provide essential vitamins and minerals without adding excess calories, making them ideal for healthy diets. Snacking on radish microgreens, adding them to salads, or blending them into smoothies are easy ways to enjoy their benefits without feeling like you're dieting. Beyond these, radish microgreens have natural detoxifying properties. Compounds in these tiny greens can help the liver and kidneys flush out toxins from the body, supporting overall health. Their antioxidants also promote healthy skin by slowing signs of aging and protecting cells from damage. Furthermore, these microgreens support good vision, thanks to the combination of vitamin C and other phytonutrients. Radish microgreens also possess anti-inflammatory properties. Bioactive compounds in the greens can help reduce inflammation in the body, which is linked to many chronic diseases. Including them regularly in meals may support overall wellness and contribute to long-term health benefits. Incorporating radish microgreens into your diet is simple and versatile. They can be sprinkled on sandwiches, added to salads, blended into smoothies, or used as a garnish for soups and main dishes. With their mild peppery flavour, they add both taste and nutrition, making healthy eating enjoyable. Overall, radish microgreens are a tiny yet mighty addition to any diet. Their impressive nutritional profile supports immunity, digestion, heart health, bone strength, weight management, detoxification, skin and eye health, and helps combat inflammation. Adding these greens to daily meals is a small change that can make a significant difference in maintaining overall wellness and vitality.

Radish Microgreen Nutritional Value Chart Based on 100-grams

Vitamin A - 8%	Manganese - 13%	Iron - 5%
Vitamin B Complex - 6 to 24%	Magnesium - 11%	Zinc - 4%
Vitamin C - 48%	Phosphorus - 11%	Copper - 6%
Vitamin E - 25%	Calcium - 5%	Potassium - 2%
		Selenium - 1%

How to Grow Radish Microgreens at Home?

Growing radish microgreens is simple, fun, and satisfying. Here's a step-by-step guide:

1. Choose the Right Seeds use high-quality radish seeds and soak the seeds 4-6 hours to speed up germination.
2. Prepare the Tray – Fill a shallow tray with soil or a hydroponic growing mat.



4. Spread Seeds Evenly – Ensure seeds are close but not overlapping.
5. Water and Maintain Moisture – Mist the tray daily to keep soil damp.
6. Provide Light – Place near a sunny window or under LED grow lights.



7. Harvest in 7–14 Days – Snip microgreens just above the soil once the first true leaves appear.



Ways to Use Radish Microgreens

Radish microgreens are tiny, young seedlings harvested just after the first leaves appear, yet they are packed with a punch of flavour and nutrients. Their sharp, peppery taste makes them a delightful addition to a wide range of dishes. One of the most popular ways to enjoy radish microgreens is by adding them to salads. They pair beautifully with other leafy greens like spinach, arugula, or lettuce, creating a vibrant mix of textures and flavours. The peppery bite of the microgreens contrasts with the mildness of other greens, making each bite refreshing and lively. They can also be combined with fresh vegetables such as cucumbers, tomatoes, and bell peppers, or topped with nuts and seeds for added crunch. A light dressing of olive oil, lemon juice, or balsamic vinegar further enhances the natural flavours of the microgreens while keeping the salad healthy and wholesome. Radish microgreens also bring a delightful crunch to sandwiches and wraps. Placing a layer of microgreens over hummus, avocado, or deli meats adds both taste and a pleasing texture. Unlike mature radish, which can be quite pungent, microgreens offer a milder, yet distinct peppery flavour that complements sandwiches without overpowering other ingredients. They work particularly well in wraps with roasted vegetables, grilled chicken, or soft cheeses. Using microgreens instead of lettuce can elevate the presentation and flavour of a simple sandwich, turning an everyday meal into something gourmet. Their bright green colour adds visual appeal, making meals not just tasty but also visually inviting. Another way to incorporate radish microgreens is through smoothies. While it may sound unusual, adding a small handful of these greens to fruit or vegetable smoothies can significantly boost nutritional value without drastically changing the taste. Radish microgreens are rich in vitamins A, C, E, and K, as well as minerals like calcium, iron, and potassium. When blended with fruits like bananas, apples, or berries, or vegetables such as carrots and beets, they create a nutrient-dense drink that supports immunity and overall health. Smoothies with microgreens can serve as a great breakfast option or a post-workout replenishment drink. Their subtle peppery flavour can also balance the sweetness of fruits, creating a more complex and satisfying taste. Garnishing is another simple yet effective way to use radish microgreens. Sprinkling them over soups, pizzas, or omelets just before serving adds a fresh, crunchy element and a burst of flavour. For instance, a creamy tomato soup or a cheesy pizza can become more vibrant and flavourful with a handful of microgreens on top. Omelets, scrambled eggs, and frittatas benefit from their bright green colour and crisp texture, which adds a refreshing contrast to warm, cooked dishes. Even roasted vegetables or grain bowls can be elevated with microgreens as a finishing touch, making meals look more appealing while adding nutritional value. Finally, radish microgreens can be used in

juices. Combining them with carrot, beet, or apple juice creates a nutrient-packed beverage that supports detoxification and energy levels. While their peppery flavour is noticeable, it blends well with the sweetness of fruits or the earthiness of root vegetables. This combination not only enhances the taste but also increases the intake of antioxidants, vitamins, and minerals in a convenient form. Juicing radish microgreens is an easy way to incorporate their health benefits into daily life, especially for those who may not enjoy eating raw greens directly. Incorporating radish microgreens into everyday meals is simple and rewarding. From fresh salads to hearty sandwiches, vibrant smoothies, decorative garnishes, and nutrient-rich juices, these tiny greens provide both flavour and a powerful nutritional boost. Their versatility allows them to be enjoyed in a variety of culinary contexts, making them an ideal choice for anyone looking to improve both the taste and healthfulness of their meals. By experimenting with different combinations and serving styles, radish microgreens can become a staple ingredient that transforms ordinary dishes into nutritious and flavourful delights.

1. Peppery Radish Microgreen Salad: Mix radish microgreens with cherry tomatoes, cucumber, and feta cheese drizzle with olive oil, lemon juice, salt, and pepper.



2. Radish microgreen Smoothie Boost:

- a. Blend radish microgreens with banana, apple, and a splash of almond milk.
- b. Optional: add a teaspoon of chia seeds for extra fiber.



3. Radish microgreen Sandwich: Add radish microgreens to avocado toast or turkey sandwiches the peppery crunch elevates simple meals to gourmet levels.



Conclusion

Radish microgreens may be small in size, but they are mighty in flavour, nutrition, and health benefits. Easy to grow at home, versatile in the kitchen, and packed with nutrients, they are rapidly becoming a favourite for health-conscious individuals and food lovers alike. Whether you want to boost your immunity, add colour to your plate, or explore new flavours, radish microgreens are a superfood you can grow and enjoy every day.

Evaluation of Sugarcane Leaf Detrasher Cum Shredder's Performance

Article ID: 72003

Dr. Sreedevi, M. S.¹

¹Principal Investigator, AICRP(FIM), ZARS, V.C. Farm, Mandya, UAS, Bangalore.

Introduction

The sugarcane industry is a significant contributor to the agricultural economy of Mandya, Karnataka, with the region being one of the major sugarcane-producing districts in the state. Sugarcane cultivation in Mandya relies heavily on proper crop management practices, including leaf detrasher and shredder operations, to ensure optimal yields. Traditionally, these operations have been performed manually or using conventional methods, which can be time-consuming and labor-intensive. However, with the increasing demand for agricultural mechanization and the need for efficient and cost-effective tools, there is a growing interest in evaluating the performance of tractor-operated sugarcane leaf detrasher cum shredder. This study aims to assess the performance of this innovative technology in sugarcane cultivation, focusing on its efficiency, productivity, and potential benefits for farmers in Mandya and beyond.

Objectives

The objectives of this study are to evaluate tractor-operated sugarcane leaf shredder developed by MPKV, its feasibility and performance through trials conducted at research stations and farmers' fields and conduct a cost-benefit analysis to determine its economic viability. By achieving these objectives, the study aims to assess the effectiveness and potential benefits of using the shredder in sugarcane cultivation.

Treatment Details

The experiment consisted of two treatments: T1 (farmer's traditional trash removal method) and T2 (Phule leaf detrasher cum shredder technology).

In T1, the farmer's traditional trash removal method, sugarcane trash is manually removed and managed by farmers using conventional practices. This method typically involves manual labor to cut, collect, and dispose of or utilize the trash, often requiring significant time and effort. While this approach is widely used, it can be labor-intensive and may not be as efficient as mechanized methods, potentially impacting farm productivity and costs.

In T2, the Phule leaf detrasher cum shredder is utilized for trash removal, offering a mechanized solution for sugarcane farmers. This tractor-operated machine efficiently removes and shreds sugarcane leaves, reducing manual labor requirements and potentially increasing farm productivity. By adopting this technology, farmers can benefit from improved efficiency, reduced labor costs, and enhanced crop management, ultimately contributing to more sustainable and profitable sugarcane cultivation practices.

Results

A tractor-operated sugarcane leaf shredder, procured from MPKV Rahuri, was put to the test in research plots at ZARS, V.C. Farm, Mandya. The study documented the device's specifications and assessed its practicality in real-world settings. Its performance was benchmarked against the traditional manual detrashing and shredding method, allowing for a thorough evaluation of its effectiveness and potential benefits for sugarcane farmers.

The sugarcane leaf detrasher cum shredder developed by Mahatma Phule Krishi Vidyapeeth (MPKV) Rahuri is an important innovation in agricultural technology. The detrasher cum shredder reduces labor requirements and saves time in sugarcane cultivation, making the process more efficient. By removing unwanted leaves, the machine promotes healthy growth and increases sugarcane yields. The machine minimizes manual labor, resulting in lower operational costs for farmers. The detrasher cum shredder promotes eco-friendly farming practices by efficiently managing crop residues and reducing waste. The

machine is designed for easy operation and handling, making it accessible to farmers with minimal training. It can be used with various sugarcane varieties and is compatible with mini tractors, making it a versatile tool for farmers.

The following specifications and performance data of the Phule leaf detrasher cum shredder were recorded at the research station:

Table 1: Technical specifications of Phule leaf detrasher cum shredder:

S.N.	Particulars	Specifications
1	Overall dimensions Length x Width x Height (mm)	1094 x 900 x 1770
2	Mass, kg	197
3	Cost, Rs.	125000
4	Make of machine	MPKV, Rahuri
5	Address of supplier: AICRP on Farm Implements and Machinery, Dr. A. S. College of Agril. Engg. & Tech., Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar- Pin - 413 722 (M.S.)	

Table 2: Comparative performance evaluation of Phule leaf detrasher cum shredder:

S.N.	Particulars	T1	T2
1.	Type of soil	Red sandy loam	
2.	Crop and Variety	Sugarcane (CoVc 18061)	
3.	Age of crop	10-12 months	
4.	Row to row spacing, mm	1220	
5.	Time required for one ha, h	8.00	3.30
6.	Theoretical Field capacity, ha/h	0.10	0.35
7.	Field efficiency, %	75.25	81.72
8.	Average length of sugarcane leaves before shredding	148	148
9.	Average length of sugarcane leaves after shredding	28.13	22.67
10.	Fuel consumption, l/h	-	3.50
11.	Operational cost, Rs/ha	10500	1800

Plate 1: Tractor operated sugarcane leaf detrasher cum shredder during field operation:



Plate 2: Sugarcane field before and after operation with sugarcane leaf detrasher cum shredder:



Inference

The sugarcane leaf detrasher cum shredder is a game-changing machine that efficiently removes leaves and trash from sugarcane while shredding them into smaller pieces. By automating the labor-intensive process of manual detrashing and shredding, this machine significantly reduces labor costs and boosts productivity. Key performance highlights (Table 2) include an effective field capacity of 0.31 hectares per hour and a field efficiency of 81.72%. Notably, the machine yields substantial cost savings of Rs. 8700 per hectare, representing an impressive 82.85% reduction compared to traditional methods. Its benefits extend beyond cost savings, offering farmers significant time savings and relief from skin irritation and rashes associated with manual harvesting without detrashing.

The prototype feasibility testing of the sugarcane leaf shredder, conducted at a research station (Plate 1 & 2), involved a total of 2634 farmers, comprising 1215 males and 1419 females. The trial covered a cumulative area of 9.30 hectares over 33 hours, with varying plot sizes and trial durations across different groups of farmers. The trial's extensive scope and diverse participation provided valuable insights into the effectiveness and usability of the sugarcane leaf shredder in real-world settings.

The sugarcane leaf detrasher cum shredder boasts several key features that make it an essential tool for sugarcane farmers and processors. It efficiently removes leaves and trash from sugarcane, while also shredding the leaves into smaller pieces for easy management and utilization. This results in reduced labor costs and increased productivity. Furthermore, the machine is specifically designed to cater to the needs of sugarcane farmers and processors. The benefits of using the sugarcane leaf detrasher cum shredder are numerous. By removing trash and leaves, it improves the overall quality of the sugarcane. Additionally, the machine reduces labor costs and increases efficiency, providing an eco-friendly solution for managing sugarcane leaves and trash. Ultimately, it enhances the overall productivity of sugarcane processing operations.

"Embracing innovative tools like the sugarcane leaf detrasher cum shredder can pave the way for a bountiful harvest, maximizing yields and minimizing efforts"

From Fireflies to Flying Robots: How Insects Inspire the Tech of Tomorrow

Article ID: 72004

Repaka Harika¹, Kota Sahithi Chowdary¹, Gopu Sushma²

¹Ph. D Scholar, Indira Gandhi Krishi Vishwavidyalaya, Raipur.

²Ph. D Scholar, Professor Jayashankar Telangana Agricultural University.

Abstract

Insects are more than small creatures—they are nature’s master engineers. From the flight of dragonflies to the glow of fireflies, their unique adaptations are inspiring groundbreaking technologies. Recent advances include Harvard’s RoboBee with crane-fly-inspired landing legs, insect-scale robots from Washington State University, firefly-based biosensors for medical research, and LED innovations modelled on insect cuticles. This article explores how insects are shaping robotics, medicine, and energy technology while raising important ethical questions about biomimicry and conservation.

Introduction

From the delicate wings of a dragonfly to the dazzling glow of a firefly, insects are masters of survival and innovation. They make up more than 80% of all known animal species and have adapted to every imaginable environment on Earth—soaring through the air, gliding across water, tunnelling underground, and even thriving in deserts and ice fields. Today, scientists and engineers are increasingly turning to these tiny creatures for inspiration. The field of biomimicry—designing technology by copying solutions from nature—has given rise to remarkable insect-inspired advances: miniature robots that fly like bees, sensors that glow like fireflies, and energy-efficient lighting modelled on insect eyes and cuticles. Unlike human inventions, which often rely on brute force or large energy inputs, insect designs demonstrate how to achieve maximum performance with minimal resources. In a time when humanity faces urgent challenges—climate change, food security, sustainable energy, and medical innovation—insects are proving to be unlikely but invaluable teachers. By studying their biology, we are not only uncovering new ways to solve problems but also reshaping the future of robotics, medicine, and technology.

A World Designed by Six Legs

On a warm evening, a firefly flickers in the dark. To most of us, it’s a fleeting moment of beauty. To scientists and engineers, it’s something more profound—a flash of innovation millions of years in the making. Insects have thrived on Earth for over 400 million years, outlasting dinosaurs and surviving every mass extinction. They can fly, burrow, swim, glow, and even navigate using the planet’s magnetic field. For engineers, these abilities are gold mines of inspiration.

“Insects are master engineers,” says Dr. Robert Wood, who leads Harvard’s RoboBee project. “They solve problems of flight, vision, and survival with astonishing efficiency. Our job is to learn from them.” This philosophy—biomimicry—is not new. Humans have copied nature for centuries, from bird-inspired flight to the invention of Velcro based on burrs. But the 21st century is different: our tools now allow us to shrink technology down to insect scales, where biology and robotics begin to overlap. And the results are breathtaking.

Landing on Six Tiny Legs: RoboBees Take Flight

Harvard’s RoboBee is one of the most famous examples of insect-inspired robotics. Weighing less than a paperclip and with wings that beat 120 times per second, RoboBee mimics the aerodynamic agility of real bees. Since its first flight in 2013, it has been a testbed for breakthroughs in tiny batteries, sensors, and artificial muscles. But one problem remained: landing. RoboBees often crashed after flights, damaging their delicate wings. In 2025, engineers unveiled a solution—a set of crane-fly-inspired legs that act like springy shock absorbers. These allow the robot to slow down and land gently, even on rough surfaces. “This small

adjustment makes a big difference,” says Dr. Xiufeng Yang, part of the RoboBee team. “It takes RoboBee closer to real-world applications.”

Applications:

- Imagine swarms of RoboBees helping to pollinate crops in regions where natural pollinators are declining.
- Picture them deployed in search-and-rescue missions, entering collapsed buildings too dangerous for humans.
- In controlled environments like vertical farms, they could even act as autonomous crop caretakers.

Micromachines Lighter than a Feather

Meanwhile, on the other side of the U.S., a team at Washington State University is pushing insect-inspired robotics even further. In 2024, they announced the creation of insect-scale robots weighing as little as 5 milligrams—roughly the weight of a grain of rice.



These robots, nicknamed MiniBug and WaterStrider, don’t rely on motors. Instead, they use shape-memory alloys (SMAs)—special metals that change shape when heated. These tiny actuators bend and snap back like insect muscles, allowing the bots to flap their legs up to 40 times per second. Even more impressive, the bots can lift over 150 times their body weight. To put that in perspective, it would be like a human lifting 10 cars. Currently, their top speed is only about 6 millimeters per second. But researchers believe future versions could crawl through rubble after earthquakes, carry miniature sensors to monitor environmental pollutants, or even swim through the bloodstream to deliver drugs.

Fireflies as Biomedical Tools

Not all insect-inspired technology flies or crawls. Some of it glows. Fireflies light up using a chemical reaction between luciferin and luciferase, enzymes in their lantern-like abdomens. Scientists have long used this glow in labs, but in 2025, researchers in Brazil made it even more powerful. They engineered a pH-sensitive luciferase that changes color depending on acidity. In mammalian cells, the enzyme glows bluish-green in neutral conditions but shifts to yellow or red as acidity increases. This provides a non-toxic, real-time way to monitor cellular environments.

Importance: Changes in pH are linked to diseases like cancer, where tumor cells create acidic microenvironments. By watching the glow, doctors could one day detect disease earlier or test how new drugs affect cells without invasive procedures.

Lighting the Future with Insect Designs

Insects don’t just inspire medical tools—they’re shaping how we light our homes and devices. Firefly cuticles are covered with microscopic “factory-roof” nanostructures that help their light shine more efficiently. Engineers mimicked this pattern to design LED lenses that achieve up to 98.3% light transmittance, far higher than traditional smooth surfaces. The same principle has been applied to OLEDs, making them ~60% brighter for the same energy. In a world where lighting accounts for about 15% of global electricity use, that’s a big deal. Even moths have contributed: the anti-reflective coatings on their eyes are now used in solar panels to reduce light loss. Once again, insects are guiding us toward a greener future.

Space, Surveillance, and Beyond

Insect-inspired technologies aren't limited to Earth. NASA has studied how desert ants and dung beetles use polarized light and magnetic fields for navigation—knowledge now applied to spacecraft orientation systems. Fruit flies have traveled aboard the International Space Station to help scientists understand how microgravity affects biology.

Back on Earth, insect-inspired cameras—based on the compound eyes of dragonflies and mantises—are improving surveillance systems, medical imaging, and even the sensors in self-driving cars. These cameras can capture wide fields of view with minimal distortion, something no traditional lens can do as efficiently.

Ethics: Should We Copy or Conserve?

For all their promise, insect-inspired technologies raise ethical questions. Should humanity invest in robotic bees while wild pollinator populations collapse due to pesticides and habitat loss? Could medical microbots raise privacy concerns if hacked or misused? Dr. Wood puts it bluntly: “If we admire insects enough to copy them, we should also protect their habitats.” Biomimicry, in other words, must go hand in hand with conservation. Otherwise, we risk creating high-tech imitations while allowing the originals to vanish.

Conclusion

Insects, with their compound eyes, lightweight wings, and chemical flashes, are more than evolutionary survivors—they are innovators by design. From safer robotic landings to microscopic medical sensors and energy-efficient lighting, their influence is already reshaping robotics, medicine, and sustainability. Yet, perhaps their greatest lesson is balance. Insects have survived for hundreds of millions of years by adapting to their environments without destroying them. If we want our insect-inspired technologies to truly succeed, we must follow that example—innovating while conserving. The next time you pause to watch a dragonfly hover or a firefly glow, remember: you may be looking at the prototype for tomorrow's most important invention.

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From Bee Stings to Maggot Medicine: “Insects as Tiny Doctors”

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Sahana S¹

¹M.Sc. (Agri) Entomology, Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore – 641003.

Introduction: When Insects Become Healers

Insects are among the most diverse and abundant creatures on Earth, with over 1 million described species and many more awaiting discoveries. However, there is a vast array of medical potential concealed behind their small bodies. Insects have long been utilized in traditional medical procedures in many cultures. Two of them **maggot therapy** (also known as maggot debridement therapy, or MDT) and **bee venom therapy (apitherapy)** stand out for their demonstrated efficacy. Both may show how insects can act as unanticipated "tiny doctors."

Bee Venom Therapy (Apitherapy): Healing Through a Sting

Historical Roots of Bee Venom in Medicine: The use of honeybees (*Apis mellifera*) in medicine dates back thousands of years. Bee stings are mentioned in ancient Egyptian papyri as a treatment for inflammation and arthritis. Galen documented the anti-inflammatory properties of bee stings, while Hippocrates, the Greek physician, recommended them for arthritis. The belief in the healing sting was strengthened by the observation made by beekeepers in many cultures that, despite frequent stings, they seldom experienced rheumatism or arthritis.

Composition of Bee Venom

Bee venom is a transparent, bitter liquid secreted by worker bees. Its medical value lies in its **rich chemical complexity**. Major components include:

1. **Melittin (40–60%):** A tiny peptide with strong **anti-inflammatory**, **anti-microbial**, and even **anti-cancer** effects. It alters immunological responses and damages microbial membranes.
2. **Apamin (2–3%):** A neurotoxin that enhances nerve conduction by blocking calcium-activated potassium channel.
3. **Adolapin (1–2%):** Reduces pain and inflammation by blocking cyclooxygenase.
4. **Phospholipase A2 (PLA2, 10–12%):** Promotes melittin activity and sets off immune system reactions.
5. **Histamine, Dopamine, and Enzymes:** Involve vascular effects and inflammation, regulates immune cell activity.

Mechanism of Action

1. Reduces **pro-inflammatory cytokines** (IL-1, TNF- α).
2. Increases **cortisol release**, mimicking natural anti-inflammatory pathways.
3. Stimulates nerve regeneration and blood circulation.
4. Exhibits direct antibacterial and antiviral activity.

Medical Applications

1. **Rheumatism and Arthritis:** Rheumatoid arthritis patients who received bee venom acupuncture reported less pain and swelling; melittin and adolapin work together to reduce chronic joint inflammation.
2. **Neurological Conditions (Parkinson's, Multiple Sclerosis):** Bee venom protects neurons in animal models. Patients with multiple sclerosis (MS) who participated in small trials reported feeling less tired and having stronger muscles.

3. Applications in Dermatology: Research indicates that bee venom lowers bacterial counts of *Propionibacterium acnes*, a major acne-causing bacterium; bee venom-based creams are marketed for psoriasis, eczema, acne, and anti-aging.

4. Potential Antimicrobial and Anticancer Effects: Research on cancer treatment indicates that melittin can specifically destroy tumour cell membranes without endangering healthy cells. It also exhibits broad-spectrum antibacterial activity.

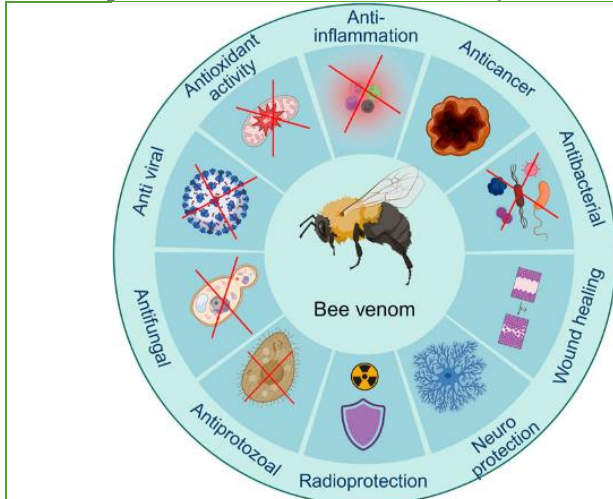


Fig.1 Biological activities of bee venom



Fig.2 Venom therapy

Risks and Controversies

- 1. Anaphylaxis:** Serious allergic reactions can occur in certain patients.
- 2. Lack of Standardization:** Preparations and dosages differ greatly.
- 3. Mixed Clinical Results:** Although encouraging, a lot of research is still in its early stages. Thus, apitherapy remains complementary rather than mainstream medicine.

Maggot Therapy (MDT): Healing Through Larvae

Historical Background:

- In world war II military of north Burma observed the therapeutic application of the fly larvae by the local population. More than 300 US American hospitals introduced maggots into their programme of wound healing between 1930 and 1940.
- The American Surgeon Forney Zacharias (1837-1901) officially documents their use during the American Civil War (1861 - 1865)
- In 1929, American orthopedic surgeon Dr. William Baer introduced sterilized maggots for treating osteomyelitis (bone infections). His work laid the foundation for modern Maggot Debridement Therapy (MDT).

Larva used in Maggot Therapy:

- Lucilia sericata* (common green bottle fly)
- Phormia regina* (black blow fly).

Why Maggots Work: The Science Behind MDT Mechanism

1. Selective Debridement:

- Maggots secrete enzymes (collagenase, serine proteases) that liquefy dead tissue.
- They feed only on necrotic tissue, sparing healthy skin.

2. Antimicrobial Action:

- Maggot secretions contain **allantoin, urea, calcium carbonate**, and antimicrobial peptides.
- Effective against resistant bacteria (*Staphylococcus aureus*, *Pseudomonas aeruginosa*).

3. Stimulation of Wound Healing: Maggot excretions increase blood supply, stimulate fibroblast growth, and promote tissue granulation.


Fig.3 Wound healing

Fig.4 Medical maggots

Clinical Applications of Maggot Treatment

Diabetic Foot Ulcers: Globally, diabetic ulcers are a leading cause of amputation. By eliminating dead tissue, eliminating bacteria, and promoting the growth of new tissue, maggot therapy heals these wounds nearly twice as quickly as traditional techniques. It can keep many patients from losing limbs.

Chronic Venous Ulcers and Bedsores: These ulcers, which are common in bedridden or elderly patients, heal slowly because of poor circulation. Maggots frequently succeed where antibiotics fail by cleaning the wound bed, reducing infection, and promoting granulation tissue.

Post-Surgical Infections and Burns: Maggots function as "microsurgeons" carefully removing necrotic tissue and inhibiting resistant bacteria from surgical wounds that are left unhealed or infected. This is particularly helpful for patients who are too weak for additional surgery.

Advantages of Maggot Therapy

- 1. Effective mode:** Necrotic tissue is successfully removed by the scratching and poking action of the "mouth hooks" of the maggots.
- 2. Safe:** The larvae are prepared in a sterile manner, so no side effects are observed
- 3. Easy to apply:** No need for a surgeon to apply the maggots and the dressings so that these can be done at home by a therapist.
- 4. Affordable:** Less expensive than surgical debridement or completely a cycle or more of antibiotics and wound dressings.
- 5. Faster wound healing:** With the removal of dead tissue, infection is prevented, and the wound is allowed to produce new tissues with improved circulation.

Challenges and Limitations

- 1. Fear of pain:** Pain during treatment may be felt if the patient has been experiencing pain prior to it. However, this may be given appropriate remedy with suitable pain medications. The pain may be due to the crawling, scratching and poking of the maggots.
- 2. Maggots are perishable:** Larva have to be used within 24 hours of delivery.

Broader Implications

- 1. Antibiotic Resistance and Insects as Solutions:** With the rise of superbugs, insect-based compounds (melittin, maggot peptides) offer new classes of antimicrobials.

2. Sustainable Medicine: Insects are abundant, inexpensive to rear, and eco-friendly making them promise in low-resource healthcare.

3. Public Perception and Acceptance: For these therapies to be widely adopted, educational efforts are needed to overcome fear and stigma.

Conclusion

From the sting of a honeybee to the crawl of a maggot, insects once dismissed as pests are proving to be valuable allies in medicine. Bee venom therapy offers potential solutions for arthritis, neurological disorders, and drug-resistant infections, while maggot therapy provides a life-saving option for chronic wounds and diabetic ulcers. These examples show that insects are not only essential to ecosystems but also partners in human health. The future of medicine may well depend on learning from the smallest of creatures our remarkable “tiny doctors.”

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From Maggots to Justice: Insects in the Courtroom

Article ID: 72006

Kota Sahithi Chowdary¹, Repaka Harika¹, Gopu Sushma²

¹Ph. D Scholar, Indira Gandhi Krishi Vishwavidyalaya, Raipur.

²Ph. D Scholar, Professor Jayashankar Telangana Agricultural University.

Abstract

Forensic entomology the study of insects in relation to crime has emerged as a powerful tool in criminal investigations. Insects act as natural evidence by revealing the time of death, movement of a body, and even traces of toxins when conventional clues are absent. Blowflies, beetles, and other species serve as “timekeepers of death” through their predictable life cycles, while habitat-specific insects provide location clues, and larvae feeding on tissues retain chemical traces useful in toxicology. Historical and modern case studies highlight its significance while in rural India, maggot studies have been vital in homicide cases where traditional forensic evidence was scarce. Despite challenges of environmental variation and limited expertise, advances in molecular tools and insect ecology are expanding the scope of forensic entomology, making it an indispensable partner in the pursuit of justice.

Introduction

Have you ever imagined that tiny flies and beetles buzzing around a body could help solve a murder mystery? This is the fascinating world of forensic entomology, the use of insects in criminal investigations. Far from being just pests, insects act as silent witnesses at crime scenes, revealing hidden stories about time, place, and even the cause of death.

What is Forensic Entomology?

Forensic entomology is the branch of science where entomologists study insect activity to aid legal cases. Although the weapon had been wiped clean, there was enough blood and other tissue residue left on the blade to attract dozens of flies, thus identifying the suspect (McKnight, 1981). By examining the types of insects, their life cycle stages, and the conditions in which they are found, investigators can estimate:

1. Postmortem interval (PMI): How long a person has been dead.
2. Whether the body was moved after death.
3. Clues about cause of death, abuse, or neglect.

Timekeepers of Death: When a body is exposed, the first responders in nature are usually blowflies (green or blue metallic-coloured flies). They can detect the smell of decomposition within minutes. These flies lay eggs in natural body openings (mouth, nose, ears, wounds).

- a. The eggs hatch into larvae (maggots), which then grow through predictable stages: egg → 1st instar larva → 2nd instar larva → 3rd instar larva → pupa → adult fly.
- b. Because their growth depends on time and temperature, forensic entomologists can match the insect’s stage to the postmortem interval (PMI) the estimated time since death.
- c. Example: If maggots are in the pupal stage, and under local weather conditions it usually takes 7–10 days to reach that stage, the investigator can say the death occurred about a week ago. Thus, insects are like biological clocks, ticking away on the crime scene.



Location Clues: Different insect species thrive in specific environments:

- Indoor vs. Outdoor: Houseflies may dominate indoors, while blowflies and carrion beetles are common outdoors.
- Urban vs. Rural: Some beetles prefer city environments, while others are restricted to fields or forests.
- Altitude & Geography: Certain flies appear only in coastal or high-altitude regions.

By identifying these species, investigators can tell whether: The body died at the location where it was found, or it was moved after death. For example, if a corpse is discovered in a house but the insects present are forest-dwelling beetles, it suggests the body was originally outdoors and later relocated indoors. This helps reconstruct the crime scene history and even narrow down possible disposal sites.

Toxicology Partners: Forensic toxicology doesn't always get enough tissue samples especially if the body is badly decomposed or skeletonized. Here's where insects step in:

- Maggots and other larvae feed on body tissues, and in the process, they also absorb drugs, poisons, or alcohol present in the victim's system.
- By chemically analyzing these larvae, forensic scientists can detect substances like morphine, cocaine, pesticides, or heavy metals.

This can reveal whether the victim was poisoned, drugged, or overdosed before death. Example: In a famous case, maggots from a corpse revealed the presence of cocaine, which helped determine the cause of death when human tissue was no longer usable. In short, insects act as mobile biological test tubes, carrying chemical evidence of the crime. Several studies have elaborated on the detection of toxins and other chemicals from insects found on decaying corpses (Kintz *et al.*, 1990; Sadler *et al.*, 1997).



Beyond Human Crime: Other Applications

- Wildlife crime investigations (poaching cases).
- Neglect/abuse cases (insects on neglected children or elderly)- Forensic entomology may also help in investigations dealing with living, but ill, people by revealing neglect. The occurrence of maggots in the wounds or natural orifices of living persons may indicate such neglects. Estimating the age of these maggots can reveal how long the neglect has been happening (Benecke, 2003).
- Archaeology (studying mummified remains).

Historical Case in Europe: Maggot Analysis Exonerating Innocent Residents

In Europe, maggot analysis once revealed that a child's death occurred earlier than suspected, freeing an innocent man. In France, 1855, Dr. Louis François Étienne Bergeret (Bergeret d'Arbois) conducted one of the earliest documented applications of forensic entomology. He analysed the succession of insect species on the skeletal remains of a child discovered behind a chimney. Based on the insect evidence, he concluded the child had died approximately seven years before the body was found. This led to the exoneration of the

current occupants of the house and resulted in the arrest and conviction of a couple who had lived there at the time of death, in 1848 (Singh *et al.*, 2009).

Challenges and Future

Despite its potential, forensic entomology faces hurdles such as lack of trained experts, environmental variations, and courtroom acceptance. However, with advances in DNA barcoding, molecular techniques, and climate-based insect growth models, this science is becoming more precise and globally recognized.

Conclusion

Forensic entomology proves that even the smallest creatures can play a big role in justice. Insects don't lie; they leave behind a timeline that helps investigators piece together the puzzle of a crime. Next time you see a fly, remember it might be more than a nuisance; it could be a witness.

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Role of Millets in the Nutritional Intervention for Adult Obesity

Article ID: 72007

Rahul Saini¹

¹MSC Research scholars FSNT, Department Science college MLSU Udaipur.

Abstract

Obesity is a chronic and multifactorial disorder, recognized globally as a major public health challenge. Its prevalence has risen dramatically, with WHO reporting a near tripling since 1975, and NFHS-5 data highlighting increasing rates among Indian adults. Obesity is associated with cardiovascular disease, type 2 diabetes, musculoskeletal complications, several cancers, and psychosocial distress. The condition develops from complex interactions among genetic, metabolic, behavioral, and environmental factors, including dietary transitions and physical inactivity. Nutritional interventions play a pivotal role in obesity management, and millets have emerged as promising dietary alternatives due to their low glycemic index, high fiber, and micronutrient density. Comparative analysis reveals that millet-based diets enhance satiety, regulate glucose levels, improve gut microbiota, and support fat metabolism, thereby offering protection against obesity and related non-communicable diseases (NCDs). Different millet varieties, such as finger millet, pearl millet, sorghum, and foxtail millet, provide unique health benefits ranging from improved cardiovascular health to enhanced bone strength. Reintroducing millets into modern diets, alongside lifestyle modifications, may represent a culturally acceptable, sustainable, and effective strategy for obesity control in India and beyond.

Introduction

Obesity is a chronic medical condition characterized by excess accumulation of body fat, posing serious health risks. According to World Health Organization (WHO) estimates, worldwide obesity has nearly tripled since 1975. In India, NFHS-5 (2019–21) data indicate that 22.9% of women and 22.8% of men aged 15–49 are overweight or obese, a sharp rise from previous decades. Overweight and obesity increase the risk of cardiovascular disease, type 2 diabetes, musculoskeletal disorders, and several cancers. They also contribute to psychosocial issues and reduced quality of life. The condition results from a complex interplay of caloric imbalance, genetics, sedentary lifestyle, and unhealthy dietary patterns, particularly the shift from traditional whole grains to refined, processed foods. Nutritional therapy is a cornerstone in obesity management. Millets, being nutrient-dense and low in glycemic index (GI), offer significant potential in dietary interventions targeted at weight control.

Classification of Adult Obesity (BMI-Based)

Category	BMI (kg/m)
Overweight	25.0 – 29.9
Obesity Class I (Mild)	30.0 – 34.9
Obesity Class II (Moderate)	35.0 – 39.9
Obesity Class III (Severe) ≥	40.0

Causes of Obesity

1. Genetic Factors – Variations in genes like MC4R, LEP (leptin), and POMC influence appetite regulation and fat storage.
2. Dietary Transition – Replacement of traditional grains (like millets) with refined carbohydrates and high-fat, high-sugar processed foods increases obesity risk.
3. Physical Inactivity – Urban lifestyles, mechanization, and high screen time reduce calorie expenditure.
4. Psychological & Behavioral Factors – Stress, depression, poor sleep, and emotional eating lead to excess calorie intake.

5. Hormonal & Metabolic Disorders – Hypothyroidism, Cushing’s syndrome, insulin resistance slow metabolism.

6. Medications – Long-term use of corticosteroids, certain antidepressants, and antipsychotics contribute to weight gain.

Symptoms of Obesity

1. High body mass index (BMI ≥ 30)
2. Excess fat accumulation (especially abdominal)
3. Fatigue or low energy levels
4. Joint pain/back pain
5. Shortness of breath, especially on exertion
6. High blood pressure & triglyceride levels
7. Fatty liver disease
8. Increased risk of sleep apnea and metabolic syndrome.

Nutritional Profile of Millets

1. Macronutrients: High complex carbohydrates, moderate protein, low fat.
2. Micronutrients: Calcium, iron, magnesium, zinc, B-vitamins.
3. Dietary Fiber: Soluble & insoluble fiber for satiety and improved digestion.
4. Bioactive Compounds: Polyphenols, antioxidants aiding metabolic health.

Table: Nutrient Comparison (per 100g):

Grain	Protein (g)	Fiber (g)	Glycemic Index	Iron(mg)	Calcium (mg)
Pearl Millet	10.6	8.5	54	8.0	42
Finger Millet	7.31	1.5	55	3.9	344
Foxtail Millet	12.3	8.0	50	2.8	31
Wheat	11.8	6.7	69	3.9	30
White Rice	6.8	0.2	73	0.2	10

Role of Millets in Diet Therapy for Obesity

Mechanisms of Action:

1. **Low Glycemic Index:** Reduces post-meal glucose spikes, improving insulin sensitivity.
2. **High Satiety Value:** Fiber and resistant starch prolong fullness, reducing calorie intake.
3. **Micronutrient Support:** Magnesium, zinc, and antioxidants support fat metabolism.
4. **Gut Microbiota Modulation:** Prebiotic fiber enhances beneficial gut bacteria.

Millet Types and Benefits

Millet Type Key Nutrients Obesity-Related Benefits

Sorghum: Iron, protein, fiber Gluten-free; aids weight control & anemia prevention

Finger Millet: Calcium, fiber, amino acids Bone health; high satiety

Pearl Millet: Magnesium, insoluble fiber Reduces cholesterol; supports heart health

Kodo Millet: Antioxidants, phytochemicals Weight loss aid; menstrual health

Proso Millet: Niacin, protein Skin health; post-illness recovery

Foxtail Millet: Magnesium, low GI Steady glucose release; heart-friendly

Little Millet: Calcium, iron, zinc Weight loss support; nutrient-rich.

Conclusion

Obesity is a complex, multifactorial health issue with rising prevalence in India and globally. Nutritional interventions remain critical to prevention and management. Millets, with their low GI, high fiber, and rich micronutrient profile, provide an effective and culturally relevant strategy for obesity control. Promoting millet consumption, alongside lifestyle changes, can improve metabolic health and reduce NCD

risk. Reintroducing these traditional grains into modern diets should be prioritized in public health policies and clinical dietary advice.

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Stridulation and Vibration: “The Bioacoustics Signalling of Nocturnal Insects”

Article ID: 72008

Sudharsan K¹

¹M.Sc. (Agri) Entomology, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India.

Introduction

As daylight fades and human activity dwindles, a remarkable transformation occurs across natural landscapes. The familiar chirping of crickets, resonant buzzing of cicadas, and melodic whispers of katydids combine to create nature's after-dark symphony. Each insect species employs specialized anatomical adaptations to produce its distinctive calls, serving vital purposes including mate attraction, territorial defense, and predator avoidance. These natural performances not only demonstrate remarkable bioacoustic engineering but also provide valuable insights into ecological relationships, animal behavior, and environmental health.

The Science of Insect Sound: Bioacoustics in Miniature

Insects have developed extraordinary solutions for auditory communication without vocal cords. The scientific field of bioacoustics has identified several primary sound production methods in insects:

- 1. Stridulation:** Sound created by rubbing specialized body parts together, such as a cricket's textured wings.
- 2. Tymbal mechanism:** Utilization of drum-like membranes that rapidly buckle to generate clicks or buzzes, as observed in cicadas.
- 3. Percussion or wing beating:** Sound production through tapping body parts against surfaces or via specialized wing vibrations.

Crickets: The Rhythm Keepers

The regular chirping of crickets represents one of nature's most recognizable nocturnal sounds. These insects serve as the steady percussionists of the insect world.

Sound Production Mechanism

Male crickets produce sound through stridulation. One forewing features “**scraper**” (sharp ridge) while the opposite wing possesses a “**file**” (like series of microscopic teeth). Rubbing these structures together generates vibrations that are amplified by thin wing membranes, creating their characteristic chirping sounds.

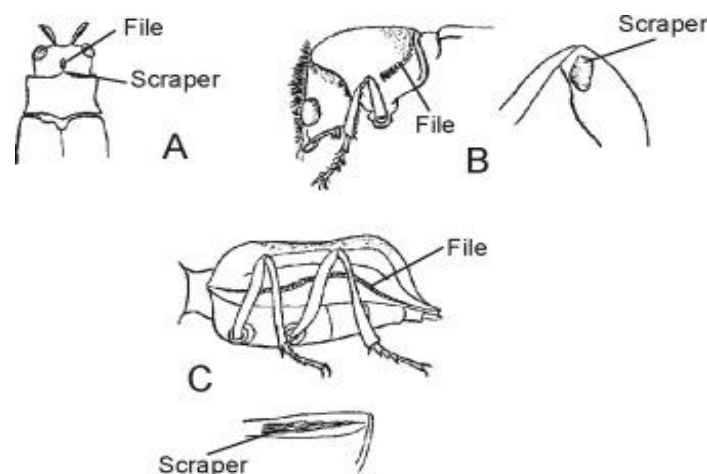


Fig.1 File and Scraper mechanism in cricket

Communication Purposes

- 1. Mating Calls:** Species-specific songs that attract females from a distance
- 2. Courtship Songs:** More intricate, quieter melodies performed near receptive females
- 3. Aggressive Signals:** Confrontational chirps directed at competing males.

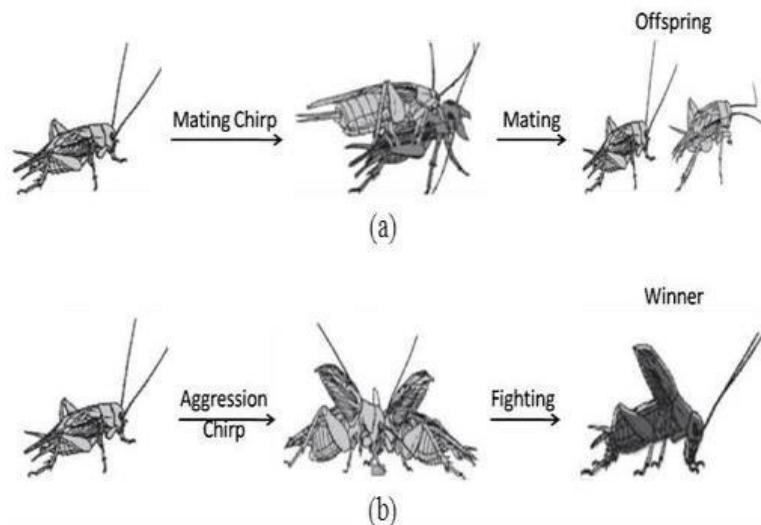


Fig.2 Cricket Behaviour a) Calling chirp b) Aggressive chirp

Species Diversity in Sound: Different cricket species have distinct chirp patterns, ranging from trills to long continuous notes. The house cricket (*Acheta domesticus*) has a familiar rhythmic chirp, while the snowy tree cricket (*Oecanthus fultoni*) produces a softer, melodious tone that has earned it the nickname “the thermometer cricket.”

Cicadas: Nature's Loudest singers: Cicadas function as the powerhouse soloists of daytime soundscapes. Their collective buzzing can exceed 100 decibels comparable to mechanical noise such as chainsaws or rock concerts.

Sound Production Mechanism: Cicadas employ paired tymbal organs located on their abdomens. Powerful muscles cause these ribbed membranes to buckle inward and snap outward hundreds of times per second. The resulting clicks resonate within insect's largely hollow body cavity, merging into continuous, buzzing and rattling of calls. Unlike crickets, cicadas don't rub body parts together; instead, their call is more mechanical like beating a tiny drum with biological amplifiers.

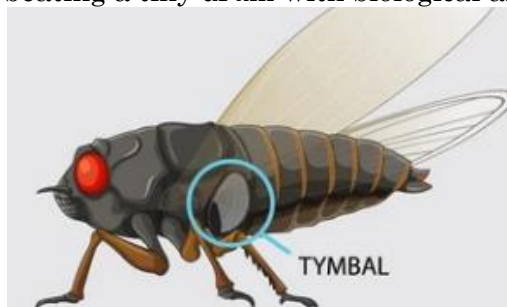


Fig.3 cicada uses tymbal as natural drums to amplify sounds

Periodical Cicada Phenomenon: Periodical cicadas (genus *Magicicada*) represent one of nature's most astonishing biological events. Their nymphs develop underground for precisely 13 or 17 years before emerging in massive, synchronized populations. Their synchronized choruses also facilitate species recognition during these mass emergences.

Communication Functions

- 1. Mate Attraction:** Males form choruses to attract females, who respond with subtle wing-flick signals
- 2. Reproductive Isolation:** Distinct species-specific calls prevent mating between different species

3. Mass Synchronization: Collective calling creates acoustic beacons that attract more females, enhancing reproductive success.

Katydids: Whispering Poets of the Canopy

Katydids, relatives of crickets, are less familiar to many but equally fascinating. Found in forests and shrublands, these leaf-like insects are named after their calls, which in some species sound like “ka-ty-did, ka-ty-didn’t.”

Sound Production Mechanism: Like crickets, katydids use **stridulation with their forewings**. However, their acoustic repertoire is remarkably diverse, including soft ticks, sustained buzzes, and ultrasonic vibrations beyond human hearing range.

Ultrasonic Communication: Many katydid communications occur in the ultrasonic spectrum, imperceptible to humans but detectable by predators like bats. Some species have evolved the ability to detect bat echolocation calls and immediately cease singing to avoid predation, engaging in an evolutionary arms race of acoustic hide-and-seek.

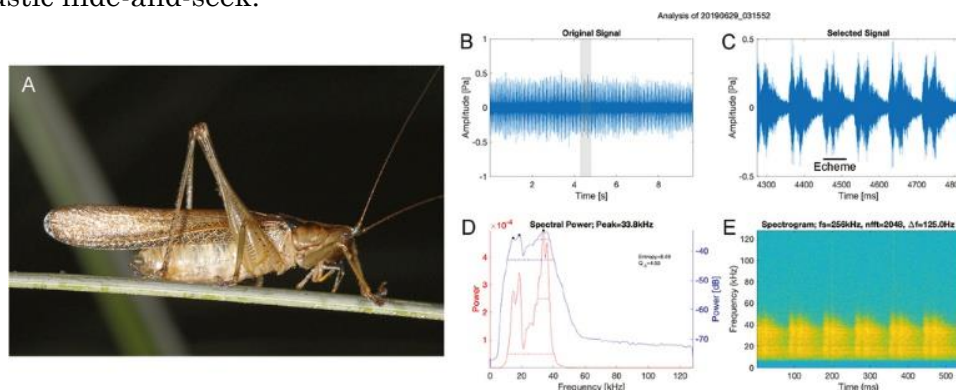


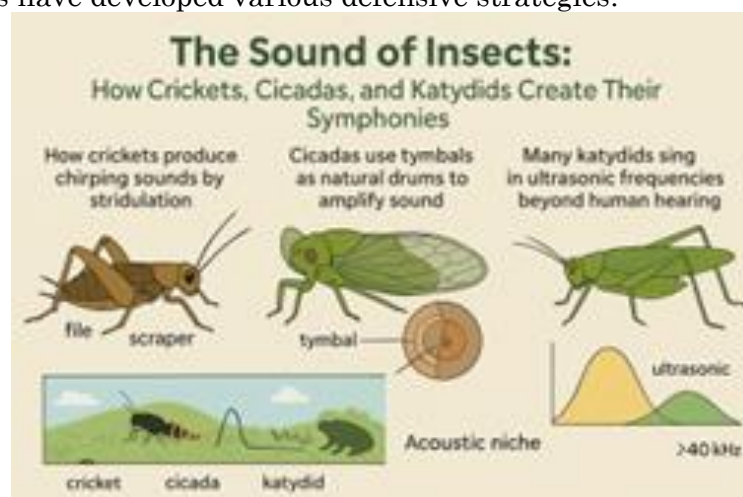
Fig.4 Katydid sound mechanism and acoustic analysis. Reproduced from Tan *et al.* (2023).

Communication Purposes

- 1. Courtship:** Females often evaluate male quality based on song complexity and duration
- 2. Species Recognition:** In biodiverse habitats, unique call patterns ensure mating with the correct species.
- 3. Territorial Defense:** Songs establish acoustic boundaries between competing males.

The Ecological Significance of Insect Choruses

Insect sounds create layered acoustic environments where each species typically broadcasts at unique frequencies or temporal patterns an ecological strategy known as niche partitioning that minimizes interference. Predators including bats, birds, and frogs have evolved to exploit insect sounds when locating prey. In response, insects have developed various defensive strategies.



Human and Insect Harmonies: Cultural and Scientific Connections

1. Mythology and Art: Ancient Greeks revered cicadas as symbols of immortality and artistic inspiration. Japanese cultural traditions celebrate cicadas as representations of summer's transient beauty. Cricket song features prominently in poetry as evocations of hearth and home.

2. Musical Inspiration: Composers including Béla Bartók and George Crumb have incorporated insect sounds into musical compositions.

3. Scientific Applications: Bioacoustics has emerged as a valuable conservation tool. Automated recording devices now monitor insect populations and biodiversity by analyzing soundscapes, providing crucial data about ecosystem health and climate change impacts.

Evolutionary Insights: The Drive for Diversity

The astonishing variety of insect songs illustrates the powerful evolutionary force of sexual selection. Female preference for males with more vigorous, complex, or louder calls has driven an evolutionary arms race. These preferences favor traits that signal genetic fitness, ultimately leading to acoustic divergence and the emergence of new species.

Conclusion

Behind the sounds of human activity persists an ancient performance the patient rhythm of crickets, the overwhelming pulse of cicadas, and the intricate whispers of katydids. This is a dynamic language of life, conveying stories of competition, courtship, and survival. It reminds us of our deep connection to a natural world that is both complex and fragile. By learning to appreciate the insect symphony, we not only gain insight into ecology but also commit to preserving a timeless heritage for future generations.

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Pulse Root Ideotype for Water Stress

Article ID: 72009

S Anitta Fanish¹

¹Assistant Professor (Agronomy), Department of Pulses, Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu.

Pulses are a key seed crop in world due to their production value, their ability to increase soil nitrogen through fixation, forming a disease break in crop rotations, and for leaving residual moisture deeper in the soil profile for use by subsequent, deep-rooted crops. Considerable research effort over several decades has been expended on physiological improvements of crop adaptation to water stress. The root system architecture of monocots has been thoroughly characterised in terminal drought conditions. In contrast to cereals, pulses are an indeterminate crop; hence, they differ significantly in their interactions between phenology, root development and response to seasonal variation. Roots serve as the interface between soil constraints and the whole plant. Changes in root system architecture (RSA) can be utilised as an adaptive strategy in achieving yield potential under limited rainfall, heterogenous distribution of resources and other soil-based constraints. Recently, a “Steep, Deep and Cheap” ideotype has been proposed to increase soil water and nitrogen acquisition in an effective manner in monocotyledons. Steep root angles and thick long laterals allow deep roots to reach soil water and nitrate at depth, whilst a structure with few laterals, large cortical cells and aerenchyma reduces the photosynthate demand on the plant. The focus on deeper roots is supported by research that has demonstrated the value of water stored deep in the soil profile to seed yield in environments characterised by terminal drought particularly in sub-tropical regions, where crops rely on water stored during summer fallows and “opportunity cropping”. Studies to date on pulse root system architecture (RSA) have identified key traits such as rooting depth, lateral root intensity, root length distribution, root angle and root diameter that have the potential to increase plant adaptation to water stress. Ramamoorthy et al. investigated some of these traits in chickpeas and observed that genotypes with higher root length density closer to the soil surface, with greater root dry weight at depth, showed the best tolerance to drought.

Water Use Efficiency (WUE) in Pulses

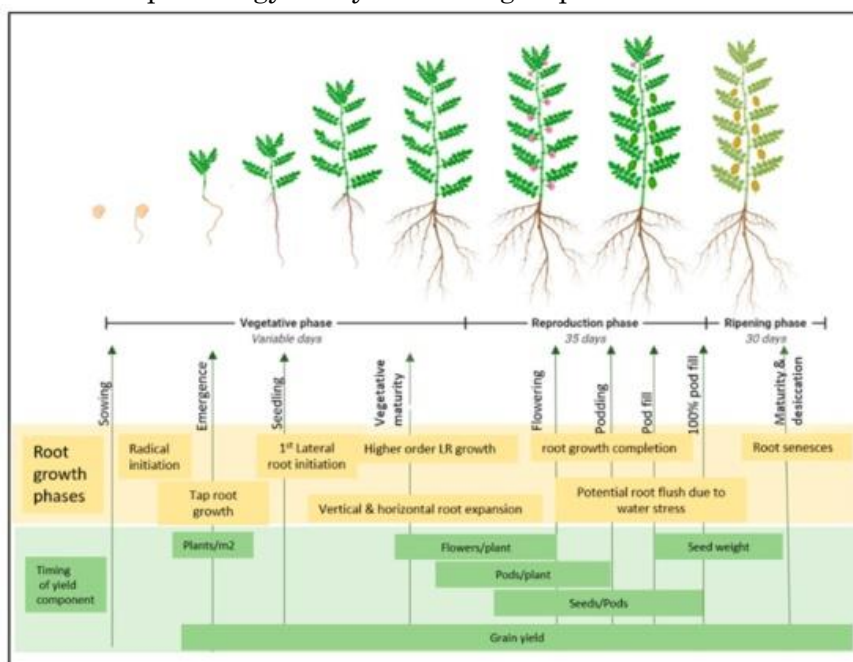
Water use efficiency (WUE) is an expression of the amount of product (grain or biomass) produced per unit of water. It can be expressed either in terms of actual water used (mm) as transpiration efficiency ($\text{m}^{-2} \text{mm}^{-1}$) or in terms of the amount of rainfall received (assuming there was no net change in soil water balance). Water use efficiency is a key metric for assessing adaptation in water-constrained environments as it is positively correlated with grain yield in most dryland cropping systems. The uptake and transportation of water in plants is a prerequisite for good water use efficiency.

Pulse Root Water Extraction Potential: Pulse crops have been observed to have a lower rate of water extraction in comparison to wheat. Of the pulses examined, chickpea was observed to have the highest amount of water extraction (approximately 12% higher) in the 60–100 cm soil depth range compared to lentil and pea. The shallow depth of water extraction by pulses such as lentil compared to wheat results in higher residual water for subsequent crops in the rotation following a pulse crop. The ability of plants to extract water is influenced by both soil properties and the plants. At maturity, chickpea was able to extract water and reduce soil water potential to a greater extent while having a similar WUE to other pulses under both low- and medium-rainfall environments. Chickpea was closely followed by faba bean, dry bean, dry pea and lentil. The increase in water availability during high-rainfall years reduced WUE especially in pea, chickpea and faba bean, suggesting that WUE is a plastic response. Drought-sensitive plants exhibited the same level of water extraction in water-stressed environments as the control of the well-watered environment.

Root Phenology and their Response to Water Stress in Pulses

In pulses, root growth is positively correlated with shoot growth and appears to halt at the late flowering/flat pod stage, after which it senesces through pod fill and desiccation. Indeterminate growth in

pulses may result in a secondary root flush if late rains occur after an intermittent drought and can result in significant increases in grain yield compared to determinate crops in some situations. This aspect of the root phenology of pulses has been relatively underutilised as a water stress adaptation. Figure 1 provides an illustration of potential root phenology and yield timing in pulses.



The current understanding of pulse root phenology aligned with the timing of factors affecting yield and yield components. After sowing, the days to maturity of pulse crops are variable depending on temperature, photoperiod and rainfall. The reproductive and ripening phase can last for approximately 30 to 35 days from maturity. The first factor for crop yield after sowing is plant emergence, which relies on good taproot growth and establishment. Following taproot, the first-order lateral roots (LR) emerge at the early seedling stage. Early vigour at a seedling stage is critical for biomass accumulation and harvest index. From seedling to flowering, roots expand rapidly, growing deeper into the soil and densifying with the emergence of higher-order laterals. Root growth contributes to nutrient and water acquisition, which feeds into the number of successful flowers that transition to seeds. During pod filling, soil moisture levels can be greatly reduced and root flush potential in pulses may allow the last surge of root growth to extract soil moisture to a greater extent.

While reduced or irregular rainfall is the main contributing factor to water stress in plants, root growth may not always be synchronised with changes in soil water potential or location. A potentially important breeding and agronomic consideration is that plants with roots that have vigorous growth early can absorb more water in the initial growth stage and build more biomass than plants that have low early root vigour. Early root vigour can prove beneficial if the genotype has a high harvest index and good WUE. However, if the plant has a low harvest index and poor WUE, early vigour roots can deplete soil moisture and induce water stress during the grain-filling stage, resulting in yield loss.

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Precision Farming: The Future of Indian Agriculture - “Using Less to Grow More” Through Smart Technologies”

Article ID: 72010

Tushar Mehra¹

¹Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology, Chatha,
Jammu, Jammu & Kashmir 180 009, India.

What is Precision Farming?

Precision farming seeks to use new technologies to increase crop yield and profitability while lowering the level of traditional inputs needed to grow crops like fertilizers, herbicides, and insecticides. In other words, farmers utilizing precision farming as “**using less to grow more**”

Techniques Used in Precision Farming

Precision irrigation: It involves use of sensors and software to optimize irrigation scheduling and water application rates as per growth stage of crop. It is achieved with the help of drip irrigation, center pivot irrigation, or sub-surface irrigation.

Drones: Used for crop monitoring, spraying, and mapping to save time and resources.

ICT (Information and communication technologies): Enables farmers to access real-time data for better decision-making.

Wireless networks: Connects farm devices and sensors for seamless data sharing.

GPS (Global Positioning System): It is satellite-based navigation system that enables farmers to map and measure fields with high precision. This data can be used to create field maps, soil type maps, moisture content, soil health and fertility condition mapping.

GIS (Geographic Information System): It is software tool that enables farmers to store and display spatial data such as field maps, soil samples and weather conditions GIS also helps to identify patterns of soil type, crop yield enabling farmers to make data driven decisions about input application and management practices.

Robotics: Automates tasks like planting, weeding, and harvesting to save labor.

Internet of Things: Smart sensors collect field data (moisture, nutrients, weather) to optimize farm operations.

Precision livestock farming: It involves use of sensors and other technologies like IVF, artificial insemination to monitor animal health, growth and behavior. It improves animal management and welfare by optimizing feeding and breeding programs and reducing environmental impact.

Data analysis and decision making: All precision techniques require data collection and analysis which can be done using various software and analytical tools which can help to make informed decisions about crop management, resource allocation, input application by using predictive models and artificial intelligence.

Precision Farming in India

Sensor based smart agriculture: ICAR and IARI formulated a project called as “SENSAGRI” (Sensor based smart agriculture). Its major objective is to develop indigenous prototype for drone-based crop and soil health monitoring system using hyper spectral remote sensing.

Project Kisan +: It is cropping insurance using space technology with the help of high-resolution remote sensing data recorded with the help of smartphones, GPS based applications for improving accuracy of crop damage, yield estimation with more efficient way.

Government schemes like **PM Krishi Sichai Yojana** involves precision agriculture practices by adopting motto of “**Per Drop More Crop**”

Case Studies

1. A **young farmer, sh. Ajit Korde** from Maharashtra has established private weather station in his farm which is helping him to get data related to temperature, weather, humidity, wind speed, which is helping him with crop management-related decisions.

2. **Group of farmers in Gujarat** used mobile based agricultural extension system which had resulted in increasing income by 7000/yr while yield is increased by 8.6 % and 28% for cotton and cumin respectively.

Issues and Concerns of Precision Farming

Lack of infrastructure: The adoption of precision farming techniques involves significant investment in infrastructure such as sensors, software, and analysis tools.

Limited access to information: In India there is a significant digital divide with many farmers lacking access to information and communication technologies which is limiting their ability to adopt precision farming.

Complexity of technology: Advanced tools require technical skills, making them difficult for small and marginal farmers.

Cost benefit analysis: High initial costs and uncertain returns discourage investment. Small farmers may be reluctant to invest in precision farming if they do not see clear return on investment

Policy and regulatory framework: The Government of India launched programs to promote precision farming and providing financial assistance to farmers, but its implementation is very poor. There is a need of clear policy and regulatory framework for using precision forming.

Environmental concerns: Though precision farming reduces input and increases yield. It may lead to environmental problems like pollution and soil degradation. Rising e-waste, energy consumption, and improper disposal of devices may affect sustainability.

Way Forward: Precision farming holds immense potential to make Indian agriculture more productive, resource-efficient, and sustainable. However, its large-scale adoption is limited by high investment costs, infrastructural gaps, and lack of technical know-how among farmers. Strengthening supportive policies, promoting affordable indigenous innovations, and enhancing farmer training can accelerate its adoption. With these efforts, precision farming can truly emerge as the future of sustainable and resilient Indian agriculture.

Geostatistics and its Agricultural Applications

Article ID: 72011

M. Radha¹, M. Nirmala Devi², S. Vishnu Shankar³, V. M. Indumathi⁴

¹Department of Agricultural Economics, Anbil Dharmalingam Agricultural College and RI, Trichy, Tamil Nadu, India.

^{2&3}Department of Physical Science & Information Technology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

⁴Department of Agricultural and Rural Development, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

Introduction

Agriculture is inherently influenced by spatial and temporal variability of soil, climate, and crop conditions. Traditional statistical methods often assume independence among data points, but in agricultural systems, observations are spatially correlated. Geostatistics, a branch of statistics originally developed in mining and geology, provides powerful tools to analyze, model, and predict spatially dependent data. Its integration into agriculture has enabled precision farming, site-specific management, and sustainable resource utilization.

Geostatistics combines concepts of spatial correlation, stochastic modeling, and interpolation techniques such as kriging to quantify and map variability. By applying these methods, farmers and researchers can optimize crop yields, reduce costs, and minimize environmental impacts.

Principles of Geostatistics

Geostatistics is based on three key components:

- 1. Spatial Autocorrelation:** Agricultural data such as soil fertility, crop yield, and moisture levels are not randomly distributed but exhibit spatial dependence. The degree of similarity between data points is modeled using variograms.
- 2. Variogram Analysis:** Variograms describe how variance between observations changes with distance, providing a basis for interpolation.
- 3. Kriging Techniques:** Kriging is a geostatistical interpolation method that predicts unknown values at unsampled locations with minimum error. Variants include ordinary kriging, universal kriging, and co-kriging.

Applications of Geostatistics in Agriculture

- 1. Soil Property Mapping:** Geostatistics is widely used to analyze spatial variation in soil properties such as pH, organic matter, salinity, and nutrient content. Soil sampling combined with kriging produces detailed maps that guide site-specific fertilizer application. For example, nutrient distribution maps can optimize nitrogen or phosphorus application, reducing excess use and improving efficiency (Webster & Oliver, 2007).
- 2. Crop Yield Prediction and Mapping:** Yield monitoring data collected from GPS-enabled harvesters can be interpolated using geostatistical tools. This helps in identifying high- and low-yield zones, which supports precision farming and better management of inputs.
- 3. Water Resource and Irrigation Management:** Water availability and soil moisture are crucial for crop growth. Geostatistics enables the mapping of groundwater levels, irrigation efficiency, and soil moisture variability. Such information supports water-saving irrigation techniques like drip irrigation.
- 4. Disease and Pest Management:** The spread of plant diseases and pests is spatially correlated. Geostatistical models help in identifying infestation hotspots and predicting spread patterns. This allows for targeted pesticide application, reducing chemical usage and environmental impact.

5. Climate and Weather Analysis: Spatial interpolation of climatic data such as rainfall, temperature, and solar radiation is another application. High-resolution weather maps support decisions on planting, irrigation scheduling, and crop selection.

6. Land Use and Precision Agriculture: Geostatistics supports precision agriculture by integrating soil, crop, and climate variability into management decisions. It provides the foundation for variable rate technology (VRT), which adjusts input applications (fertilizers, water, pesticides) according to site-specific requirements (McBratney et al., 2005).

Advantages of Geostatistics in Agriculture

- 1. Improved accuracy** in mapping soil and crop variability.
- 2. Cost-effective management** by reducing excessive use of inputs.
- 3. Sustainability** through environmentally friendly practices.
- 4. Decision support** for precision agriculture and land use planning.

Challenges and Limitations

1. Requires **dense and high-quality data** for accurate modeling.
2. Computational complexity and need for specialized software (e.g., GS+, ArcGIS, R).
- 3. Sampling costs** can be high in large-scale studies.
4. Interpretation of variograms and kriging requires technical expertise.

Conclusion

Geostatistics has revolutionized modern agriculture by providing methods to analyze and manage spatial variability. From soil mapping to pest control and precision farming, it offers solutions that improve productivity, sustainability, and environmental stewardship. As remote sensing, GIS, and big data technologies advance, geostatistics will continue to play a vital role in the digital transformation of agriculture.

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Minimum Support Price and its Impact on Indian Agriculture

Article ID: 72012

Deepa B. Hiremath¹, Shreeshail Rudrapur², Netravathi G.³

¹Assistant Professor, Department of Agricultural Economics, College of Agriculture, Navsari Agricultural University, Bharuch, Gujarat.

²Assistant Professor, Department of Agricultural Economics, College of Agriculture, Navsari Agricultural University, Waghai, Gujarat.

³Assistant Professor, Department of Agricultural Extension, College of Agriculture, Navsari Agricultural University, Bharuch, Gujarat.

Introduction

Indian agriculture stands as the backbone of the nation's economy, employing millions and ensuring food security for its vast population. However, the sector faces numerous challenges, including volatile market prices, weather uncertainties, and inadequate infrastructure. In the quest for stability and sustainability, Minimum Support Price (MSP) has emerged as a crucial policy tool. It serves as a lifeline for Indian farmers, providing them with a safety net against market uncertainties and ensuring a minimum income for their produce. The calculation of MSP involves a meticulous process that considers various factors such as input costs, demand-supply dynamics, and agricultural sustainability. This article delves into the concept of MSP, its historical context, determinants and methodology for calculation, impact, challenges, and the way forward for Indian agriculture.

Understanding Minimum Support Price (MSP)

Minimum Support Price (MSP) is a form of agricultural price support policy implemented by the Government of India to safeguard the interests of farmers by ensuring them a guaranteed price for their produce. The MSP acts as a floor price, below which the government commits to purchase the farmer's crop if market prices fall especially during bumper crop production. The Commission for Agricultural Costs and Prices (CACP), an autonomous body under the Ministry of Agriculture, recommends MSPs for 23 different crops based on comprehensive analysis and consultations with stakeholders. It primarily applies to major crops like wheat, rice, pulses, and oilseeds.

Historical Context

The origin of MSP can be traced back to the aftermath of the Green Revolution in the 1960s when India aimed to achieve self-sufficiency in food grain production. The MSP was introduced to incentivize farmers to adopt modern agricultural practices, increase productivity, and mitigate the risks associated with market fluctuations.

Factors Influencing MSP Calculation

The determination of MSP is based on various factors like the cost of production including input costs, market prices, demand-supply dynamics, international prices *etc.*

Some of the major factors that come into play while calculating MSP, ensuring it reflects the ground realities of agricultural production and market dynamics:

1. Cost of Production: The cornerstone of MSP calculation is the cost of production, which includes expenses on seeds, fertilizers, pesticides, labour, machinery, and land rent. The CACP conducts comprehensive cost studies across different regions to ascertain the cost structure for various crops.

2. Input Costs: Fluctuations in input prices, such as fertilizers, pesticides, and fuel, directly impact the cost of production for farmers. MSP calculation considers changes in input prices to adjust the support price accordingly, ensuring farmers are adequately compensated.

3. Market Prices: MSP is aligned with prevailing market prices to maintain price stability in the market. Market prices are influenced by factors like demand, supply, weather conditions, and government policies. MSP ensures that farmers receive a fair price for their produce, even if market prices fall below the MSP.

4. Demand-Supply Dynamics: MSP calculation takes into account demand-supply dynamics to prevent shortages or surpluses in the market. It aims to balance the interests of farmers and consumers by ensuring adequate supply of essential commodities at reasonable prices.

5. International Prices: Global price trends for agricultural commodities influence domestic MSP calculation, especially for crops with significant export-import dynamics. The government considers international prices to align domestic support prices with global market trends and ensure competitiveness in international trade.

Once the MSP is announced by the Central Government, government agencies like the Food Corporation of India (FCI) and state procurement agencies undertake procurement operations during the harvesting season. Farmers have the option to sell their produce either at MSP-designated procurement centers or in the open market.

Methodology for MSP Calculation

The methodology of MSP calculation varies depending on the crop and the cost structure involved. Two primary methods are used:

1. Cost of Cultivation and Production (C2): Under this method, MSP is determined based on the comprehensive cost of cultivation and production (C2), which includes all expenses incurred by farmers in the production process. This method provides a realistic assessment of the cost of production and ensures farmers receive remunerative prices for their crops.

2. A2+FL Method: Some crops follow the A2+FL method for MSP calculation, which considers the actual expenses on inputs (A2) such as seeds, fertilizers, pesticides, and fuel, along with imputed costs of family labour (FL) and the value of owned land. While A2 accounts for out-of-pocket expenses, FL accounts for the opportunity cost of family labour, and the value of owned land reflects the rental value of land.

Impact of MSP on Indian Agriculture

MSP has played a significant role in transforming Indian agriculture as follows:

1. Income Security for Farmers: MSP assures farmers of a minimum income for their produce, providing them with financial stability and reducing their dependence on volatile market prices.

2. Price Stabilization: By setting a floor price, MSP helps stabilize market prices, preventing distress sales by farmers during periods of glut and ensuring adequate returns during times of scarcity.

3. Encouraging Crop Diversification: MSP incentivizes the cultivation of MSP-supported crops, thereby promoting crop diversification and reducing the risk of monoculture.

4. Food Security: MSP ensures an uninterrupted supply of essential food grains at reasonable prices, contributing to national food security and poverty alleviation efforts.

5. Rural Development: MSP-led procurement generates rural employment opportunities, strengthens agricultural infrastructure, and fosters economic development in rural areas.

Challenges and Criticisms

MSP faces several challenges and criticisms despite its benefits:

1. Limited Coverage: MSP primarily covers wheat, rice, and a few other major crops, leaving out many other agricultural commodities, leading to disparities in income security among farmers.

2. Distortionary Effects: MSP-led procurement often results in overproduction of MSP-supported crops, leading to market distortions, inefficiencies in resource allocation, and storage problems.

3. Procurement and Distribution Issues: Inadequate procurement infrastructure, bureaucratic hurdles, and inefficiencies in distribution channels often impede the effective implementation of MSP, leading to delays and leakages.

4. Cost Escalation: The MSP regime imposes a financial burden on the government exchequer, especially when procurement prices exceed market prices, leading to inflationary pressures and fiscal strain.

5. Incomplete Cost Coverage: MSP calculation may not fully capture all costs incurred by farmers, leading to underestimation of the actual cost of production.

6. Market Distortions: MSP distorts market signals, discouraging private investment in agriculture and inhibiting market-driven reforms.

The Way Forward

To address the challenges and enhance the efficacy of MSP, several measures may be considered:

1. Diversification of MSP: Expanding the coverage of MSP to include more crops, especially horticultural and commercial crops, to ensure income security for a wider spectrum of farmers.

2. Market Reforms: Augmenting agricultural marketing infrastructure, promoting contract farming, and strengthening agricultural market linkages to facilitate efficient price discovery and reduce market distortions.

3. Price Deficiency Payment Scheme: Introducing complementary mechanisms like the Price Deficiency Payment (PDP) scheme, wherein farmers are compensated for the difference between MSP and actual market prices, to enhance market efficiency and minimize government intervention.

4. Technology Integration: Leveraging technology and digital platforms for efficient procurement, storage, and distribution of MSP-supported crops, thereby reducing leakages and enhancing transparency.

5. Strengthening Farmer Producer Organizations (FPOs): Empowering FPOs and farmer cooperatives to enhance bargaining power, facilitate collective marketing, and ensure fair remuneration for farmers beyond MSP.

Conclusion

Minimum Support Price stands as a cornerstone of India's agricultural policy, providing income security to millions of farmers apart from ensuring food security for the nation. While it has contributed significantly to the growth and stability of Indian agriculture, MSP faces inherent challenges that necessitate continuous reforms and innovation. By addressing these challenges and adopting a holistic approach encompassing market reforms, technology integration, and institutional strengthening, India can unleash the full potential of its agriculture sector, fostering sustainable growth and prosperity for all stakeholders.

Soil Health Under Natural Farming Practices

Article ID: 72013

S. Sowmiya¹, T. Ragul²

¹M. Sc Research Scholar, Dept of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-3.

²M. Sc Research Scholar, Dept of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-3.

Introduction to Soil Health

Soil is much more than just a medium for plant growth, and it is the most vital living system on Earth. Healthy soil is teeming with billions of tiny organisms, including bacteria, fungi, protozoa, nematodes, and earthworms, all of which interact within a network known as the soil food web. This living system plays a crucial role in moving nutrients through the soil, storing carbon, regulating water, and supporting food production. Instead of relying on numerous chemicals, natural farming focuses on nurturing the living organisms in the soil, promoting its health in various ways without using synthetic substances.

Principles of Natural Farming for Soil Health

Natural farming is based on the idea that "**feed the soil, and the soil will feed the plant.**" The main ideas are:

- 1. Avoidance of synthetic chemicals** – No synthetic chemicals are used, which means no chemical fertilizers or pesticides are added. This avoids harmful effects and keeps the soil's microbes in balance.
- 2. Biological enrichment** – The soil is enriched with helpful microbes from special natural mixtures made on the farm.
- 3. Soil cover** – The soil is kept covered with mulch or cover crops all the time. This helps prevent the soil from being washed away and keeps it from getting too hot or too cold.
- 4. Crop diversity** – Intercropping, crop rotation, and mixed cropping systems enhance nutrient availability and pest resistance. This helps the soil stay rich in nutrients and makes it harder for pests to spread.
- 5. Minimal soil disturbance** – The soil is not disturbed much, like not plowing deeply. This helps maintain the soil's structure and the homes for tiny life forms in the soil.

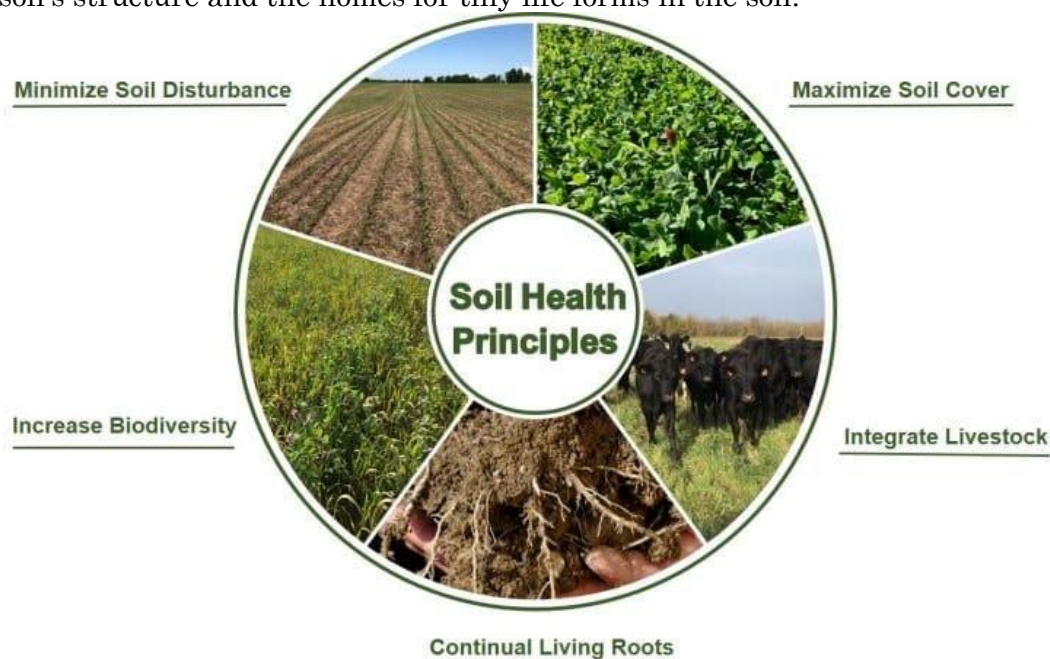


Fig.1 Principles of Soil Health

Practices that Enhance Soil Health in Natural Farming

1. Application of Bio-inoculants: One key method in natural farming is the use of Jeevamrutha, which is a rich microbial mixture made from cow dung, cow urine, jaggery, pulse flour, and local soil.

a. Function: Jeevamrutha brings in a wide variety of helpful microorganisms that break down organic material, make nutrients available, and help control harmful pathogens.

b. Scientific evidence: Research by ICAR (Ramesh et al., 2020) found that soils treated with Jeevamrutha have much higher levels of microbial biomass carbon (MBC) and enzyme activity than soils managed with chemical methods.

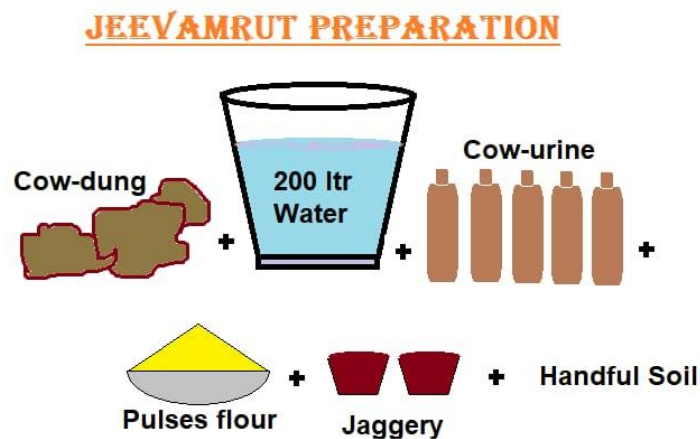


Fig.2 Jeevamirutha

2. Mulching and Organic Matter Addition: Mulching with crop residues, straw, or green leaves prevents evaporation, moderates soil temperature, and provides continuous food for soil organisms.

a. Impact: Enhances **soil organic carbon (SOC)**, which improves aggregate stability, water infiltration, and nutrient-holding capacity.

b. Example: In Andhra Pradesh ZBNF plots, SOC increased by **0.3–0.4% within three years** (La Via Campesina, 2020).



Wood Mulch



Lawn Clippings



Straw & Hay

Fig.3 Mulching

3. Legume Integration and Nitrogen Fixation:

a. Growing cereals along with legumes helps keep nitrogen levels in the soil steady. Legumes have root nodules where Rhizobium bacteria live, and these bacteria turn nitrogen from the air into a form plant can use.

b. This helps cut down on the need for nitrogen fertilizers and makes the soil healthier over time.

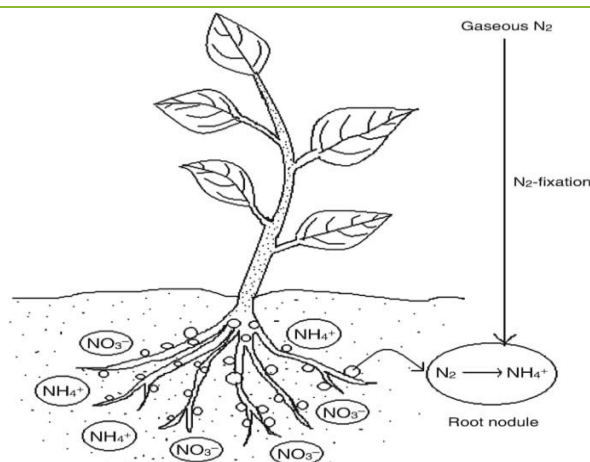


Fig.4 Legume Integration

4. Minimal Tillage: Not disturbing the soil deeply helps keep the mycorrhizal fungi networks intact, keeps the soil structure stable, and stops organic matter from breaking down too quickly.

Effect: This leads to better soil aeration, more water soaking in, and less soil being washed away

5. Green Manuring: Grow leguminous plants like sun hemp, cowpea, and Dhaincha in the soil. These plants help add nitrogen from the air into the soil and also increase the amount of organic carbon in the soil

6. Composting & Vermicomposting:

- Transform farm waste and organic materials into nutrient-dense compost.
- This process increases the amount of humus in the soil, helps it hold more water, and creates a better environment for helpful soil organisms

7. Use of Beejamrutha:

- Beejamrutha is a seed treatment made from cow dung, cow urine, and lime, used before planting to stop fungal problems and make seedlings stronger.
- It helps healthy seedlings grow fast and develop strong roots that hold the soil together

PREPARATION OF BEEJAMRUT

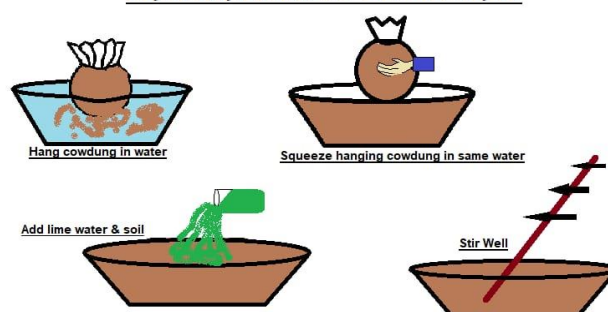


Fig.5 Beejamrutha

How Natural Farming Improves Soil Health – Mechanisms

1. Physical Health of Soil:

- Adding more organic material helps improve soil structure by reducing how tightly the soil is packed and making it easier for the soil particles to stick together, which helps prevent soil from becoming too compacted.
- Covering the soil with mulch stops a hard crust from forming on the surface and also helps prevent soil from being washed or blown away.

2. Chemical Health of Soil:

- Organic materials slowly provide both major and trace nutrients, keeping the nutrient levels in balance
- Using fertilizers that don't make the soil too acidic helps keep the pH close to neutral, which makes it easier for plants to absorb nutrients.

3. Biological Health of Soil:

- a. Having more types of microbes helps the soil process nutrients better.
- b. Keeping plant residue in the soil leads to more earthworms, which helps mix the soil and improves air flow.

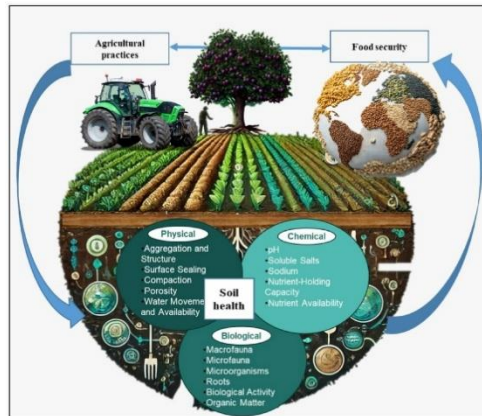


Fig.6 Mechanism of soil Health

Long-term Benefits of Soil Health under Natural Farming

Soils that hold more water mean less need for frequent watering. Healthy soils help crops handle droughts, floods, and extreme weather better. When soils have more organic matter, they help capture and store carbon, which fights climate change. Farmers can cut down on buying chemical fertilizers and pesticides. Good soil health also supports a variety of living things like bees and other helpful insects.

Challenges in Transition

- 1. Yield drop in early years:** Farmers might experience a lower crop output during the first few years as the soil's natural life starts to recover.
- 2. Labour requirements:** Making bio-inputs and applying mulch can take a lot of work.
- 3. Knowledge gap:** The success of this method relies on educating farmers and sharing knowledge within the community.

Despite these challenges, the long-term benefits for both the environment and the economy are usually greater than the initial problems.

Conclusion

Soil health is the key to long-term farming success, and natural farming helps bring it back to good condition. By using fewer chemicals, encouraging living things in the soil, and letting nature take care of itself, farmers can grow strong crops while also helping the environment. Changing to this way of farming might take time and some adjustments, but in the end, it leads to better soil, lower costs for farm supplies, and methods that work with nature instead of fighting it. In the end, natural farming is more than just a way to grow food - it's a promise to protect healthy soil for people who will come after us.

Microbial Interventions in Phosphorous Nutrition of Plants – A Natural Booster for Agriculture

Article ID: 72014

T. Ragul¹, S. Sowmiya²

¹M. Sc Research Scholar, Dept of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-3.

²M. Sc Research Scholar, Dept of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-3.

Introduction

Phosphorus is one of the most important nutrients that plants need for growing and developing properly. It helps with processes like making food for plants through photosynthesis, moving energy around in the form of ATP, building DNA and RNA, and supporting the growth of roots. Even though phosphorus is commonly found in soil, it's often not available in a form that plants can use, which limits how much of it they can take in. Because of this, farmers usually rely on chemical fertilizers to supply the necessary phosphorus for their crops. But these fertilizers can harm the environment by causing water pollution and damaging the soil. They are also costly and not very effective, as only about 10 to 30 percent of the phosphorus in these fertilizers is actually absorbed by the plants.

Microbial interventions are really helpful here. Nature has given us tiny helpers called beneficial soil microbes that can release phosphorus from the soil and make it available for plants to use. These little helpers not only help plants grow better but also support farming in a way that's better for the environment.

Phosphorous Problems in Agriculture

Plants utilize phosphorus in the form of orthophosphates, which are $H_2PO_4^-$ and HPO_4^{2-} . However, more than 60 to 80% of the phosphorus in agricultural soils is in a form that plants cannot directly use. In alkaline soils, this phosphorus gets locked up with calcium, and in acidic soils, it binds with iron and aluminium. This makes it hard for plants to access. Because of this, farmers often use a lot of phosphorus fertilizers. But only a small part of that is actually used by the plants, while the rest becomes unavailable or causes pollution. Also, in most soils, phosphorus ends up in a form that plants can't use because of these reasons.

Chemical Fixation (Binding with Cations Like Ca^{2+} , Fe^{3+} , Al^{3+})

Organic phosphorous (It is present in decaying matter but not absorbed directly)

As a result, farmers applying excessive phosphate fertilizers, leading to:

- Eutrophication** (algal blooms from runoff phosphorus)
- Soil degradation** (Microbial activity are reduced)
- High production costs.**

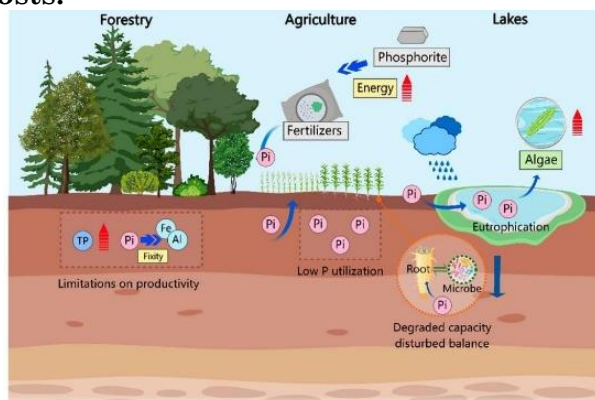


Fig.1 Phosphorus uptake problem in soil

Microbial interventions present a promising solution by enhancing phosphorus availability naturally.

How Microbes Helps to Increase Phosphorus Uptake

1. Phosphate-Solubilizing Microorganisms (PSMs): Certain bacteria and fungi release organic acids such as citric, gluconic, and oxalic, which help break down mineral phosphates. This process makes phosphorus available for plants to use. These microbes play a key role in converting phosphorus from an unavailable form into a usable one. Some of the main organisms involved are:

- a. **Bacteria:** *Bacillus*, *Pseudomonas*, *Rhizobium*
- b. **Fungi:** *Aspergillus*, *Penicillium*, *Trichoderma*
- c. **Actinomycetes:** *Streptomyces*

In addition to producing organic acids, these microbes also create enzymes called phosphatases that help break down organic phosphorus compounds.

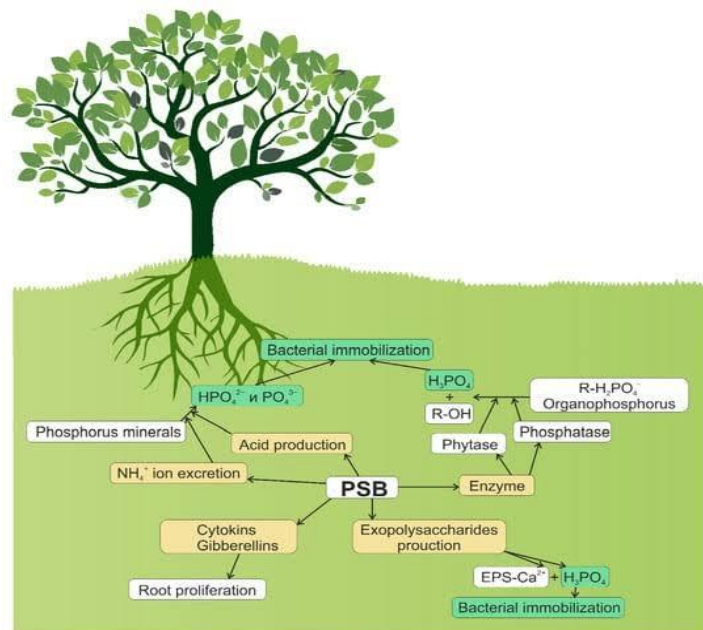


Fig.2 Phosphate solubilizing Micro organism

2. Mycorrhizal Fungi: Nature's Phosphorus: Arbuscular mycorrhizal fungi form a symbiotic relationship with plant roots. Their tiny threads, called hyphae, grow into the soil and greatly expand the root's ability to absorb nutrients. This network creates a kind of underground "super root system" that helps the plant take in phosphorus and other important nutrients more effectively.

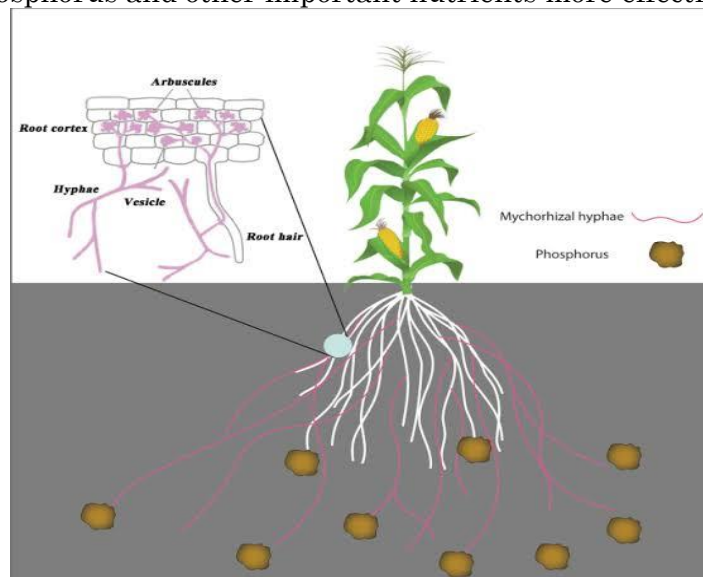


Fig.3 AM fungi

3. Phosphatase Enzyme Producers: Certain bacteria and fungi make enzymes known as phosphatases, which help break down complex phosphorus compounds found in organic materials into simpler forms that plants can easily take in and use.

Advantages of Microbial Phosphorus Solutions

- 1. Reduced fertilizer dependency** – Lowers costs and environmental impact.
- 2. Soil Health Improvement:** The activity of microbes boosts the variety of life in the soil and helps keep the ecosystem in balance.
- 4. Higher crop yields** – Better phosphorus uptake leads to stronger growth.
- 5. Climate resilience** – Supports plants under drought and nutrient stress.
- 6. Eco-friendly and Sustainable** - Microbial inoculants reduce input of chemicals, leading to reduced environmental impact and healthier ecosystems.

Real-World Applications

Biofertilizers that include bacteria capable of releasing phosphorus and fungi that form associations with plant roots are already being used in crops like rice, wheat, maize, legumes, and fruit and vegetable plants. Farmers who use these natural enhancers notice not only improved crop production but also enhanced soil health over time. Many governments and agricultural organizations are now encouraging the use of microbial products as part of broader plans to manage soil nutrients effectively.

Challenges and Future Prospects

Microbial treatments offer a lot of hope, but there are still some difficulties to overcome:

1. Different strains work better in certain types of soil and with specific crops.
2. Microbes need to survive in the soil, where they face competition from other native organisms.
3. Farmers need to know how to properly use these microbes, which requires education.
4. The effectiveness of these microbes can change based on weather, soil condition, and the type of plant being grown.
5. Many microbial products don't last long and have strict storage needs.

Scientists are working on improving these microbes through genetic improvements, using nano-biofertilizers, and combining multiple types of microbes to boost their effectiveness.

Advances in how microbial products are made, which strains are used, and how farmers are taught can help solve these problems. Using microbial fertilizers along with modern farming techniques and digital tools to monitor soil health could greatly improve how nutrients are managed.

Conclusion

Microbial interventions in phosphorus nutrition offer a sustainable path forward for agriculture. By harnessing the power of phosphate-solubilizing bacteria and mycorrhizal fungi, we can reduce reliance on chemical fertilizers, improve soil health, and boost crop productivity naturally. As science advances, these tiny allies may well become the cornerstone of eco-friendly farming.

Risk Management Strategies of Small and Marginal Farmers in Namakkal District

Article ID: 72015

Dr. K. Poovarasana¹, V. Madhumitha², M. Malathi Vairam², S. Manikandan², R. Manonmani²,
Merugu Manaswi², K. Mohan², G. Mohanraj²

¹Ph.D. (Agricultural extension), PGP college of agricultural sciences, Namakkal, Tamil Nadu.

²B.Sc. (Hons.) Agriculture, PGP college of agricultural sciences, Namakkal, Tamil Nadu.

Summary

Small and marginal farmers in Namakkal district face multiple risks that threaten their farm income and livelihood security, with market risk emerging as the most significant. Limited land holdings, inadequate access to credit, price fluctuations, and dependency on middleman further aggravate their vulnerability. This study explores the prevailing risk management strategies adopted by these farmers and evaluates their effectiveness. Primary data were collected through structured interviews and focus group discussions along selected villages in Namakkal district. The findings highlight that farmers commonly adopt crop diversification, livestock integration, group marketing and reliance on informal credit as coping strategies. However, the adoption of formal risk mitigation tools such as crop insurance and forward contracts remains limited due to lack of awareness and accessibility. Strengthening farmer producer organization (FPOs), promoting collective marketing, enhancing access to institutional finance and improving knowledge of crop insurance schemes can significantly reduce market-related uncertainties. The study emphasizes the need for policy interventions tailored to the realities of small and marginal farmers, ensuring resilience and sustainable agricultural livelihoods in Namakkal district.

Introduction

Risk is the integral part of agriculture, which occur with high frequency. The risk faced by the farmer are categorized into five forms such as production, marketing, financial and human capital and environmental risk. The small and marginal farmer constitute a dominant segment, often comprising more than 80 percent (National statistical office, 2021) of farming households. These farmers typically operate on fragmented landholdings of less than two hectares (GOI, 2015-16). The unpredictable weather patterns and pest infestation to fluctuating market prices and limited access to credit poses significant threat to their livelihoods and food security. As a result, a failed crop or a sudden drop in market prices can quickly push these households into cycles of debt and poverty, undermining not only their livelihoods but also broader goals of rural development and food security. The major risk is market risk which refers to the potential loss or fluctuation in income due to change in market conditions, such as prices, demand and supply. In the above backdrop, there is a dire need, first and foremost, to further strengthen the access of small and marginal farmers to agricultural credit, inputs, technology and 'extension services.' At the same time there is a need to plug bottlenecks in transaction costs associated with their market entry and attaining economies of scale. To do so, aggregation of farmers into Farmer Producer Organizations (FPOs) and more specifically Farmer Producer Companies (FPCs) has been suggested by experts as the way forward. In this study, we fill this research gap by investigating market risk carried away by the small and marginal farmers in their production activity.

Research Methodology

The study was conducted in four villages namely Pattanam, Koneripatti, Kakaveri, Singalandhapuram from Rasipuram block of Namakkal district. The sample size consists of 40 respondents selected from these villages by random sampling methods.

There are 12 independent variables namely age, gender, education, occupation, type of farmers, credit access, market information, market access, risk perception, annual income, storage facilities, institutional participation were considered for this study.

There are 4 dependent variables namely risk faced, market risk faced by farmers, coping strategies followed by farmers, schemes provided by government for risk are the dependent variable considered in this study.

The respondents were interviewed personally by a well-structured and pre-tested interview schedule. The statistical tools of percentage analysis and cumulative frequency were used to analyse collected data. The findings were meaning fully interpreted and relevant conclusions were drawn.

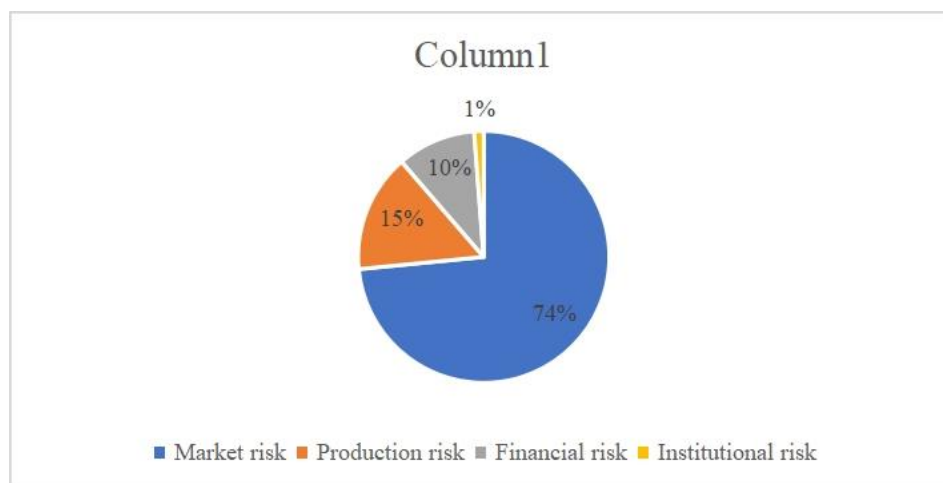
Findings and Discussions

The result of the study showed that majority of the male respondents belonged to old age category, mostly follow farming only. Most of the farmers have completed high school education and having small area of land. Out of 40 respondents, 55 percent did not access to credit and they maintain loyalty relation with buyers. 90 percent of respondents access the market in closest city and distant market. More than 90 percent of the respondents facing market risk. The 45 percent of respondents having high annual income of (Rs.70,000) and 50 percent store their produce in sacks. Out of 40 respondents, more than half have low institutional participation.

Farmers face wide range of risks that can affect their productivity, income and long-term sustainability. These risks can be broadly categorised into production, market, financial, institutional and human resource risk.

Distribution of Respondents to their Risk Faced by the Farmer

S.No.	Risk	Score	Percent
1	Market risk / Price risk	29	72.5
2	Production risk	6	15
3	Financial risk	4	10
4	Institutional risk / legal risk	1	2.5
	Total	40	100



Pie chart depicting risk faced by the farmers

The table 16 reveals that more than half of respondents (74%) facing market risk followed by 15% facing production risk, 10% facing financial risk and 1% facing institutional risk. From the findings, it may be concluded that majority of respondents facing market risk.

Market risks are uncertainties that arise from changes in prices, demand and marketing conditions of agricultural products. They directly affect farmers income and profitability.

Distribution of Respondents to their Market Risk Faced by the Farmer

S.No	Market Risk	Score	Percent
1	Natural disaster	38	95
2	Lack of Market Information	26	65
3	Lack of Storage Facilities	22	55
4	Minimum Support Price	19	47.5

5	Lack of demand	17	42.5
6	Malpractices in selling	4	10
7	Middleman Interference	16	40
8	Input cost volatility	37	92.5
9	Risk in value addition	17	42.5
10	Risk in transportation	15	37.5

The table 17 reveals that 95% of respondents facing natural disaster as a major risk and this is due to the lack of awareness of weather forecasting followed by 92.5% of the respondents facing input cost volatility mainly due to less availability of inputs , gradually increases of cost of inputs, 65% of respondents undergoing lack of market information's our respondents belongs to old age category and so they lack knowledge on new technology to obtain the and market information's, 55% of the respondents undergoing lack of storage facilities, as our respondents are small and marginal farmers they avail storage godowns and government ware houses but due to high transport charges they couldn't reach it and failed to store their produce, 47.5% of respondents undergoing the risk of MSP as the MSP is fixed all over the country and the cost of production varies for different regions so we suggest to fix MSP for every region according to their cost of production, 10% respondents facing malpractices in selling as a risk. From the findings, it may be concluded that majority of respondents facing natural disaster as a market risk.

Coping Strategies Followed by Farmers

Traditional strategies such as diversification, agricultural insurance, contract farming and financial savings provide foundation and risk mitigation. Diversification spreads risk across various crop and livestock, while insurance policies protect against financial losses from unforeseen events. Scoring procedure followed by Munesh *et al.* (2015).

Distribution of Respondents to Management Strategies Followed by the Farmer

S. No.	Risk	Management	Score	Percent
1	Natural disaster	Schemes	26	65
2	Lack of Market Information	Mobile apps, Government Databases (e NAM, AGMARK), FPO, KCC, kisan portal	15	37.5
3	Lack of Storage Facilities	Schemes (PM-Kisan sampada Yojana), Government and private warehousing (WRS), cooperative storage (FPO), Cold chain storage	18	45
4	Minimum Support Price	Direct marketing, Agri processing and value addition, storing, alternate income sources (livestock, poultry)	24	60
5	Lack of demand	Mixed cropping, value addition, postharvest technology.	2	5
6	Malpractices in selling	Direct marketing (Uzhavar sandhai), Implementation of ENAM, Encourage contract farming, QR codes and mobile receipts	32	80
7	Middleman Interference	Direct marketing, Digital Platforms (Agribazaar), Government procurement, Cooperatives, Promotion of storage and processing units	7	13.5
8	Input cost volatility	Input procurement, Government subsidies (SMAM, PM-KISAN, Soil health card scheme)	28	70

9	Risk in value addition	Subsidies and loans (NABARD, PMFME), MSME loans, Certification (FSSAI, AGMARK)	30	75
10	Risk in transportation	Use of Government Transport schemes (PMFME, AGMARKNET), Develop rural transport hubs and godowns	2	5

The table 18 reveals that 80% of respondents choose to sell in uzhavar sandhai to mitigate risk because of the easy transport and no middleman interference followed 75% of the respondents avoid the value addition risk using subsidies and loans which is easier to reach. 70% of the respondents mitigate input cost volatility using input procurement from government in subsidies and minimum support price risk is mitigated through direct marketing.

Schemes Provided by Government for Risk

The Indian government provides several schemes to reduce production, market and financial risk for farmers.

Distribution of Respondents to the Schemes Provided by the Government for Market Risk

S. No.	Schemes	Score	Percent
1	PMFBY	17	42.5
2	PM-KISAN	39	97.5
3	e-NAM	13	32.5
4	FPO	17	42.5
5	NAIS	17	42.5

The table 19 reveals that more than half of respondents (97.5%) avail PM-KISAN and 42.5% avail farmers PMFBY which is less than PM-KISAN due to lack of awareness so Farmers should use the Pradhan Mantri Fasal Bima Yojana (PMFBY) because it offers financial protection against crop loss, which is critical in a profession highly dependent on unpredictable factors like weather and pests, PMFBY: Protection Against Natural Calamities and Low Premium Rate, FPO, NAIS. From the findings, it may be concluded that majority of respondents are availing PM-KISAN.

Suggestions of the Research Study

1. Existing crop schemes (PM-FBY) provide 35,000 subsidies as crop insurance which include only the production cost. So, it is suggested to include the input cost, transportation cost, labour cost in the insurance which will help the farmers to cope up their risk.
2. To overcome the risk in value addition farmers are suggested to attend the trainings and skill development programmes based on value addition in KVKs to learn the modern processing techniques.
3. To avoid transportation charges for distant market farmer can utilize the nearest and local hubs run by the government.
4. In case of input cost volatility, the farmers are advised to use the soil health card scheme which provides information on the optimum use of inputs like fertilizers, pesticides.
5. To avoid the middleman interference farmers are put forward to reach the nearby cooperative societies.
6. To minimize the risk in minimum support prize farmers can adopt alternate income source like poultry, livestock, apiculture and others.
7. To minimize the risk in storage facilities farmers can move to government warehousing which provides subsidies on storage.
8. Contract farming will help the farmers to overcome malpractices in which avails steady income and loyal customers.

9. To create awareness regarding market information, assistant agricultural officers can be appointed in panchayat level which help the farmers to obtain the information earlier.

10. In case of low demand, farmers are requested to follow post-harvest technologies to prevent the damage from post-harvest losses.

Conclusion

It is concluded that the risk faced by the farmers and the existing management strategies are found through the study and the suggestions are interpreted based on their risk, these suggestions could help farmers minimize their difficulties in marketing and helps to increase their farm income and aid in sustainable agriculture.

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Fragmented Land Holdings and Low Mechanization: The Double Bind of Indian Agriculture

Article ID: 72016

Boniga Mohan Uday Raj¹, D.A. Rajini Devi²

¹Ph.D Research Scholar, Department of Agricultural Economics, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad-500030, Telangana, India.

²Field Officer (Scientist), Cost of Cultivation Scheme, Department of Agricultural Economics, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad-500030, Telangana, India.

Introduction

Indian agriculture today faces a paradox: while technological innovations have transformed productivity in many nations, India remains caught in the twin challenges of shrinking landholdings and incomplete mechanization. According to the Agriculture Census (2015–16), the average size of operational holdings declined to 1.08 hectares, down from 2.3 hectares in 1970–71. More recent surveys (NAFIS, SAS) place the effective average closer to 0.56–0.70 hectares. This trend means that over 86% of India's farmers are small or marginal, operating less than 2 hectares of land (Government of India, 2023).

While land fragmentation undermines economies of scale, mechanization remains partial averaging only 45% overall. Certain tasks like land preparation achieve high mechanization (70%), but sowing (~40%), weeding (~33%), and harvesting (~34%) remain dependent on manual labor (PIB, 2025). These structural limitations keep costs high, yields unstable, and rural incomes constrained.

Why Fragmentation Hinders Mechanization?

1. Uneconomical Scale of Operation: Large machinery such as tractors and combines are most cost-effective on contiguous land. With scattered plots, the per-hectare cost rises due to higher fuel use, travel time, and under-utilization (Birthal & Hazrana, 2019).

2. Timing Vulnerabilities: In India's monsoon-driven cropping cycles, delays in sowing or harvesting translate into yield losses. Small farmers without reliable machine access often miss these windows (Basantaray *et al.*, 2024).

3. Credit and Ownership Barriers: Mechanization usually requires capital investment. However, fragmented holdings reduce collateral value, making it difficult for smallholders to access institutional finance (Jain *et al.*, 2021).

4. Under-Utilization of Assets: A tractor on a 1-hectare farm remains idle for much of the year. Without service markets, ownership is uneconomical.

Current Policy Interventions

1. Sub-Mission on Agricultural Mechanization (SMAM): The SMAM scheme subsidizes machinery purchases and encourages Custom Hiring Centres (CHCs), where farmers rent machines on an hourly or acreage basis. Revised guidelines (2024–25) also support drone-based services, enabling smallholders to access precision spraying at lower costs (Government of India, 2023).

2. Farm Power Growth: Farm power availability has increased from 0.36 kW/ha in the mid-1970s to ~2.5 kW/ha in 2016–17 (PwC, 2024). However, India still lags behind nations like China and Brazil, where farm power exceeds 4–6 kW/ha.

3. Drones and Emerging Technologies: In 2025, subsidies cover 40–50% of drone costs for individual farmers, and up to ₹10 lakh for ICAR institutions. The model prioritizes service providers, not individual ownership, making drones accessible to fragmented farms (PIB, 2025).

The Economist's Perspective

From an economic standpoint, fragmented landholdings increase transaction costs, while low mechanization reduces productivity growth. The challenge is to design policies that deliver functional scale without physical consolidation.

1. Service-Based Models: Aggregating demand through CHCs, drone hiring services, and farmer producer organizations (FPOs) allows cost-sharing and improves utilization.

2. Smallholder-Centric Machinery: Mini-harvesters, lightweight tillers, and modular attachments are crucial for fragmented plots.

3. Finance Innovation: Credit should follow machine use, not ownership—linking loans to service invoices rather than land collateral.

4. Skill Development: Mechanization creates jobs for operators, mechanics, and drone pilots—especially benefiting rural youth and women.

Conclusion

India's farm structure, marked by small and fragmented holdings, continues to restrict agricultural mechanization. Yet, by promoting service-based delivery models, smallholder-appropriate machines, and financial innovation, India can overcome structural constraints. The future of mechanization lies not in every farmer owning machines, but in shared access that balances scale with equity.

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Zinc-Based Formulations: A Step Towards Micronutrient Efficiency in Crops

Article ID: 72017

Pinniboina Nagendra Babu¹, Billa Sindhu Reddy¹

¹Research Associate, Department of R&D, Senior Research Associate, Department of R&D, Sowbhagya Biotech Pvt. Ltd., Cherlapally, Hyderabad – 500051, India.

Summary of Article

Zinc deficiency in soils limits plant growth, stress tolerance, and nutritional quality of food grains. Advances in zinc-based formulations—including zinc oxide nanoparticles (ZnO NPs), chelated compounds, and microbial consortia—are transforming micronutrient delivery. Recent field studies demonstrate that ZnO NPs significantly enhance rice yield and quality, foliar application boosts drought resilience, and zinc-solubilizing bacteria improve bioavailability in soils. These innovations represent a step toward micronutrient-efficient and climate-resilient agriculture.

Introduction

Zinc (Zn) is a critical micronutrient required for enzymatic activity, protein synthesis, and auxin regulation in plants. Its deficiency is widespread in calcareous and alkaline soils, leading to stunted growth, chlorosis, poor grain filling, and nutritional deficits in humans relying on zinc-deficient crops (Singh et al., 2015). Conventional amendments like zinc sulfate are limited by rapid soil fixation and low efficiency.

To address this, modern zinc formulations—nanoparticles, chelates, and microbial inoculants—are being developed. These innovations not only increase zinc solubility and uptake but also enhance stress tolerance and food quality (Zhang et al., 2025).

Recent Advances in Zinc-Based Formulations

Zinc Oxide Nanoparticles (ZnO NPs): ZnO NPs applied basally at 7.5–30 kg ha⁻² in rice significantly improved yield (0.34–0.50 t ha⁻² increase), zinc concentration in grains, and overall fertilizer use efficiency compared to zinc sulfate (Zhang et al., 2025a).

Foliar sprays of ZnO NPs at the panicle initiation stage improved photosynthesis, delayed leaf senescence, and enhanced grain quality, including reduced chalkiness and better cooking properties (Zhang et al., 2025b).

In eggplant, foliar ZnO NP applications (50–100 ppm) under drought improved relative water content, membrane stability, and yield by ~22%, highlighting their role in stress management (Ali et al., 2021).

In pea (*Pisum sativum*), ZnO NPs mitigated salinity-induced oxidative stress, improving root length and physiological performance (Kaur et al., 2024).

Zinc-Solubilizing Bacteria (ZSB): Zinc-solubilizing bacteria (e.g., *Pseudomonas*, *Bacillus*, *Enterobacter*) enhance zinc bioavailability by secreting organic acids, siderophores, and chelators. A recent study confirmed that ZSB inoculation improved soil enzyme activity, microbial diversity, and zinc uptake in wheat under field conditions, reducing the need for chemical fertilizers (Singh et al., 2025).

Table 1. Comparison of Zinc Delivery Strategies:

Sl No	Formulation / Strategy	Key Benefits	Recent Evidence
1	ZnO Nanoparticles (basal)	Higher yield & zinc concentration in rice	Zhang et al., 2025a
2	Foliar ZnO NPs	Better photosynthesis & grain quality	Zhang et al., 2025b
3	ZnO NPs under stress	Drought and salinity stress mitigation	Ali et al., 2021; Kaur et al., 2024

4	Zinc-Solubilizing Bacteria	Sustainable nutrient cycling & soil health	Singh et al., 2025

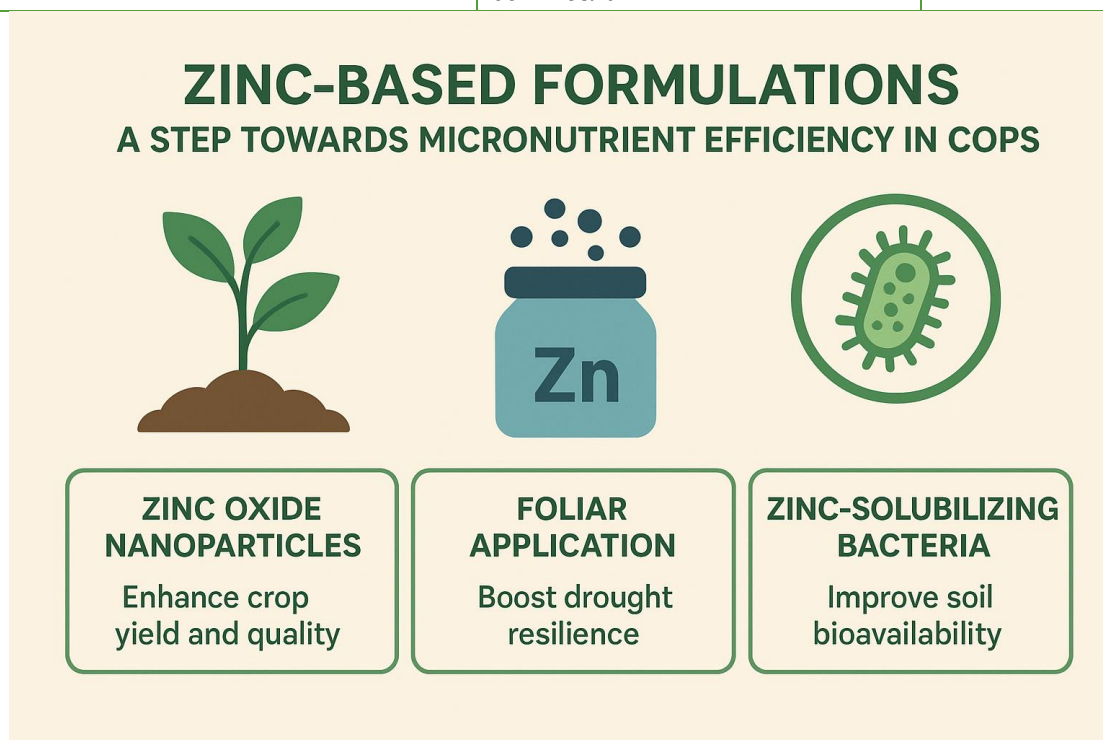


Fig-1: Zinc Delivery Strategies

Personal Opinion

Zinc nanotechnology and microbial inoculants are not competitors but complementary tools. I strongly believe that integrating nano-zinc with zinc-solubilizing microbes could deliver both immediate and long-term improvements in crop nutrition. However, large-scale field validations and biosafety studies remain crucial before mass adoption.

Summary/Conclusion

Zinc-based formulations are ushering in a new era of micronutrient management in agriculture. ZnO nanoparticles significantly improve yield, stress resilience, and nutritional quality, while zinc-solubilizing bacteria promote eco-friendly nutrient cycling. Together, they provide a robust path toward sustainable, nutrient-efficient, and resilient farming systems.

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Mechanisms of Nutrient Mobilization by Microbial Consortia: Enzymatic Pathways and Gene Expression

Article ID: 72018

Billa Sindhu Reddy¹, Pinniboina Nagendra Babu¹

¹Senior Research Associate, Department of R&D, Research Associate, Department of R&D, Sowbhagya Biotech Pvt. Ltd., Cherlapally, Hyderabad, 500051, India.

Summary

Microbial consortia are pivotal in enhancing soil nutrient availability by transforming bound nitrogen, phosphorus, and potassium into plant-accessible forms. This occurs through a series of enzymatic processes including nitrogenase-mediated fixation, secretion of phosphatases and organic acids for phosphorus release, and mineral weathering that mobilizes potassium. At the molecular level, functional genes such as *nifH*, *phoD*, and *pqq* act as regulators, modulating microbial nutrient release under changing soil and rhizosphere conditions. Understanding these biological mechanisms is vital for designing advanced microbial formulations that support soil fertility while reducing dependence on synthetic fertilizers.

Introduction

Soil nutrient deficiencies—especially of nitrogen (N), phosphorus (P), and potassium (K)—remain key constraints to achieving high crop productivity. Although chemical fertilizers provide a short-term solution, their excessive use often disrupts soil health, reduces microbial diversity, and contributes to environmental degradation (Singh et al., 2015). As an alternative, microbial consortia—diverse communities of bacteria and fungi—offer sustainable pathways to replenish soil fertility. These microbes act collectively, secreting enzymes and metabolites that mobilize nutrients otherwise locked in unavailable forms (Negi et al., 2024).

Nitrogen Fixation by Microbial Communities

Nitrogen is the most limiting nutrient in many soils, and its biological fixation is a crucial microbial service. Genera such as *Rhizobium*, *Azotobacter*, and *Azospirillum* convert atmospheric N₂ into plant-usable ammonia using the nitrogenase enzyme complex. This process is tightly regulated by genes such as *nifH*, *nifD*, and *nifK*, with their expression responding to soil nitrogen availability and oxygen levels (Kumar & Sharma, 2018). Advances in synthetic microbial communities (SynComs) have enabled the integration of nitrogen-fixing species with phosphorus- and potassium-solubilizing microbes, thereby improving crop growth under real field conditions (Singh et al., 2025).

Phosphorus Solubilization

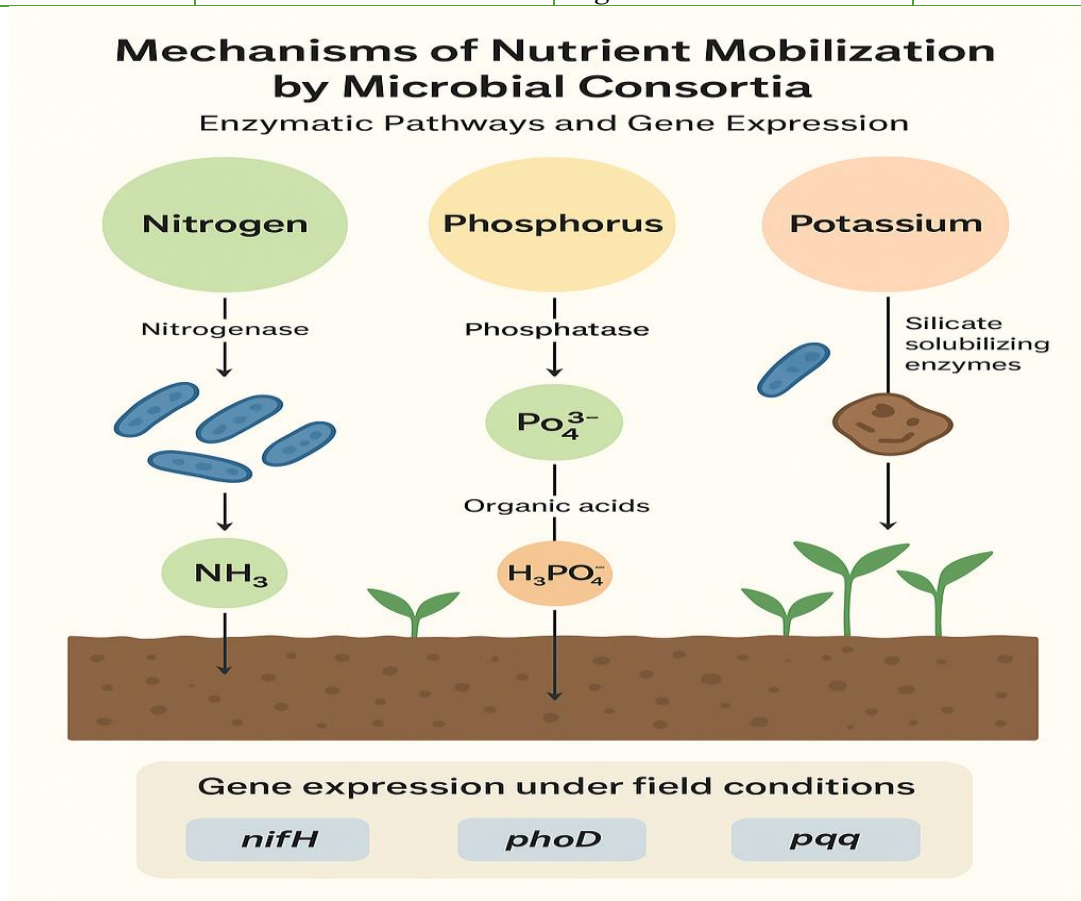
Although phosphorus is abundant in soils, most of it exists in insoluble mineral or organic complexes. Microbes such as *Bacillus*, *Pseudomonas*, and *Aspergillus* increase phosphorus availability by secreting low-molecular-weight organic acids (gluconic, citric, oxalic acids) that dissolve mineral phosphates, along with enzymes like phosphatases and phytases that release P from organic matter. Genetic regulators such as *phoD* (alkaline phosphatase) and *pqq* (cofactor for glucose dehydrogenase) are strongly expressed under P-deficient conditions (Gupta et al., 2021). Recent reports show that combining microbial consortia with biochar enhances phosphate mobilization in nutrient-depleted soils (X. et al., 2025).

Potassium Release through Microbial Weathering

Much of the soil potassium is bound in primary minerals such as feldspar and mica. Potassium-solubilizing microorganisms (KSMs) like *Bacillus mucilaginosus* and *Aspergillus niger* secrete organic acids that dissolve silicate minerals and release exchangeable K⁺. These processes offer a biological substitute for chemical potash fertilizers. Tailor-made microbial consortia with enhanced K-solubilizing traits have demonstrated significant improvements in nutrient uptake and yield of cereals and legumes (Meena et al., 2016; Negi et al., 2024).

Table 1. Key mechanisms, microbes, and genetic markers for nutrient mobilization:

Nutrient	Mechanism Enzymes	Representative Microbes	Genetic Markers
Nitrogen	Nitrogenase-mediated fixation	<i>Rhizobium</i> , <i>Azotobacter</i> , <i>Azospirillum</i>	<i>nifH</i> , <i>nifD</i> , <i>nifK</i>
Phosphorus	Phosphatases, phytases, organic acids	<i>Bacillus</i> , <i>Pseudomonas</i> , <i>Aspergillus</i>	<i>phoD</i> , <i>pqq</i> , <i>gcd</i>
Potassium	Silicate mineral solubilization	<i>B. mucilaginosus</i> , <i>A. niger</i>	Organic acid metabolism genes


Fig1. Mechanism of Nutrient mobilization by Microbial consortia

Gene Expression in Field Conditions

While controlled experiments demonstrate strong enzymatic activity, microbial gene expression in field soils is influenced by multiple environmental factors such as pH, temperature, soil texture, and crop rhizosphere exudates. For example, *nifH* is upregulated under nitrogen starvation but suppressed in nitrogen-rich soils, whereas *phoD* expression increases under phosphorus scarcity (Patel et al., 2020). Transcriptomic studies in field-grown crops reveal that microbial consortia dynamically regulate nutrient-related genes, enabling them to adapt to fluctuating soil conditions (Gupta et al., 2021). This adaptability highlights the potential of SynCom-based biofertilizers in improving nutrient-use efficiency.

Conclusion

Microbial consortia enhance nutrient availability through nitrogen fixation, phosphorus solubilization, and potassium weathering. Their efficiency depends on both enzymatic activity and the expression of genes such as *nifH*, *phoD*, and *pqq* under field conditions. Emerging tools such as synthetic microbial communities and multi-omics approaches provide opportunities to harness these interactions for sustainable agriculture. By replacing a portion of chemical fertilizers, microbial biofertilizers can play a central role in maintaining soil fertility and improving crop productivity.

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Endophytes: The Hidden Allies for Crop Growth and Stress Management

Article ID: 72019

Pinniboina Nagendra Babu¹, Billa Sindhu Reddy¹

¹Research Associate Department of R&D, Senior Research Associate Department of R&D, Sowbhagya Biotech Pvt. Ltd., Cherlapally, Hyderabad, 500051, India.

Summary of Article

Endophytes—symbiotic microorganisms living inside plant tissues without causing disease—are increasingly recognized as natural allies in crop growth and stress resilience. They improve nutrient acquisition, produce phytohormones, and enhance tolerance against abiotic stresses like drought, salinity, and heat. Endophytes also prime plant immunity and offer biocontrol against pathogens by producing antimicrobial metabolites. Their dual role in promoting growth and protecting against stress highlights their potential as sustainable alternatives to chemical fertilizers and pesticides.

Introduction

What Are Endophytes: Endophytes are bacteria and fungi residing asymptotically within plant tissues, including roots, stems, and leaves. Unlike pathogens, they establish a mutualistic association with the host, offering benefits such as enhanced growth, nutrient uptake, and stress tolerance (Singh et al., 2015). Their ecological importance has been increasingly recognized in the context of sustainable agriculture, as they help plants adapt to environmental challenges while reducing chemical input reliance (Verma et al., 2022).

Role in Crop Growth Promotion

Endophytes improve crop productivity through multiple mechanisms. They synthesize phytohormones such as indole-3-acetic acid (IAA), gibberellins, and cytokinins, which stimulate root growth and shoot development (Singh and Mishra, 2015). Many endophytic bacteria also fix atmospheric nitrogen, solubilize phosphate, and mobilize potassium, thereby improving nutrient availability (Gupta et al., 2021).

Stress Management by Endophytes

Endophytes play a vital role in mitigating abiotic stresses:

- 1. Drought Stress:** Endophytes increase osmolyte accumulation, regulate stomatal function, and enhance water-use efficiency (Kumar et al., 2023).
- 2. Salinity Stress:** They reduce ion toxicity by balancing Na^+/K^+ ratios and boosting antioxidant activity.
- 3. Heat Stress:** Endophytes stimulate heat-shock protein expression and stabilize membranes under high temperature.

Endophytes also help combat **biotic stresses** by producing secondary metabolites such as alkaloids, flavonoids, and antimicrobial peptides that suppress pathogens (Patel et al., 2022).

Table 1. Functional Roles of Endophytes in Plant Stress Management:

Stress Type	Endophytic Mechanism	Example Microbes	Key Traits / Genes
Drought	Osmolyte accumulation, ABA regulation	<i>Bacillus subtilis</i> , <i>Piriformospora indica</i>	ACC deaminase activity
Salinity	Ion balance, antioxidant enzymes	<i>Pseudomonas fluorescens</i> , <i>Trichoderma spp.</i>	Na^+/K^+ transporter genes
Heat	Induction of heat-shock proteins	<i>Burkholderia cepacia</i>	HSP70 expression
Pathogens	Antimicrobial metabolites, ISR	<i>Streptomyces</i> , <i>Fusarium oxysporum</i> (non-pathogenic strains)	Antibiotic biosynthesis clusters

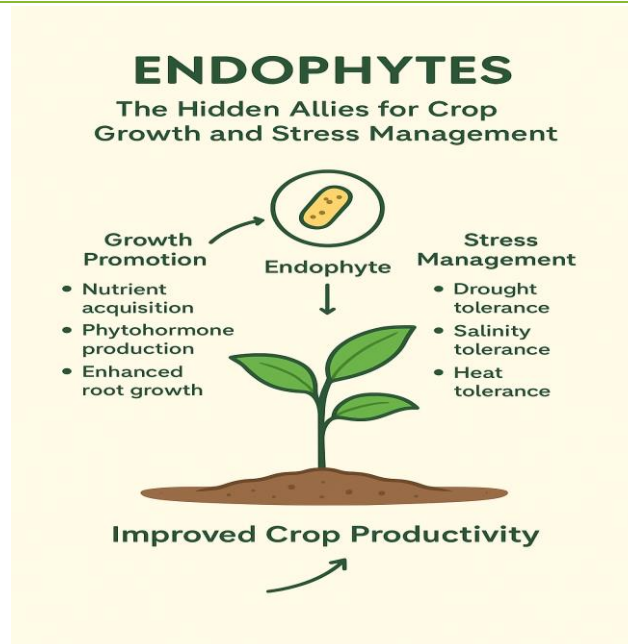


Fig. 1: Endophyte-Mediated Productivity

Field Evidence of Endophyte Applications

Recent studies confirm that endophyte inoculations in crops such as rice, maize, and wheat improve yield under stress-prone conditions (Rahman et al., 2023). For example, endophytic *Piriformospora indica* enhances phosphorus uptake and tolerance to drought, while *Bacillus* spp. have been shown to reduce salt stress damage in tomato and cucumber. Integrating endophyte-based bioinoculants into conventional farming practices represents a promising strategy for climate-resilient agriculture (Yadav et al., 2024).

Personal Opinion

In my view, endophytes represent the **future of biofertilizer and biopesticide technology**. They provide a “dual advantage” of growth promotion and stress tolerance, which is particularly valuable in the face of climate change. However, the major challenge lies in **formulation stability, host specificity, and large-scale commercialization**. More investment in **multi-omics research, strain selection, and delivery systems** is needed to unlock their full potential for farmers worldwide.

Summary/Conclusion

Endophytes act as hidden allies in agriculture, strengthening plant growth and stress resilience through multiple physiological, biochemical, and molecular mechanisms. Their ability to enhance nutrient uptake, produce phytohormones, and regulate stress-responsive genes makes them indispensable tools for sustainable farming. With advancing research and innovation, endophyte-based bioinoculants can become vital components of climate-smart crop production systems.

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Multi-Strain Probiotics: Enhancing Fish Health and Growth in Aquaculture

Article ID: 72020

Billa Sindhu Reddy¹, Pinniboina Nagendra Babu¹

¹Senior Research Associate, Department of R&D, Research Associate, Department of R&D, Sowbhagya Biotech Pvt. Ltd., Cherlapally, Hyderabad, 500051, India.

Summary

Multi-strain probiotics—mixtures of two or more beneficial microbes—are increasingly recognized as reliable tools to improve growth, feed efficiency, disease resistance, and gut health in farmed fish and shrimp. Compared with single strains, carefully designed consortia exploit complementary mechanisms such as pathogen exclusion, secretion of antimicrobial metabolites and enzymes, enhanced nutrient digestibility, and broad immunostimulation.

Studies show consistent gains in growth rate, survival, and innate immune markers when multi-strain blends of *Bacillus*, *Lactobacillus*/*Limosilactobacillus*, and other genera are fed for 30–90 days or applied via water, with effects often exceeding those of single strains (Sabri, 2021; Xie et al., 2024). However, “quality by design” is critical—accurate strain identification, safety screening for antibiotic resistance, dose optimization, and proof of viability through the value chain are essential steps.

Overall, multi-strain probiotics are not a silver bullet, but when integrated with good husbandry and biosecurity, they offer a practical, eco-friendly lever for stronger performance and resilience in aquaculture.

Introduction

The FAO and WHO define probiotics as “live microorganisms which, when administered in adequate amounts, confer a health benefit to the host” (FAO/WHO, 2002). This definition has shaped their application across food animals, including aquaculture. In fish and shrimp production, probiotics emerged as sustainable alternatives to antibiotics, showing benefits for growth, feed utilization, immune function, microbiome balance, and water quality (Melo-Bolívar et al., 2023).

Why Multi-Strain?

Mixed cultures often provide broader mechanisms of action and more consistent performance across variable pond or recirculating aquaculture system (RAS) conditions. Reviews and controlled studies indicate that multi-strain blends frequently outperform single strains in terms of growth and immune stimulation (Sabri, 2021; Xie et al., 2024).

How Multi-Strain Probiotics Work (Mechanisms)

- 1. Colonization resistance & pathogen suppression:** Beneficial microbes compete for adhesion sites and nutrients while producing bacteriocins and organic acids that inhibit pathogens (Sabri, 2021).
- 2. Digestive support:** Enzyme-producing *Bacillus* spp. enhance proteolysis, amylolysis, and lipolysis, improving feed conversion and growth (Melo-Bolívar et al., 2023).
- 3. Immune modulation:** Multi-strain feeding elevates lysozyme activity, complement proteins, and cytokine levels, enhancing disease resistance (Xie et al., 2024).
- 4. Microbiome balancing:** Consortia stabilize gut microbial communities more effectively than single strains, improving resilience under stress (Sabri, 2021).
- 5. Water quality co-benefits:** Certain strains assist in metabolite degradation and nitrogen cycling, improving pond water quality (Melo-Bolívar et al., 2023).

Evidence Snapshot (Fish Examples)

- 1. Hybrid grouper (*Epinephelus* spp.):** A two-strain combination of *Bacillus cereus* and *Exiguobacterium acetylicum* improved growth, intestinal health, and immune status beyond single-strain treatments (Xie et al., 2024).
- 2. Tilapia:** Meta-analyses show dietary probiotics, particularly multi-strain formulations, significantly enhance growth, immune response, and disease resistance (Sabri, 2021).
- 3. Across species:** Reviews consistently report that probiotics boost weight gain, feed efficiency, survival, and pathogen resistance in freshwater and marine systems (Melo-Bolívar et al., 2023).

Designing an Effective Multi-Strain Consortium

- 1. Choose complementary roles.** Enzyme producers such as *Bacillus subtilis*, *B. licheniformis*, and *B. pumilus* should be combined with lactic acid bacteria for adhesion and immune priming (Sabri, 2021).
- 2. Verify identity & safety.** Whole-genome sequencing ensures correct identification, while screening for antimicrobial resistance (AMR) and toxins aligns with EFSA guidelines (European Food Safety Authority, 2012).
- 3. Optimize dose & delivery.** Evidence shows feed inclusion provides the most consistent benefits, while water application may supplement during stress conditions (Xie et al., 2024).
- 4. Assure viability.** Use spore-formers like *Bacillus* for stability and protect LAB with encapsulation methods (Melo-Bolívar et al., 2023).
- 5. Validate on farm.** Run 8–12-week pilots, tracking growth, feed conversion, survival, and immune markers (Sabri, 2021).

Implementation Notes

Feed delivery ensures accurate dosing and consistent gut colonization, while water application can help balance pond microbiota. In practice, both methods may be complementary (Melo-Bolívar et al., 2023).

Safety & Regulatory Considerations

Although probiotics are generally safe, certain strains may harbor transferable AMR genes. These must be identified and excluded (European Food Safety Authority, 2012). Proper documentation of strain identity, purity, and viable counts is necessary for regulatory compliance and farmer trust.

Personal Opinion

From a farm-level view, multi-strain probiotics are most effective when treated as nutritional-health inputs rather than “quick fixes.” The best outcomes come from pairing hardy *Bacillus* spp. with gut-colonizing lactic acid bacteria, applied daily via feed and supported by sound water quality management. Using poorly characterized products without genomic safety checks is risky and may undermine both farm performance and food safety.

Conclusion

The collective evidence supports multi-strain probiotics as an eco-friendly strategy to enhance fish growth, immunity, and resilience, often surpassing single-strain products. Success depends on strain selection, safety verification, and consistent application under farm conditions. With proper design and management, multi-strain probiotics can reduce reliance on antibiotics while delivering both biological and economic benefits to aquaculture.

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Waste to Wealth: Agro-Industrial Byproducts as Carriers for Biofertilizers

Article ID: 72021

Billa Sindhu Reddy¹, Pinniboina Nagendra Babu¹

¹Senior Research Associate, Department of R&D, Research Associate, Department of R&D, Sowbhagya Biotech Pvt. Ltd., Cherlapally, Hyderabad, 500051, India.

Summary

Agro-industrial residues such as paddy husk, biochar, fly ash, and other crop byproducts are increasingly being explored as cost-effective and eco-friendly carriers for biofertilizer formulations. Unlike traditional carriers such as peat and lignite, which are non-renewable and environmentally unsustainable, these waste-derived materials enhance microbial survival, storage stability, and field performance. Studies have shown that paddy husk effectively supports *Bacillus subtilis* viability during prolonged storage, maintaining higher microbial counts than conventional carriers (Journal of Material Cycles and Waste Management, 2012). Similarly, combining biochar with fly ash has demonstrated prolonged viability of *Bacillus* and *Burkholderia* strains, while significantly improving eggplant yield, soil nutrient content, and water retention capacity (Tripti et al., 2022). Pre-treatment of agro-waste carriers—through sterilization, particle sizing, and moisture optimization—is key to ensuring microbial compatibility and shelf stability (Mandal et al., 2024). Overall, using agro-industrial waste as carrier material creates a win-win scenario: reducing disposal challenges while advancing sustainable biofertilizer development. Its integration into mainstream agriculture, however, requires standardization, farmer training, and supportive policies.

Introduction

The rapid buildup of agro-industrial waste, including rice husk, sugarcane pressmud, sawdust, and bagasse, is a growing environmental issue. At the same time, the biofertilizer sector faces limitations due to reliance on costly, non-renewable carriers such as peat and lignite. Transitioning to agro-waste-based carriers addresses both challenges by converting underutilized residues into valuable agricultural inputs. These materials not only reduce environmental load but also provide a sustainable, low-cost medium to deliver beneficial microbes effectively to the field. This approach strengthens circular economy practices while advancing sustainable agriculture.

Key Examples & Mechanisms

Paddy Husk as Carrier for *Bacillus subtilis*: Experiments have shown that paddy husk maintains viable counts of *Bacillus subtilis* (up to 2.46×10^5 CFU/g at 28 °C) even after long-term storage, outperforming lignite in sustaining microbial activity. Its abundance, biodegradability, and low cost make it a strong candidate for widespread use (Journal of Material Cycles and Waste Management, 2012).

Biochar-Fly Ash Blend for Eggplant Cultivation: A recent study demonstrated that combining biochar derived from crop residues with fly ash supported the survival of *Burkholderia* and *Bacillus* strains for up to 270 days. The formulation enhanced eggplant growth, seed germination, fruit yield, and soil fertility indicators, underscoring its dual role as a carrier and soil improver (Tripti et al., 2022).

Formulation Considerations: For agro-waste to function as reliable carriers, they require treatments such as sterilization, moisture regulation, and particle-size optimization. Proper inoculation, curing, and storage processes ensure carrier compatibility with microbial inoculants, making them a practical solution for biofertilizer production (Mandal et al., 2024).

Waste to Wealth: Agro-Industrial Byproducts as Carriers for Biofertilizers



Agro-industrial residues such as paddy husk, biochar, fly ash, and other crop byproducts are increasingly being explored as cost-effective and eco-friendly carriers for biofertilizer formulations.



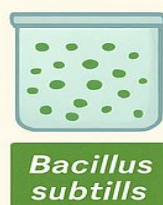
Key Examples & Mechanisms

Paddy husk as carrier



for *Bacillus subtilis*

Experiments have shown that paddy husk maintains viable counts of *Bacillus subtilis* (up to 2.46×10^9 CFU/g at 28°C) even after long-term storage, outperforming lignite in sustaining microbial activity.



Bacillus subtilis

Biochar-Fly ash Blend for eggplant cultivation



Combining biochar with fly ash has demonstrated prolonged viability of *Bacillus* and *Burkholderia* strains, while significantly improving eggplant yield, soil nutrient content, and water retention capacity.

Formulation Considerations

Pre-treatment of agro-waste carriers—through sterilization, particle sizing, and moisture optimization—is key to ensuring microbial compatibility and shelf stability.

Agro-industrial byproducts such as paddy husk, biochar, and fly ash are proving to be effective alternatives to conventional biofertilizer carriers. They enhance microbial survival, extend storage life, and enrich soil health while reducing environmental waste.



Fig.1 Sustainable Carriers for Biofertilizers

Personal Opinion

From my perspective, agro-waste utilization represents one of the most impactful pathways for sustainable agricultural innovation. These residues, often considered disposal problems, can be transformed into resources that support microbial delivery and soil improvement. Farmers may be more inclined to adopt such biofertilizers since the raw materials are locally familiar and affordable. Nevertheless, widespread use depends on establishing clear protocols for carrier processing, ensuring consistent microbial performance, and strengthening regulatory approval systems. If these gaps are addressed, agro-waste-based carriers could redefine the economics and sustainability of biofertilizers.

Conclusion

Agro-industrial byproducts such as paddy husk, biochar, and fly ash are proving to be effective alternatives to conventional biofertilizer carriers. They enhance microbial survival, extend storage life, and enrich soil health while reducing environmental waste. Adopting such carriers aligns perfectly with sustainable agriculture and circular economy principles. Moving forward, farmer education, standardization of

formulation protocols, and supportive government policies will be essential to shift these approaches from experimental validation to large-scale practice.

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Potassium Fulvic Humate: A Key Input for Enhancing Soil Fertility and Nutrient Uptake

Article ID: 72022

Pinniboina Nagendra Babu¹, Billa Sindhu Reddy¹

¹Research Associate Department of R&D, Senior Research Associate Department of R&D, Sowbhagya Biotech Pvt. Ltd., Cherlapally, Hyderabad, 500051, India.

Summary of Article

Potassium fulvic humate, derived from humic substances, is emerging as an eco-friendly soil amendment with multiple agronomic benefits. It enhances nutrient solubility, improves root development, and stimulates beneficial soil microbes, leading to better crop growth and stress resilience. Its unique chelating ability facilitates efficient nutrient uptake, particularly in nutrient-deficient or alkaline soils. Recent studies highlight its role in increasing nutrient use efficiency, tolerance to abiotic stress, and crop yield quality. Incorporating potassium fulvic humate into nutrient management systems provides a sustainable pathway for modern agriculture.

Introduction

Maintaining soil fertility and balanced nutrient management is one of the key challenges in agriculture today. The overuse of chemical fertilizers has often resulted in nutrient depletion, declining soil organic matter, and reduced crop productivity. To address these challenges, bio-based products such as **potassium fulvic humate** are increasingly being recognized for their multifunctional role in crop production (Singh et al., 2019).

Fulvic substances are low molecular weight fractions of humic substances rich in functional groups like hydroxyl and carboxyl, which can bind with essential nutrients. This property improves nutrient solubility and mobility in the soil, making them more readily available for plant uptake (Li et al., 2023). Potassium fulvic humate combines the benefits of fulvic acids with the additional supply of potassium, making it a superior alternative to conventional fertilizers.

Role in Soil Fertility and Nutrient Uptake

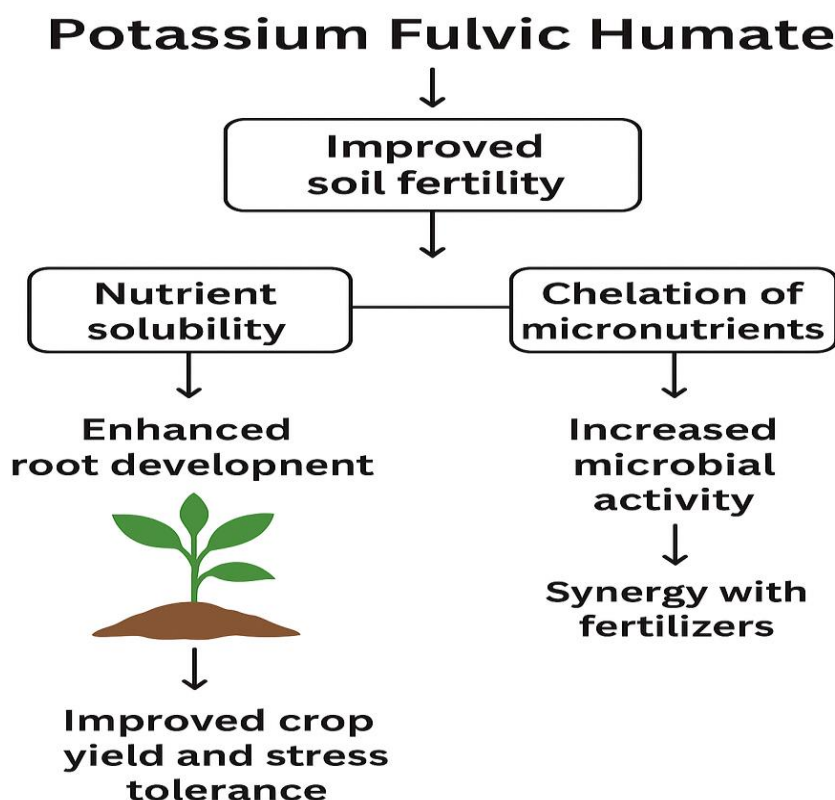
- 1. Chelation of Micronutrients:** Potassium fulvic humate enhances the solubility and availability of micronutrients such as iron, zinc, and manganese, minimizing nutrient fixation issues in alkaline and calcareous soils (Kumar and Yadav, 2022).
- 2. Stimulation of Root Growth:** It promotes root elongation and branching by mimicking plant hormones like auxins, which leads to better soil exploration and nutrient uptake.
- 3. Promotion of Microbial Activity:** As a carbon-rich input, it supports the growth of beneficial microbial populations that accelerate nutrient cycling and organic matter breakdown (Gupta et al., 2024).
- 4. Synergistic Effect with Fertilizers:** When applied along with chemical fertilizers, it improves fertilizer efficiency, reduces nutrient leaching, and helps maintain yield levels even with reduced fertilizer doses.

Recent Advances and Applications

- In **maize cultivation**, potassium fulvic humate enhanced nitrogen uptake by nearly 20% and increased grain yields in rainfed conditions (Li et al., 2023).
- In **wheat trials**, foliar application improved chlorophyll content, photosynthesis, and drought resistance (Gupta et al., 2024).
- In **vegetable crops** such as cucumber and tomato, it improved fruit nutritional quality, including vitamin C and sugar content.

Table 1. Benefits of Potassium Fulvic Humate in Crops:

Application Mode	Major Benefits	Reference
Soil Application	Greater nutrient solubility, improved root growth	Kumar and Yadav, 2022
Foliar Spray	Higher photosynthetic efficiency, stress tolerance	Li et al., 2023
Combined with NPK	Reduced nutrient loss, improved yield	Gupta et al., 2024


Fig1.Role of Potassium Fulvic Humate

Personal Opinion

In my opinion, potassium fulvic humate is more than just an additive; it represents a **revolutionary input** for sustainable farming. It improves soil fertility, reduces dependence on synthetic fertilizers, and enhances overall crop resilience. However, more large-scale trials, formulation standardization, and awareness among farmers are essential for maximizing its benefits.

Summary/Conclusion

Potassium fulvic humate serves as a promising bio-based input for sustainable agriculture. Its role in improving soil fertility, facilitating nutrient uptake, stimulating beneficial microbes, and increasing stress tolerance highlights its importance in modern crop production. Looking ahead, crop-specific formulations and dosage optimization for diverse soil types will be crucial in scaling its adoption.

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Endophytic Lignocellulolytic Microbes: Dual Role in Plant Growth and Residue Degradation

Article ID: 72023

Billa Sindhu Reddy¹, Pinniboina Nagendra Babu¹

¹Senior Research Associate, Department of R&D, Research Associate, Department of R&D, Sowbhagya Biotech Pvt. Ltd., Cherlapally, Hyderabad, 500051, India.

Summary

Endophytic lignocellulolytic microbes are emerging as vital contributors to sustainable agriculture due to their dual functions in enhancing plant growth and decomposing lignocellulosic crop residues. These microorganisms colonize internal plant tissues without causing harm, while producing a wide range of enzymes such as cellulases, hemicellulases, and lignin peroxidases. Their plant growth-promoting roles include nutrient solubilization, phytohormone production, and stress mitigation. Simultaneously, they accelerate the degradation of agricultural residues like rice straw, maize stalks, and sugarcane bagasse, thereby improving soil organic matter, nutrient cycling, and reducing the environmental hazards of residue burning. The integration of these microbes into agricultural systems supports circular bioeconomy and climate-smart farming.

Introduction

Agricultural sustainability depends heavily on soil fertility, nutrient recycling, and effective crop residue management. Modern farming practices generate enormous amounts of crop residues rich in **cellulose, hemicellulose, and lignin**, collectively referred to as lignocellulosic biomass. While these residues are a potential nutrient resource, their recalcitrant structure often hinders natural decomposition (Singh et al., 2015). Farmers frequently resort to open-field burning of residues such as rice straw, which causes nutrient loss and environmental pollution (Kumar et al., 2019).

Endophytic microbes, particularly lignocellulolytic ones, offer a promising biological solution. They colonize the internal tissues of plants and produce extracellular enzymes including **cellulase, xylanase, laccase, and lignin peroxidase**, enabling the breakdown of complex plant polymers (Patel and Verma, 2020). These enzymes not only facilitate nutrient mobilization from residues but also improve **soil carbon sequestration** and **soil structure** (Singh and Mishra, 2015).

Dual Role of Endophytic Lignocellulolytic Microbes

1. Plant Growth Promotion:

- Synthesis of phytohormones like indole acetic acid (IAA) and gibberellins.
- Solubilization of phosphorus, potassium, and micronutrients.
- Induction of systemic resistance against pathogens.
- Enhancement of tolerance to abiotic stresses such as salinity and drought.

2. Residue Degradation:

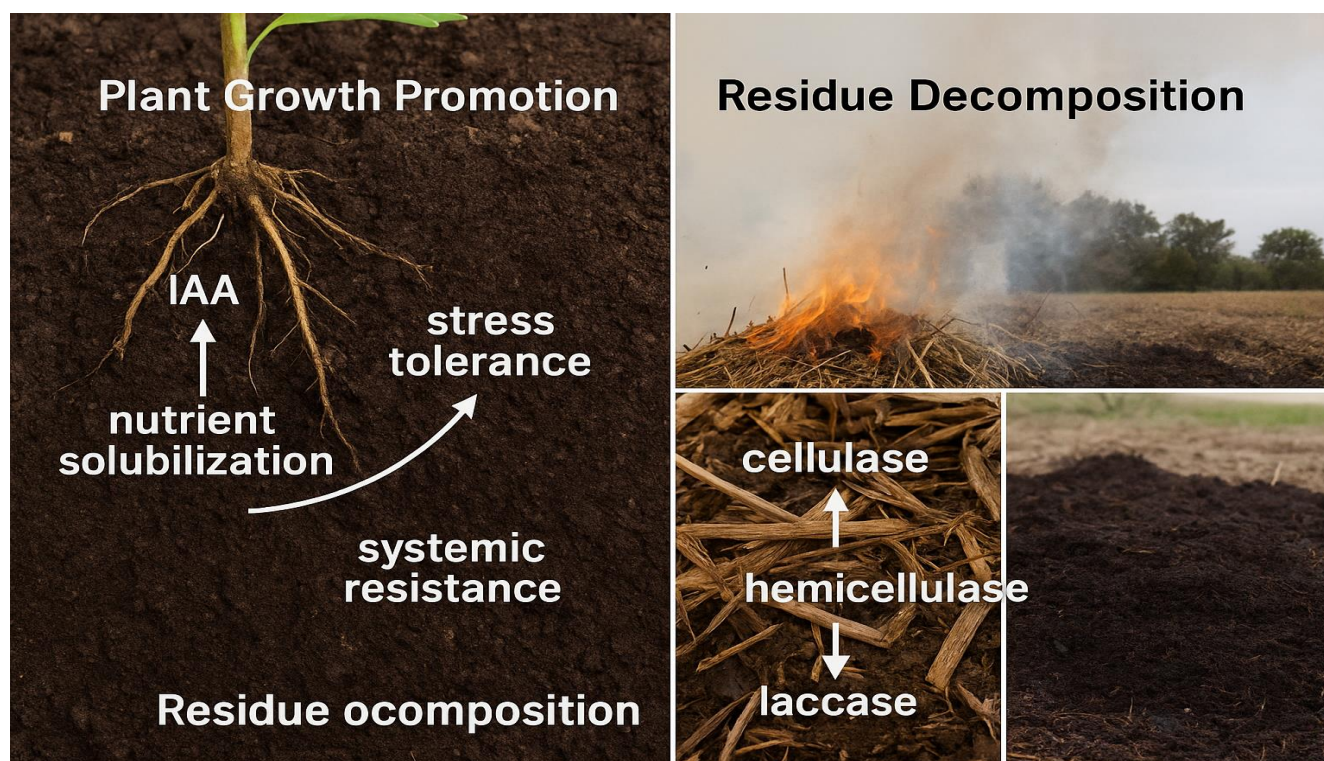
- Cellulases and hemicellulases** hydrolyze cellulose and hemicellulose into simple sugars.
- Laccases and peroxidases** break down lignin, which is otherwise highly resistant.
- Facilitate conversion of straw, husks, and stalks into nutrient-rich compost or biofertilizers.

Agricultural Applications

- Crop Residue Management:** Sustainable alternative to burning (Rao et al., 2021).
- Composting and Vermicomposting:** Enhanced decomposition rates with higher nutrient content.
- Biofertilizer Development:** Microbial consortia act as natural inputs for nutrient mobilization.
- Climate-Smart Agriculture:** Reduction of greenhouse gas emissions through residue bioconversion.

Table 1: Role of Endophytic Lignocellulolytic Microbes in Agriculture:

Function	Mechanism	Agricultural Benefit
Plant Growth Promotion	Hormone production, nutrient solubilization	Higher yields, stress tolerance
Residue Degradation	Cellulase, hemicellulase, laccase activity	Faster residue decomposition
Soil Fertility Improvement	Enhanced nutrient cycling, carbon sequestration	Long-term soil productivity
Biocontrol	Induced systemic resistance	Reduced chemical pesticide use


Fig1.Plant Growth and Residue Management

Personal Opinion

In my opinion, **endophytic lignocellulolytic microbes** represent the future of eco-friendly farming practices. Unlike synthetic agrochemicals, they provide a dual advantage—boosting plant growth while also addressing one of agriculture’s major challenges, crop residue management. More field-based trials and formulation development are required to commercialize these microbes as **next-generation bioinoculants**.

Conclusion

Endophytic lignocellulolytic microbes offer a unique dual role in agriculture: improving plant growth and promoting sustainable crop residue decomposition. Their enzymatic capacity helps in recycling nutrients, enriching soil organic matter, and supporting climate-smart agriculture. The development of microbial consortia and bioformulations could revolutionize their application as biofertilizers and compost accelerators. Future research should focus on strain improvement, large-scale inoculant production, and integration into existing farming systems for wider adoption.

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Impact of Zinc Gluconate on Plant Nutrition and Productivity

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Pinniboina Nagendra Babu¹, Billa Sindhu Reddy¹

¹Research Associate Department of R&D, Senior Research Associate Department of R&D, Sowbhagya Biotech Pvt. Ltd., Cherlapally, Hyderabad, 500051, India.

Summary

Zinc gluconate, a chelated formulation derived from zinc, gluconic acid, and amino acids, is gaining recognition as a sustainable agricultural input. It provides a highly bioavailable form of zinc, an essential micronutrient vital for enzyme activation, chlorophyll synthesis, and reproductive growth. The gluconic acid component enhances chelation, solubility, and zinc mobility in plant tissues, while amino acids act as carriers and metabolic enhancers. This synergistic interaction improves nutrient uptake efficiency, particularly under stress conditions. As a result, zinc gluconate not only promotes plant growth and yield but also enhances crop quality, positioning it as a superior alternative to conventional zinc fertilizers.

Introduction

Zinc (Zn) deficiency is one of the most widespread micronutrient disorders in global agriculture, especially in calcareous and alkaline soils where Zn availability is limited (Singh, Sharma and Verma, 2015). Conventional fertilizers such as zinc sulfate are often constrained by low solubility, poor mobility, and fixation in soils, leading to inefficient nutrient delivery (Alloway, 2008).

Zinc gluconate, a chelated formulation that integrates zinc with gluconic acid and amino acids, has been developed to address these limitations. Zinc is an essential element involved in numerous physiological functions, including auxin metabolism, enzyme activation (carbonic anhydrase, dehydrogenases), and protein synthesis. Its deficiency results in stunted growth, chlorosis, poor grain filling, and reduced crop yields (Singh and Mishra, 2015).

The role of gluconic acid as a natural organic chelator ensures higher solubility and stability of zinc ions. Unlike inorganic forms, it supports efficient nutrient transport across both xylem and phloem, enhancing uniform distribution within the plant (Cakmak, 2008). Amino acids contribute further by acting as biostimulants that facilitate membrane transport, improve nitrogen assimilation, and enhance tolerance to abiotic stress (Kumar, Patel and Rao, 2020). Collectively, these properties make zinc gluconate an innovative solution for correcting Zn deficiency and improving productivity.

Technical Relevance in Agriculture

- 1. Nutrient Solubility and Uptake:** Zinc gluconate demonstrates higher solubility in calcareous and alkaline soils compared to zinc sulfate, thereby reducing fixation losses.
- 2. Chelation Efficiency:** Gluconic acid stabilizes zinc ions, ensuring controlled release and improved translocation within plants.
- 3. Metabolic Enhancement:** Amino acids act synergistically to improve enzyme activity, nitrogen metabolism, protein synthesis, and photosynthetic efficiency.
- 4. Crop-Specific Benefits:**
 - a. Cereals (wheat, maize, rice):** Enhanced tillering, grain filling, and yield performance.
 - b. Horticultural crops (tomato, chili, grapes):** Improved fruit firmness, reduced physiological disorders, and enhanced shelf-life.
 - c. Pulses:** Better nodulation, flowering, and pod formation.

Personal Opinion

Zinc gluconate represents a next-generation solution in plant nutrition. Its advantages in solubility, bioavailability, and stress resilience make it more efficient than conventional fertilizers. With wider

adoption, zinc gluconate can play a significant role in reducing micronutrient malnutrition in crops and improving global food security. However, further field trials across different agro-climatic regions, along with cost-benefit analyses, are needed to optimize its application.

Conclusion

Zinc gluconate, comprising zinc, gluconic acid, and amino acids, is a scientifically validated input that effectively enhances plant growth and productivity. Its high bioavailability and chelation efficiency ensure improved nutrient uptake and distribution. Furthermore, amino acids enhance metabolic activities and stress tolerance, contributing to superior yield quality. Given its potential, zinc gluconate could be a sustainable alternative to traditional zinc fertilizers in modern agriculture.

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Brassica juncea: A Golden Crop for Punjab's Agricultural Future

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Akshita Awasthi¹, Indu Rialch¹

¹Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana-141004.

Summary

Punjab, widely referred to as India's breadbasket, traditionally has been based on the rice-wheat crop system. This grain-crop-based dependence has, however, spawned a sequence of environmental and fiscal issues in the form of severe groundwater depletions, declining quality of soils, and fiscal instability among the producers. There is a need to shift the paradigm to relatively more sustainable crop systems. Herein, *Brassica juncea* or Indian mustard is a viable option, providing a water-conserving, sustainable, and economically viable solution. With its low irrigational need, capacity to improve soil quality, and tolerance for climatic stresses, the cultivation of mustard can revolutionize the agricultural sector of Punjab at large.

Introduction

The Case for Mustard: A Water-Smart Alternative: Punjab's dwindling groundwater resource is a cause for concern. Rice needs approximately 5,000 litres of water to produce one kilogramme of rice, and this results in exponential depletion rates, where one extra metre more water is extracted than recharged every year. Conversely, mustard needs almost 80% less water, making it an eco-friendly crop for a state rapidly heading towards a water crisis. Apart from water-saving, mustard's extensive root system improves soil quality, aeration, and levels of organic material, preventing erosion and lowering depletion of nutrients. Punjab Agricultural University (PAU) research focuses on how replacing wheat following rice with mustard increases wheat yields by 8-10% due to improved soil health and pest cycles. This change would not only make the soil fertile but also reduce reliance on chemical fertilizers, in terms of input expenses to farmers.

Economic Viability and Market Potential

The economic benefit of the mustard crop goes beyond the saving on input costs. Mustard oil is monounsaturated and high in omega-3 content, and it is better than the most consumed oils palm and soybean. The oil extraction residue, mustard cake, is an organic manure and a high-protein cattle feed, lowering the cost of external farm inputs.

India currently imports close to 70% of edible oil, indicating a severe shortfall in indigenous production (GOI, 2023). Enhanced mustard cultivation can prevent import dependence, enhance food safety, and stabilize farmer incomes. The government-run National Food Security Mission (NFSM)-Oilseeds mission offers subsidy for mustard seed procurement, securing guaranteed prices and profitability for the farmers. Additionally, contract farming with the edible oil processing mills can also increase the marketability of mustard, ensuring long-term economic returns to the growers.

Mustard as a Climate-Resilient Crop

As weather conditions get extreme with climate change, agriculture in Punjab needs to adapt to changing rainfalls and temperatures. Mustard is heat-resistant and drought-resistant, and it can thrive under Punjab's semi-arid climatic conditions. ICAR studies reveal that heat-tolerant mustard varieties like Pusa Vijay and RH 749 resist up to 35°C at flowering stage, a temperature wherein wheat suffers massive yield loss (ICAR, 2022). Additionally, mustard's water stress tolerance and salt tolerance make it the most suitable choice for Punjab's changing climatic conditions.

Addressing Punjab's Agricultural Challenges

Punjab's rice-wheat monoculture heritage resulted in severe nutrient loss and excessive reliance on synthetic fertilizer. Mustard's ability to generate soil organic matter, restrict nitrogen fixation, and break pest and disease cycles offers a hope of renewal for the recovery of soil. A 20% adoption of mustard in lieu

of paddy can result in billions of litres of water savings annually and provide relief to Punjab from its groundwater situation. Further, the lower vulnerability of mustard to pest infestation minimizes pesticide reliance, thereby being a green alternative.

Additionally, unstable Minimum Support Prices (MSP) of wheat and rice have put the farmers in vulnerable economic positions. The enormous demand for mustard oil, complemented by government-supported procurement activities, provides a secure and well-paying alternative source of income for the farmers (GOI, 2023).

Policy Recommendations for Promoting Mustard Cultivation

To speed up the transition towards mustard cultivation in Punjab, a multi-dimensional policy intervention is required: Development and Dissemination of High-Yielding Varieties – Research organizations have to popularize mustard varieties with improved yields, disease tolerance, and climate adaptability. Guaranteed MSP and Effective Procurement Mechanisms – Government procurement mechanisms for mustard need to be made robust so that the farmers adopt it. Financial Incentives to Farmers – Subsidy on mustard-derived biofertilizers and biopesticides has to be enhanced. Industry-Farmer Linkages – Such linkages among mustard farmers and food oil industries can ensure market access and prices regularly. Public Awareness and Extension Services – Special training programs and campaigns must enlighten farmers on the economic and environmental benefits of mustard.

Conclusion

The cultivation of *Brassica juncea* in Punjab is a revolutionary move towards agrarian sustainability, economic strength, and climate resilience in Punjab. By conserving water, improving soil health, and making farmers more profitable, mustard is a silver lining in Punjab's agricultural sky. Firm scientific backing, visionary policy initiatives, and extensive farmer adoption will be the drivers to harvest the gains of mustard. With proper planning, mustard can transform Punjab cropping systems, ensuring long-term farm prosperity and ecological protection.

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Smart Packaging for Fresh Fruits: A Pathway to Increasing Farmers' Income

Article ID: 72026

Dr. Dinesh Rajak¹, Dr. Vishal Kumar², Dr. Devendra Kumar³

^{1&2}Associate Professor and ²Professor,

Processing and Food Engineering, College of Agricultural Engineering & Technology, Dr. RPCAU, Pusa, Samastipur (Bihar).

Introduction

Fresh fruits are highly perishable commodities that often suffer from post-harvest losses due to improper handling, storage, and packaging. Traditional packaging methods usually provide only physical protection and fail to address issues such as microbial spoilage, ripening control, and quality monitoring. Smart packaging, an emerging technology in the agri-food sector, offers innovative solutions that not only extend the shelf life of fruits but also add value for both farmers and consumers. By adopting smart packaging, farmers can reduce losses, access wider markets, and ultimately increase their income.

What is Smart Packaging?

Smart packaging goes beyond conventional packaging by integrating science and technology to actively monitor, protect, and communicate information about the product. It is generally classified into two main categories.

Active Packaging

Active packaging is designed not only to contain fruits but also to interact with the internal environment of the package to maintain quality and extend shelf life. Unlike conventional packaging, which is passive, active packaging plays a protective and functional role.

Key Features of Active Packaging for Fresh Fruits:

- a. Moisture Control:** Absorbent pads or films help prevent excess moisture that can cause microbial growth.
- b. Ethylene Scavengers:** Special sachets or films capture ethylene gas, a natural ripening hormone, thereby slowing down fruit ripening.
- c. Oxygen Scavengers:** Reduce oxygen levels inside the pack, minimizing oxidation and spoilage.
- d. Antimicrobial Films:** Packaging materials coated with natural antimicrobials (like essential oils or silver nanoparticles) inhibit the growth of bacteria and fungi.
- e. Carbon Dioxide Emitters:** Maintain optimal CO₂ levels inside the package to delay respiration and senescence.

Benefits for Farmers and Consumers:

- a. Extends freshness during storage and transport.
- b. Reduces post-harvest losses and wastage.
- c. Allows farmers to sell fruits in distant and export markets.
- d. Provides safer, higher-quality fruits to consumers.

Intelligent Packaging

Intelligent packaging is a system that provides **real-time information** about the condition of fresh fruits during storage, transport, and sale. Unlike active packaging, which preserves quality, intelligent packaging **monitors and communicates** the status of the product to farmers, traders, and consumers.

Key Features of Intelligent Packaging for Fresh Fruits:

- a. Time-Temperature Indicators (TTIs):** Labels or stickers that change color based on the temperature exposure of fruits, ensuring the cold chain is maintained.

- b. Freshness Indicators:** Sensors or labels that detect changes in gases (like CO₂ or volatile compounds) and show whether the fruit is still fresh.
- c. Ripeness Indicators:** Color tags or smart inks that indicate the stage of ripeness, helping consumers choose the right fruit.
- d. RFID Tags & QR Codes:** Provide digital information about origin, harvest date, storage conditions, and traceability throughout the supply chain.
- e. Biosensors:** Detect microbial contamination, ensuring safety and quality.

Benefits for Farmers and Consumers:

- a. Builds **trust and transparency** by showing product quality.
- b. Reduces losses by identifying spoilage early.
- c. Helps farmers **access premium markets** where traceability is required.
- d. Improves consumer satisfaction by allowing informed purchasing decisions.

Benefits of Smart Packaging for Fresh Fruits

1. Extended Shelf Life – One of the most significant advantages of smart packaging is its ability to **extend the shelf life of fresh fruits**. Since fruits are highly perishable, they continue to respire and ripen even after harvest, which shortens their marketable period. Smart packaging technologies help slow down these natural processes, ensuring fruits remain fresh for longer.

How Shelf Life is Extended:

- a. Modified Atmosphere Packaging (MAP):** Balances oxygen and carbon dioxide inside the package to reduce respiration rate.
- b. Ethylene Absorbers:** Trap ethylene gas, delaying the ripening process.
- c. Moisture Regulators:** Prevent excess humidity that can cause fungal growth.
- d. Edible Coatings:** Form a thin protective layer on fruits, reducing water loss and microbial attack.
- e. Temperature Indicators:** Help maintain the cold chain, avoiding premature spoilage.

Benefits:

- a. Farmers get **more time to sell** their produce without worrying about fast spoilage.
- b. Fruits can be transported to **distant and export markets** in good condition.
- c. Consumers receive fruits that stay fresh for **longer periods at home**, reducing food waste.

2. Reduced Post-Harvest Losses – Post-harvest losses are a major challenge for fruit farmers, often leading to **30–40% wastage** before the produce reaches consumers. These losses occur due to improper storage, handling, microbial spoilage, and uncontrolled ripening. Smart packaging helps minimize such losses by creating a controlled and protective environment around the fruits.

How Smart Packaging Reduces Losses:

- a. Antimicrobial Films & Coatings:** Prevent fungal and bacterial infections that cause decay.
- b. Moisture Absorbers:** Reduce excess humidity inside packaging, preventing mold growth.
- c. Oxygen Scavengers:** Limit oxidation and preserve natural color and texture.
- d. Shock-Resistant Materials:** Protect fruits during transport, reducing mechanical damage.
- e. Real-Time Monitoring:** Intelligent indicators alert stakeholders about spoilage risks, ensuring corrective action can be taken early.

Benefits:

- a. Farmers can **sell a higher percentage of harvested produce**, boosting income.
- b. Retailers face **lower rejection rates** from spoiled fruits.
- c. Consumers enjoy **fresher and safer produce** with less wastage along the supply chain.

3. Market Competitiveness – In today's globalized fruit market, competition is not only about quantity but also about **quality, freshness, and safety**. Smart packaging gives farmers and suppliers a competitive edge by ensuring fruits reach the market in excellent condition while meeting consumer and regulatory expectations.

4. Consumer Trust – Consumer trust is essential in the fruit market, where freshness, safety, and authenticity are top priorities. Smart packaging builds confidence by offering **transparency and**

assurance about the quality and origin of fresh fruits. When consumers know the produce is safe, traceable, and fresh, they are more willing to pay a premium price.

5. Better Price Realization – One of the ultimate goals of smart packaging is to help farmers obtain **fair and higher prices** for their produce. By delivering fruits that are fresher, safer, and traceable, farmers can access premium markets and negotiate better value for their hard work.

Technologies Used in Smart Packaging

1. Modified Atmosphere Packaging (MAP): Regulates oxygen and carbon dioxide to slow down respiration.

2. Edible Coatings: Biodegradable layers (e.g., chitosan, aloe vera gel) that delay ripening and act as barriers to microbes.

3. Ethylene Absorbers: Control the natural ripening hormone, extending freshness.

4. Freshness Indicators: Color-changing labels that reflect fruit quality in real-time.

5. QR/Barcodes with Blockchain: Ensure traceability and build trust in the supply chain.

Impact on Farmers' Income

Adopting smart packaging leads to:

1. Lower Wastage: Lowering wastage is one of the most practical benefits of smart packaging for fresh fruits. Fruits are highly perishable, and a significant portion of the harvest is often lost due to spoilage, mechanical damage, or poor handling. Smart packaging helps **minimize these losses** at every stage of the supply chain.

2. Access to Export Markets: Smart packaging enables farmers to **meet international quality and safety standards**, opening doors to lucrative export markets. Many countries have strict regulations regarding freshness, shelf life, traceability, and food safety, which traditional packaging often fails to satisfy.

3. Premium Pricing: Smart packaging allows farmers to **command higher prices** for their fruits by ensuring superior quality, freshness, and safety. Consumers are increasingly willing to pay a premium for products that are traceable, fresh, and visually appealing.

4. Brand Creation: Smart packaging provides farmers and cooperatives with an opportunity to **establish their own brand identity**, differentiating their produce in competitive markets. By combining quality assurance with attractive and informative packaging, farmers can build trust and loyalty among consumers.

Challenges and Future Prospects

While smart packaging offers many benefits, challenges such as high initial cost, lack of awareness, and limited access to technology hinder widespread adoption. Training farmers, government subsidies, and industry collaboration can accelerate implementation. With increasing consumer demand for safe, fresh, and traceable fruits, the future of smart packaging is promising and will play a vital role in doubling farmers' income.

Conclusion

Smart packaging is not just a technological innovation but a transformative solution for the fruit industry. By ensuring freshness, reducing losses, and enhancing transparency, it directly contributes to higher farmer incomes and greater consumer satisfaction. As India and other agricultural nations move towards sustainable and technology-driven farming, smart packaging will be a key enabler of growth and prosperity.

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Biofertilizers: Formulations and their Application

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Dr. Ipsita Das¹, Dr. Pragyan Paramita Rout¹, Dr. Rahul Deb Behera², Dr. Meenakhi Prusty³

¹Department of Soil Science & Agricultural Chemistry, College of Agriculture, OUAT, Chiplima.

²Department of Soil Science & Agricultural Chemistry, KVK, Bargarh, OUAT.

³Department of Soil Science & Agricultural Chemistry, AICRP on LTFE, OUAT, Bhubaneswar.

Introduction

Biofertilizers are the eco-friendly alternative substances to chemical fertilizers, containing living cells or latent cells of efficient strains of microorganisms that enhance plant growth by improving nutrient availability in soil. Bio-fertilizers enrich the soil with nutrients through natural processes of nitrogen fixation, solubilization and/or mobilization of nutrients, and stimulating plant growth through the synthesis of growth-promoting substances and phytohormones. Biofertilizer formulation aim to enhance plant growth, improve soil health, and reduce reliance on chemical fertilizers and can be obtained with a suitable carrier material combining the beneficial microorganisms by creating a stable, effective, and easy-to-use product. By selecting appropriate microbial strains, choosing a suitable carrier (like peat, talc, or vermiculite), optimizing the formulation for desired application methods and environmental conditions, these formulations can be prepared.

Key Aspects of Biofertilizer Formulation

- 1. Microbial Selection:** Choosing effective and compatible strains of bacteria, fungi, or algae that promote plant growth (e.g., nitrogen-fixing bacteria, phosphate-solubilizing bacteria, or mycorrhizal fungi).
- 2. Carrier Material:** Carrier supports microbial survival, which provides nutrients, and facilitates easy application. Common carriers include peat, lignite, vermiculite, compost, and charcoal.
- 3. Formulation Methods:** Solid-based formulations (e.g., granular, powder), liquid formulations, and cell immobilization are commonly used methods.
- 4. Quality Control:** good quality materials ensure the viability, purity, and stability of the biofertilizer throughout its shelf life and under field conditions.

Types of Biofertilizer Formulations

- 1. Solid Formulations:** Carrier-based formulations (peat, lignite, talc, etc.) are common, offering stability and ease of handling. Granular formulations, often using prills, can improve application and reduce dust.
- 2. Liquid Formulations:** Liquid biofertilizers offer ease of application, especially through irrigation systems. They require careful selection of microbes and protective agents (e.g., glycerol, DMSO) to maintain viability.
- 3. Cell Immobilization:** Microbial cells are entrapped within a matrix, enhancing their survival and effectiveness in the soil.

Factors Influencing Formulation Success

- 1. Crop Type:** Different crops may require specific microbial consortia and formulations.
- 2. Soil Conditions:** Soil type, pH, and nutrient availability influence microbial performance.
- 3. Application Method:** Seed treatment, soil application, or foliar application may require different formulations.
- 4. Environmental Factors:** Temperature, moisture, and salinity can impact microbial survival and activity.
- 5. Cost and Availability:** The cost of materials and production processes also play a role in the commercial viability of a formulation.

Biofertilizer for Different Crops

1. *Rhizobium* for legume crops.
2. *Azotobacter* and *Azospirillum* for non-legume crops.
3. *Acetobacter* for sugarcane only.
4. Blue-green algae (BGA) and *Azolla* for low-land paddy.
5. *Frankia* for *Casuarina* and *Alnus*.

<i>Rhizobium</i> sp.	Crops
<i>R. leguminosarum</i>	Pea (<i>Pisum</i>), <i>Lathyrus</i> , <i>Vicia</i> , lentil (<i>Lens</i>)
<i>R. trifoli</i>	Berseem clover (<i>Trifolium</i>)
<i>R. phaseoli</i>	Kidney bean (<i>Phaseolus</i>)
<i>R. lupine</i>	<i>Lupinus</i> , <i>Ornithopus</i>
<i>R. japonicum</i>	Soybean (<i>Glycine</i>)
<i>R. meliloti</i>	<i>Melilotus</i> , alfalfa (<i>Medicago</i>), fenugreek (<i>Trigonella</i>)
<i>Rhizobium</i> spp.	Cowpea, Clusterbean, Greengram, Blackgram, Redgram, Groundnut, Mothbean, Dhaincha, Sunhemp, <i>Glyricidia</i> , <i>Acacia</i> etc.

Methods of Biofertilizer Application

Biofertilizers, which are microbial cultures, can be applied to crops through various methods like seed treatment, seedling/root treatment, and soil application.

Seed Treatment: It involves coating seeds with a biofertilizer slurry. The biofertilizer is mixed with 10% jaggery solution to create a slurry. And then the seeds are coated evenly with the slurry and dried in the shade. This method is suitable for both small and large quantities of seeds.

Generally, 750 grams of biofertilizer is enough to treat seeds for a one-hectare area.

Seedling/Root Treatment: This method involves dipping seedlings' roots in a biofertilizer solution. The roots of seedlings are soaked for a few hours before transplanting. This method is particularly useful for crops like rice, where seedlings are transplanted.

Soil Application: Soil application can be done by mixing biofertilizers with compost and incorporating it into the soil or by broadcasting the biofertilizer over the field. For BGA (Blue-Green Algae) biofertilizer, it can be broadcasted into the rice field 2-3 weeks before transplanting. Proper moisture is ensured and excessive watering is avoided immediately after application to prevent the microbes from washing away. To encourage the activity and retention of microbes, use of organic mulch is advisable.

Self-inoculation or tuber inoculation: This method is exclusively suitable for application of *Azotobacter*. In this method, 50 litres of water is taken in a drum and 4–5 kg of *Azotobacter* biofertilizer is added and mixed properly. Planting materials required for one acre of land are dipped in this mixture. Similarly, if we are treating potato, then the tubers are dipped in the mixture and planting is done after drying the materials in the shade.

Important Considerations

1. Avoid mixing biofertilizers with insecticides, fungicides, herbicides, or chemical fertilizers.
2. Compatible combination of bacterial biofertilizers is ensured.
3. For optimal results, biofertilizers are applied at the right time and right method.
4. Temperature, moisture, and pH of soil is to be considered when choosing and applying biofertilizers.
5. Some biofertilizers can also be applied as foliar sprays using a knapsack sprayer.

Precautions to be Followed for Using Biofertilizers

1. Biofertilizer packets need to be stored in cool and dry place away from direct sunlight and heat.
2. Right combinations of biofertilizers have to be used.
3. As *Rhizobium* is crop specific, one should use for the specified crop only.
4. Other chemicals should not be mixed with the biofertilizers.

5. Each packet should be provided with necessary information like name of the product, name of the crop for which intended, name and address of the manufacturer, date of manufacture, date of expiry, batch number and instructions for use.
6. The packet should be used before its expiry, only for the specified crop and by the recommended method of application.
7. Proper care should be maintained during storage of biofertilizers.
8. Both nitrogenous and phosphatic biofertilizers are to be used to get the best results.
9. It is important to use biofertilizers along with chemical fertilizers and organic manures.
10. Biofertilizers should be treated as replacement of fertilizers as it can supplement plant nutrient requirements.
11. For problematic soils, use corrective methods like lime or gypsum pelleting of seeds or correction of soil pH by use of lime.

Environmental Limitations for Application of Biofertilizers

1. Unavailability of suitable carrier resource constraint
2. Market level constraints and lack of awareness of farmers
3. Lack of quality assurance and limited resource generation for biofertilizers production
4. Seasonal and unsure requirement
5. Soil and climatic factors and inadequately experienced staff
6. Native microbial population, faulty inoculation techniques and mutation during fermentation

Conclusion

Biofertilizers are the promising formulations of biological origin that serves as a supplementary source of plant nutrients. Besides, inclusion of biofertilizers has wider scope in INM as well as in organic farming as it sustains soil health and mitigates a cascade of environmental and health problems arising due to non-judicious application of chemical fertilizers. However, the success and wide applicability of biofertilizer technology among the farmers mainly relies on proper selection of strains, cell count and shelf life of the formulations, method of application, soil health and crop management.

HFSS Food Labels: A Public Health Tool for Healthier Choices and Obesity Prevention

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Shantanu Sitaram Konde¹, Anuprita Joshi², Bhanudas Patil³, Kishor Anerao⁴, Prasad Gangakhedkar⁴

¹Department of Food Engineering, CFT, VNMKV, Parbhani-431402.

²Assistant Professor, Department of Food Process Technology, CFT, VNMKV, Parbhani-431402.

³Assistant Professor, Department of Food Engineering, CFT, VNMKV, Parbhani-431402.

⁴Ph.D. Research Scholar, Department of Food Microbiology and Safety, CFT, VNMKV, Parbhani-431402.

Abstract

High in Fat, Salt and Sugar (HFSS) food labels have emerged as a vital public health intervention to combat the rising prevalence of obesity, diabetes, and cardiovascular diseases. By providing clear, front-of-package (FOP) nutritional information, these labels aim to empower consumers to make informed dietary choices and encourage food manufacturers to reformulate products. This article reviews the definition and health relevance of HFSS labels, examines global regulatory frameworks, and compares diverse labelling formats such as traffic light systems, health star ratings, and warning symbols. It highlights evidence on consumer perception and behavioural impacts, noting that intuitive and visually clear labels tend to enhance understanding and promote healthier purchasing decisions. The article also explores implementation challenges, including regulatory inconsistencies, industry resistance, and variable consumer nutrition literacy, alongside emerging innovations such as interactive digital labels and personalized nutrition tools. Future policy perspectives emphasize the need for harmonized, mandatory labelling systems supported by public education to maximize health outcomes. Overall, HFSS food labelling represents a promising strategy to foster healthier diets, though its effectiveness depends on robust regulation, cultural adaptation, and continuous innovation.

Keywords: HFSS foods, front-of-package (FOP) labelling, nutritional labelling, consumer behaviour, public health policy, obesity prevention.

Introduction

“High in Fat, Salt and Sugar (HFSS) foods are products that exceed specified thresholds for saturated fat, sodium, and added sugars content.” However, the definition varies significantly across jurisdictions and regulatory frameworks. The classification typically employs one of three approaches:

Absolute thresholds: Fixed amounts per serving or per 100g

Per-calorie ratios: Nutrient density relative to energy content

Nutrient profiling algorithms: Composite scoring systems like the UK's Nutrient Profiling Model or Chile's warning label thresholds (Dunford et al., 2024).

High in Fat, Salt and Sugar (HFSS) food labels are a critical tool in public health strategies aimed at combating diet-related diseases. These labels are designed to inform consumers about the nutritional content of food products, particularly those high in unhealthy nutrients, to promote healthier dietary choices. The implementation of HFSS labels varies globally, with different countries adopting diverse regulatory frameworks and label formats. This article explores the definition and public health relevance of HFSS labels, global regulatory frameworks, types and formats of labels, consumer perception and behavioural impact, challenges in implementation, emerging innovations, and future policy perspectives. The effectiveness of HFSS labels in influencing consumer behaviour remains a topic of ongoing research, with varying results based on cultural and contextual factors.



Fig. 1: HFSS Food Categories Source: (Gill Hyslop, 2024)

Definition and Public Health Relevance

HFSS labels identify foods high in saturated fats, sugars, and sodium, which are linked to obesity, diabetes, and cardiovascular diseases (Becher et al., 2019) (Dunford et al., 2024). These labels aim to empower consumers to make informed dietary choices and encourage manufacturers to reformulate products for better health outcomes ("Food Nutritional Information: Transparency and Public Health," 2018). The ongoing evolution of HFSS labelling reflects a growing recognition of the need for clear nutritional guidance to combat the rising prevalence of diet-related health issues.

These labels aim to reduce the consumption of unhealthy foods and encourage healthier eating habits, addressing the global obesity epidemic and related health costs (Becher et al., 2019) (Ganderats-Fuentes & Morgan, 2023).

Global Regulatory Frameworks

Countries like Brazil have implemented mandatory front-of-package (FOP) labelling systems to alert consumers about high levels of unhealthy nutrients (Cattafesta, 2024). In Brazil, front-of-package labelling has proven effective in raising consumer awareness and promoting healthier choices, reflecting a significant step towards improving public health outcomes (Borges et al., 2024). Other countries, such as Chile, have also adopted similar mandatory labelling systems, demonstrating the global trend towards enhancing consumer awareness and promoting healthier dietary habits through effective food labelling policies. (George et al., 2025). In light of these developments, it is crucial to evaluate the impact of such labelling systems on consumer behaviour and public health outcomes across different cultural contexts.

The U.S. FDA is exploring FOP labels using a threshold of $\geq 20\%$ of the recommended daily value to define "high-in" nutrients (Dunford et al., 2024). Research indicates that the adoption of such labelling could significantly influence consumer purchasing decisions and encourage healthier food industry practices, particularly in the context of the U.S. market (George et al., 2025). Implementing mandatory FOP labelling in the U.S. could lead to substantial reductions in sodium and sugar intake, potentially averting numerous diet-related non-communicable disease deaths (Flexner et al., 2024). Such policies could also align with global trends and evidence supporting the effectiveness of mandatory labelling in reducing unhealthy nutrient consumption (Flexner et al., 2024). As countries adopt these strategies, the potential for improved public health outcomes becomes increasingly evident.

Over 44 countries have introduced FOP labelling schemes, with varying degrees of mandatory and voluntary implementation (Giner et al., 2023). The success of HFSS labelling initiatives hinges on robust regulatory frameworks and public health campaigns that educate consumers about making healthier choices.

Types and Formats of Labels

Label Format Categories: Research has identified several distinct categories of FOP nutrition labels, each with different strengths and applications:

- 1. Warning Labels:** Simple, directive labels that identify products exceeding nutrient thresholds. Evidence shows these are highly salient, easy to understand, and effective at discouraging purchases of HFSS products.
- 2. Interpretive Summary Labels:** Systems like Nutri-Score that provide an overall nutritional quality rating. These excel at helping consumers compare products within categories but may be less effective at discouraging HFSS consumption.
- 3. Traffic Light Labels:** Multi-nutrient systems using colour coding to indicate nutrient levels. These provide detailed information but may be cognitively demanding for rapid decision-making.
- 4. Nutrient-Specific Labels:** Focus on specific nutrients of concern (e.g., sugar content labels). These can be highly targeted but may miss overall nutritional quality.

Common FOP label formats include traffic light systems, health star ratings, and warning symbols (Becher et al., 2019) (Jones et al., 2019). The choice of label format can significantly affect consumer understanding and behaviour, highlighting the importance of tailored approaches based on cultural and contextual factors. Emerging evidence suggests that the design and clarity of HFSS labels play a crucial role in shaping consumer choices, with simpler formats often leading to better understanding and healthier purchasing decisions (George et al., 2025).



Fig. 2: FSSAI - Draft Labeling and Display Regulation including a 'red light' label for high fat, sugar and salt (HFSS) food.

Brazil uses a magnifying glass symbol to indicate high levels of sugars, saturated fats, and sodium (Cattafesta, 2024). This clear visual cue aids consumers in quickly identifying unhealthy products, thereby promoting healthier dietary choices and aligning with global public health objectives. These developments underscore the importance of effective labelling in guiding consumer choices and fostering a healthier food environment. Research shows that clear and intuitive FOP labels can lead to significant reductions in unhealthy nutrient consumption, ultimately supporting better dietary choices and improved public health outcomes (George et al., 2025) (Ganderats-Fuentes & Morgan, 2023).

The effectiveness of these labels depends on their design and the clarity of the information provided (Ganderats-Fuentes & Morgan, 2023). Research indicates that well-designed HFSS labels can enhance

consumer understanding and significantly influence purchasing behavior, ultimately contributing to improved public health outcomes.

Consumer Perception and Behavioural Impact

FOP labels can positively influence consumer purchasing decisions by making nutritional information more accessible and easier to understand (George et al., 2025). However, the extent of their impact varies based on factors such as cultural context and individual consumer literacy regarding nutrition.

Studies show that intuitive label designs lead to better consumer understanding and healthier food choices compared to numerical information alone (Ganderats-Fuentes & Morgan, 2023). While FOP labels generally enhance consumer understanding, their effectiveness can be limited by varying levels of nutrition literacy and cultural perceptions of health messaging.

Challenges in Implementation

Regulatory challenges include the need for consistent nutrient criteria and the risk of legal challenges from the food industry (Jones et al., 2019). Moreover, addressing these challenges requires collaboration among policymakers, public health advocates, and the food industry to ensure effective implementation and compliance with HFSS labelling regulations.

Voluntary labelling schemes often result in low uptake and are typically applied to healthier products, limiting their impact (Ganderats-Fuentes & Morgan, 2023). Mandatory HFSS labelling can enhance consumer awareness and encourage manufacturers to reformulate products, ultimately contributing to healthier dietary choices and improved public health outcomes (Ganderats-Fuentes & Morgan, 2023). The ongoing debate about the effectiveness of HFSS labels necessitates further research to identify optimal labelling strategies that can consistently drive positive health outcomes across diverse populations.

Emerging Innovations

Innovations in label design focus on improving consumer understanding and encouraging product reformulation by the food industry (Giner et al., 2023). These innovations may include the use of augmented reality, interactive labels, and personalised nutrition guidance, which aim to enhance consumer engagement and promote healthier dietary choices (Tezçi, 2023). These advancements highlight the potential for technology to transform how consumers interact with nutritional information, ultimately fostering healthier eating habits and supporting public health initiatives. The integration of technology in nutrition labelling, such as augmented reality and interactive features, could revolutionize consumer engagement by providing personalized dietary guidance and enhancing understanding of nutritional information. (Lowe et al., 2013)

The use of digital tools and apps to complement FOP labels is being explored to enhance consumer engagement and education (Pereira et al., 2017). Such tools can provide real-time nutritional information and personalized recommendations, thereby empowering consumers to make healthier choices and navigate the complexities of food labelling effectively. The ongoing evolution of food labelling practices necessitates continuous evaluation to ensure they effectively address public health challenges and contribute to healthier dietary behaviours.

Future Policy Perspectives

Policymakers are encouraged to adopt evidence-based, mandatory FOP labelling systems to maximize public health benefits (Jones et al., 2019). Implementing such policies can enhance consumer awareness, promote healthier choices, and ultimately contribute to reducing the burden of diet-related diseases on public health systems.

Future policies should focus on harmonizing nutrient criteria across regions to facilitate trade and improve label effectiveness (Giner et al., 2023). The establishment of mandatory HFSS labelling could significantly reshape consumer food choices and improve public health outcomes, aligning with global efforts to combat diet-related diseases.

While HFSS labels are a promising tool for promoting healthier diets, their success depends on effective implementation and consumer education. Challenges such as regulatory inconsistencies and industry

resistance must be addressed to enhance the impact of these labels. Additionally, ongoing research and innovation in label design and technology can further support public health goals by making nutritional information more accessible and actionable for consumers.

Conclusion

HFSS food labels are an effective public health tool to guide consumers toward healthier dietary choices and reduce the burden of diet-related diseases. While global experiences show promising outcomes, challenges such as regulatory inconsistencies, industry pushback, and varying consumer literacy remain. Strengthening mandatory labelling policies, promoting consumer education, and leveraging technological innovations can enhance their effectiveness. Ultimately, well-designed and consistently implemented HFSS labels hold the potential to reshape food environments and contribute significantly to improved public health outcomes.

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Advancing Agricultural Frontiers through Space Breeding, Pathogen Défense, and Agronomic Insights

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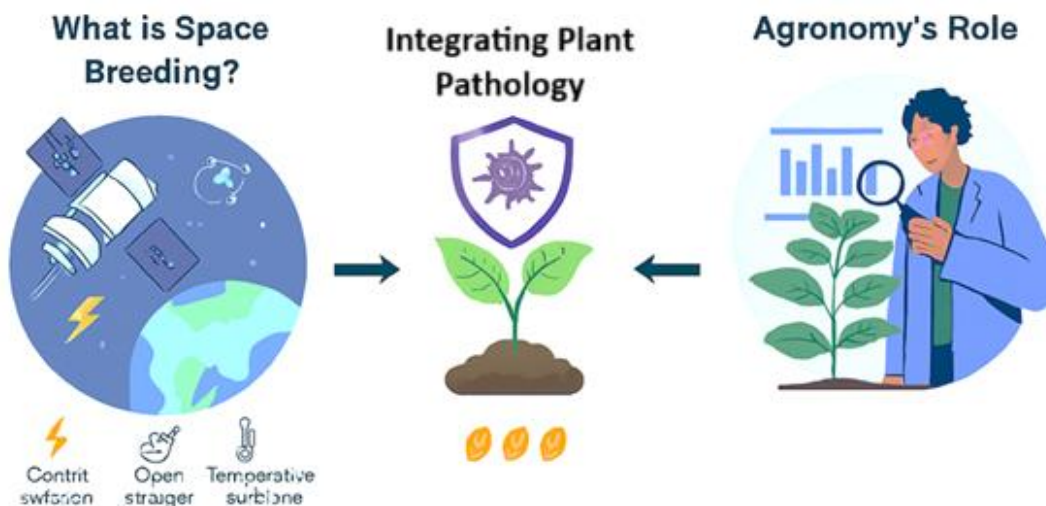
A. Kavitha Reddy¹, D. Shivani², K. Mahendra³, N. Varsha⁴

¹Assistant Professor, Dept. of Genetics and Plant Breeding, School of Agriculture, Kaveri University, Hyderabad, Telangana.

²Assistant Professor & Head, Dept. of Genetics and Plant Breeding, School of Agriculture, Kaveri University, Hyderabad, Telangana.

³Assistant Professor & Head, Dept. of Plant Pathology, School of Agriculture, Kaveri University, Hyderabad, Telangana.

⁴Assistant Professor, Dept. of Agronomy, School of Agriculture, Kaveri University, Hyderabad, Telangana.



What is Space Breeding?

As humanity ventures beyond Earth and nations intensify their investments in space exploration, space breeding is emerging as a transformative approach to develop resilient crops for extraterrestrial cultivation while simultaneously strengthening global food security. It involves sending plant seeds into space, where they are exposed to extreme conditions such as:

- Cosmic radiation
- Microgravity
- Ultra-vacuum
- Temperature extremes
- Weak geomagnetic fields.

These stressors trigger mutations at genetic and epigenetic levels, leading to traits like improved yield, nutritional quality, and stress resistance. Unlike conventional mutation breeding, space offers a unique mutagenic environment that accelerates genetic diversity.

What Happens to Plants in Space?

During spaceflight, plants experience stressors that Earth-bound crops never encounter:

- High-energy cosmic radiation
- Microgravity altering fluid dynamics and cell signaling
- Weak geomagnetic field
- Ultra-vacuum and temperature fluctuations
- Persistent sub-cellular and metabolic stress.

These lead to **space flight mutations**, including:

- a. Chromosomal aberrations and DNA damage
- b. Altered signal transduction pathways
- c. Changes in cell wall structure and metabolism
- d. Modified growth patterns and morphology
- e. Epigenetic shifts passed to progeny
- f. Variations in photosynthesis, germination, and antioxidant activity^{1,2}
- g. Space becomes a natural mutagenic lab, accelerating trait diversity that would take decades to achieve on Earth.

Advantages of Space Breeding

The appeal of space breeding lies in its unique advantages:

- 1. Accelerated innovation:** It induces a higher rate of desirable mutations in a relatively short time.
- 2. Unlocking potential:** It is especially useful for crops with naturally low variability.
- 3. Safety assurance:** Despite exposure to radiation, space-bred crops undergo rigorous multi-layered testing to ensure they are safe and contain no harmful radiation residues.

Challenges and Limitations

1. Very expensive and needs advanced technology.
2. Mutations are random
3. Needs extensive screening for identification of desirable mutants
4. Risk of harmful genetic changes.
5. Radiation may damage DNA, reducing seed survival.
6. Plants may show poor growth under space conditions.
7. Takes time to test and confirm new varieties on Earth.
8. Risk of contaminating space with biological material.
9. Only a few countries can afford such research.

Integrating Plant Pathology in Space Breeding

Plant pathology plays a vital role in ensuring the health and viability of space-bred crops:

- 1. Disease Resistance Screening:** Mutated plants are screened for resistance to fungal, bacterial, and viral pathogens.
- 2. Pathogen Behavior Monitoring:** Microgravity may alter pathogen virulence, requiring close observation of host-pathogen interactions.
- 3. Biosecurity in Closed Systems:** In space habitats, disease outbreaks could compromise life support systems. Plant pathology ensures crops remain disease-free.
- 4. Post-flight Analysis:** Returned seeds undergo rigorous testing for pathogen resistance and safety.

This discipline safeguards both astronaut health and crop sustainability in space agriculture.

Agronomy's Role in Cosmic Cultivation

Agronomy, the science of soil management and crop production, is essential for translating space-bred traits into viable agricultural systems:

- 1. Phenotypic Evaluation:** Agronomists assess growth, yield, and adaptability of space-mutated crops under terrestrial and simulated space conditions.
- 2. Environmental Optimization:** They help design controlled environments (e.g., hydroponics, aeroponics) suitable for space farming.
- 3. Trait Stabilization:** Agronomic practices ensure that beneficial mutations are retained across generations.
- 4. Integration with Genomics:** Agronomy bridges field performance with molecular data, enhancing breeding efficiency.

Together with plant pathology, agronomy ensures that space-bred crops are not only innovative but also agronomically sound and scalable

Global Progress in Space Breeding

The most advanced research in this field is led by China, which has invested heavily in space mutagenesis. In 2006, China launched Shijian-8, the first dedicated space breeding satellite. Since then, over 3,000 experiments have been carried out, leading to the development of more than 260 approved staple crop varieties and over 100 new varieties of vegetables, fruits, flowers, and forestry plants. The United States and Russia are also active players, using the ISS and other space missions to study cosmic crops.

India's Entry into Cosmic Agriculture

India, too, is stepping into the frontiers of space research. With the revival of human spaceflight missions and the upcoming Gaganyaan project, space breeding presents India with a unique opportunity to make significant contributions to global food security and agricultural innovation the entry of astronaut Shubhanshu Shukla into the ISS marks a new chapter, not only in human spaceflight but also in India's aspirations to develop its own space station by 2035. Indian scientists are increasingly involved in collaborative experiments, positioning the country as a leader in space science diplomacy.

The Future of Space Breeding

Looking ahead, space breeding holds immense promise for both Earth and extra-terrestrial farming. Future research will focus on:

1. Simulating space conditions on Earth
2. Comprehensive analysis of morphological, physiological, biochemical, and molecular changes in space-exposed seeds.
3. Genome and transcriptome sequencing to decode variations triggered by cosmic radiation.
4. Identifying genetic markers through SNP analysis and genome-wide association studies (GWAS).
5. Using AI and modeling studies to integrate genomic, phenotypic, and environmental data for efficient selection of space-bred crops.

Conclusion

Space breeding is more than a scientific novelty; it is a bold reimagining of agriculture. By combining the precision of plant pathology, the practicality of agronomy, and the innovation of space mutagenesis, humanity is poised to cultivate crops that can thrive in the harshest environments. These cosmic crops may one day feed astronauts on Mars and farmers in drought-prone regions alike.

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Elicitors and Their Role in Horticultural Crops

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P. Agalya¹, A. Kingsly Raj¹

¹Ph. D Scholar, Department of Vegetable science, Horticultural college and research institute, TNAU, Coimbatore – 641003.

Introduction

Elicitors are low molecular weight molecules that trigger the plant's defense system by activating secondary metabolite production—a phenomenon known as *elicitation*. They are classified as:

- Exogenous elicitors (pathogen-derived)
- Endogenous elicitors (plant-derived)

Depending on the pathogen type, plants initiate different hormonal signaling pathways:

- Necrotrophs trigger responses via jasmonic acid (JA) and ethylene
- Biotrophs activate salicylic acid (SA) pathways.

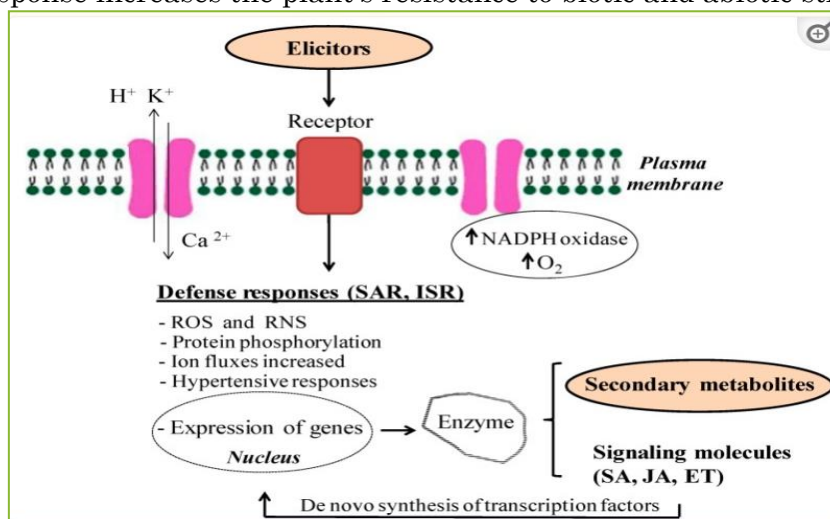
Cross-talk between these signaling molecules orchestrates a complex defense response tailored to the invading pathogen.

Mode of Action

Each plant cell can recognize and respond to stress through receptor-mediated recognition of elicitors. These receptors often include protein kinases, which play essential roles in recognizing pathogen-associated molecules. Upon recognition, a cascade of responses is triggered, including:

- Production of pathogenesis-related (PR) proteins
- Accumulation of reactive oxygen species (ROS) and reactive nitrogen species (RNS)
- Ion flux changes (e.g., Ca^{2+} influx, K^{+} efflux)
- Protein phosphorylation, lipid peroxidation, and reinforcement of the cell wall
- Activation of transcription factors involved in secondary metabolite synthesis

This multi-layered response increases the plant's resistance to biotic and abiotic stresses.



Advantages of Using Elicitors

- Enhances natural plant defenses
- Reduces insect feeding damage
- Attracts beneficial insects via induced volatiles
- Non-toxic and biodegradable
- Environmentally friendly and leaves no harmful residues.

Disadvantages

1. May reduce photosynthesis and growth rate
2. Can lower overall plant fitness
3. Some elicitors are cost-intensive.

Application in Horticultural Crops

1. Preharvest Elicitation: Elicitors can be applied via seed priming, foliar sprays, or integrated into hydroponic systems. Their effect is strongly influenced by treatment concentration, timing, and the plant's genetic makeup.

2. Postharvest Applications: Used to maintain or enhance nutritional value and quality of fruits and vegetables. Techniques include:

- a. UV irradiation
- b. Temperature modulation
- c. Controlled gas atmospheres

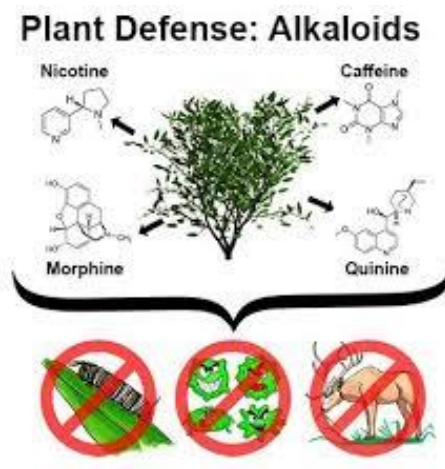
3. Influence on Primary Metabolism: Although primarily impacting secondary metabolism, elicitors also affect primary metabolic processes like:

- a. Photosynthesis
- b. Respiration
- c. Nutrient transport

These changes are part of the plant's adaptation to stress.

4. Defense Mechanisms Activation: Plants have:

- a. Constitutive defenses (always present): e.g., waxy cuticles, bark, thorns
- b. Induced defenses (activated upon attack): e.g., enzyme production, toxic compounds, programmed cell death.



5. Enhancement of Bioactive Compounds: Elicitors promote accumulation of health-promoting phytochemicals such as:

- a. Phenolic Compounds:** Important for color, flavor, and plant defense; also provide antioxidant and anti-inflammatory benefits to humans.
- b. Glucosinolates:** Found in cruciferous vegetables; protect against pests and diseases, and reduce cancer and cardiovascular disease risks in humans.
- c. Carotenoids & Betalains:** Pigments with antioxidant and photoprotective properties; contribute to disease prevention.

Classification of Elicitors

1. General Elicitors (MAMPs/PAMPs/DAMPs): These act broadly across different plant cultivars and initiate primary immunity. Examples include microbial cell wall fragments or plant damage signals.

2. Specific Elicitors (Effectors): Produced by specialized pathogens, these trigger secondary immune responses in genetically compatible plant varieties via receptor-mediated recognition.

Synthetic Elicitors in Use

Synthetic Elicitor	Function/Source
Polyamines	Regulate cell growth; includes putrescine, spermidine, spermine
Salicylic Acid	Triggers systemic acquired resistance (SAR)
Jasmonic Acid	Activates defenses against necrotrophs and herbivores
Chitosan	Derived from crustaceans; induces PR-proteins
Brassinosteroids	Plant hormones enhancing stress tolerance
Tricontinol	Fatty alcohol promoting plant growth and defense

Crop-Specific Elicitor Applications

Crop	Elicitor	Effect	Reference
Butter lettuce	Wounding + Ethylene	Increased phenolics	Tomás-Barberán et al. (1997)
Citrus	Cold storage (4°C)	Anthocyanin accumulation	Lo Piero et al. (2005)
Apple	UV-B & Light	Elevated phenolics	Hagen et al. (2007)
Grapes	UV exposure	Antioxidant enhancement	Crupi et al. (2014)
Broccoli	Methyl Jasmonate	Increased flavonoids & glucosinolates	Pérez-Balibrea et al. (2011)
Strawberry	Elevated CO ₂	More anthocyanins & flavonols	–
Pea sprouts	Folic acid + Vitamin C	Boosted total phenolics	–
Radish	NaCl stress	Higher phenolic content	–

Conclusion

Elicitors represent a sustainable and environmentally responsible approach to enhancing plant resistance and improving crop quality. Unlike conventional agrochemicals, they are biodegradable, non-toxic, and leave no harmful residues. Their use can significantly enhance the nutritional and medicinal value of horticultural crops through the activation of plant defense pathways and the stimulation of bioactive compound production. Integrating elicitors into modern horticultural practices offers a promising route toward sustainable agriculture and improved human health.

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Sources of Agricultural Greenhouse Gas Emission and its Mitigation Strategies

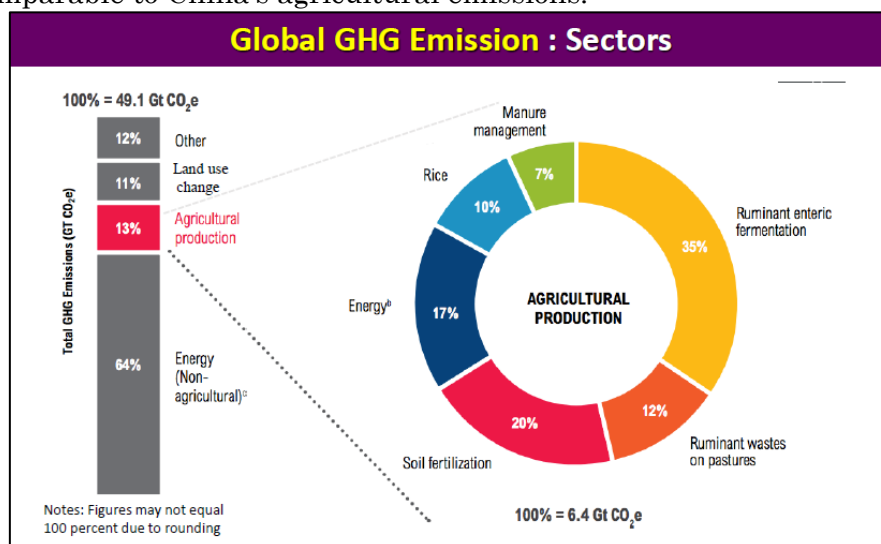
Article ID: 72031

P. Agalya¹, A. Kingsly Raj¹

¹Ph. D Scholar, Department of Vegetable science, Horticultural college and research institute, TNAU, Coimbatore – 641003.

Introduction

India is one of the largest contributors to global greenhouse gas (GHG) emissions, ranking third with approximately 2.6 billion tonnes of CO₂ equivalent emitted annually (Global Carbon Atlas). The energy sector remains the largest emitter (44%), followed by manufacturing and construction (18%), and agriculture, forestry, and land use sectors (14%). Although agriculture's relative share has declined from 28% in 1994 to 14% in 2016, its absolute emissions have increased, reaching around 650 million tonnes CO₂ eq in 2018—comparable to China's agricultural emissions.



In India, the primary contributors to GHG emissions from agriculture include:

- Livestock sector – 54.6%
- Nitrogen-based fertilizers – 19%
- Rice cultivation – 17.5%
- Manure management – 6.9%
- Crop residue burning – 2.1%

Climate Change and Global Warming

Global average temperatures rose by 0.6°C during the 20th century, and projections indicate a further rise of 2 to 6°C during the 21st century. This warming trend is closely linked to the increasing atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), among others—many of which are associated with agricultural activities.

Key Greenhouse Gases in Agriculture

Agriculture contributes to the emission of several greenhouse gases, primarily:

- Carbon Dioxide (CO₂)
- Methane (CH₄)
- Nitrous Oxide (N₂O)

Other greenhouse gases include Chlorofluorocarbons (CFCs), ozone (O₃), and water vapor, but their association with agriculture is comparatively limited.

1. Carbon Dioxide (CO₂): CO₂ is released primarily through:

- Soil organic matter decomposition and biomass burning during land conversion to agriculture
- Combustion of fossil fuels used in the production and operation of farm machinery, fertilizer manufacturing, and irrigation systems

Mitigation strategies:

- Adopt low-tillage or no-till farming
- Cover cropping during non-growing seasons to enhance soil carbon storage
- Shift to renewable energy sources and energy-efficient farm operations

2. Methane (CH₄): CH₄ is a potent GHG with a global warming potential 28 times that of CO₂. Agricultural sources include:

- Enteric fermentation in ruminant livestock (main source)
- Manure management
- Rice paddies, due to anaerobic microbial activity in flooded soils

Mitigation strategies:

- Improve livestock feed efficiency
- Use methane inhibitors or feed additives
- Introduce alternate wetting and drying (AWD) in rice fields
- Capture methane from manure through biogas systems

3. Nitrous Oxide (N₂O): N₂O has the highest GWP among the major GHGs—273 times more potent than CO₂. It is primarily released from:

- Nitrogen-rich fertilizers, manure, and compost
- Microbial conversion of soil nitrogen via nitrification and denitrification

Mitigation strategies:

- Enhance nitrogen-use efficiency (NUE)
- Use precision agriculture tools for optimized fertilizer application
- Apply organic amendments judiciously
- Incorporate legume rotations and cover crops to fix atmospheric nitrogen naturally

Agricultural Mitigation Strategies

1. Reducing Fuel Use: Fuel combustion in agricultural machinery is a direct source of CO₂. Strategies to reduce emissions include:

- Conservation tillage, which reduces field passes
- Grazing livestock directly instead of mechanical forage harvesting
- Field drying of grains before harvest to save energy
- Site-specific nutrient management to minimize fuel use and fertilizer needs

2. Carbon Sequestration: Agricultural soils and vegetation act as carbon sinks. Sequestration strategies include:

- Conservation agriculture (reduced tillage, cover cropping)
- Permanent grasslands and agroforestry systems
- Crop residue management
- Land resting or fallowing programs.

These practices increase soil organic carbon, improving both soil health and GHG mitigation.

3. Improving Nitrogen Use Efficiency (NUE): Efficient nitrogen management reduces both environmental pollution and N₂O emissions. Key practices:

- Use of soil and plant tissue tests to guide N applications
- Timed fertilizer applications to match crop needs
- Adoption of GIS and precision agriculture tools
- Incorporation of green manures and biological nitrogen fixation
- Establishing filter strips near water bodies to capture excess nitrogen.

4. Enhancing Ruminant Digestive Efficiency: Livestock are major contributors to methane emissions through enteric fermentation and manure decomposition.

Livestock-related strategies:

- i. Modify diets to improve digestion and reduce methane
- ii. Add lipids or feed additives to reduce CH₄ production
- iii. Capture and utilize biogas from manure
- iv. Convert waste into fertilizer through composting or anaerobic digestion

Rice cultivation strategies:

- i. Implement intermittent flooding to reduce anaerobic decomposition
- ii. Adopt rice varieties with lower methane emission potential
- iii. Optimize fertilizer and water management.

Conclusion

Although agriculture accounts for a smaller share of total emissions compared to energy or industry, its role in climate change is significant due to the high warming potential of methane and nitrous oxide. Implementing sustainable farming practices, improving nitrogen and resource efficiency, and adopting low-emission technologies can help mitigate GHG emissions from this sector. A transition toward climate-smart agriculture not only helps in emission reduction but also contributes to food security and environmental sustainability.

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Honeycomb Breeding – A Smart Way to Develop Better Crops

Article ID: 72032

Dr. Kosenepalli Manasa¹

Introduction

India is a land of farmers, where agriculture is the backbone of our economy and food security. Farmers are constantly in search of crop varieties that give **high yield, withstand diseases, and adjust to changing climate conditions**. Scientists, through breeding methods, try to develop such improved varieties. But one major challenge in crop improvement is **competition among plants**. In normal field planting, plants compete with each other for sunlight, water, and nutrients. A plant may look superior, not because it has good genes, but because it had a favorable position in the field. This makes it difficult for breeders to identify plants that are truly superior due to their **genetic potential**. To solve this problem, researchers developed a unique method called **honeycomb breeding**. Just as honeybees arrange their hives in a neat hexagonal pattern, here also, plants are planted in a **hexagonal honeycomb design**. This ensures that **each plant gets equal space and opportunity to grow**, and scientists can judge their true ability.

What is Honeycomb Breeding?

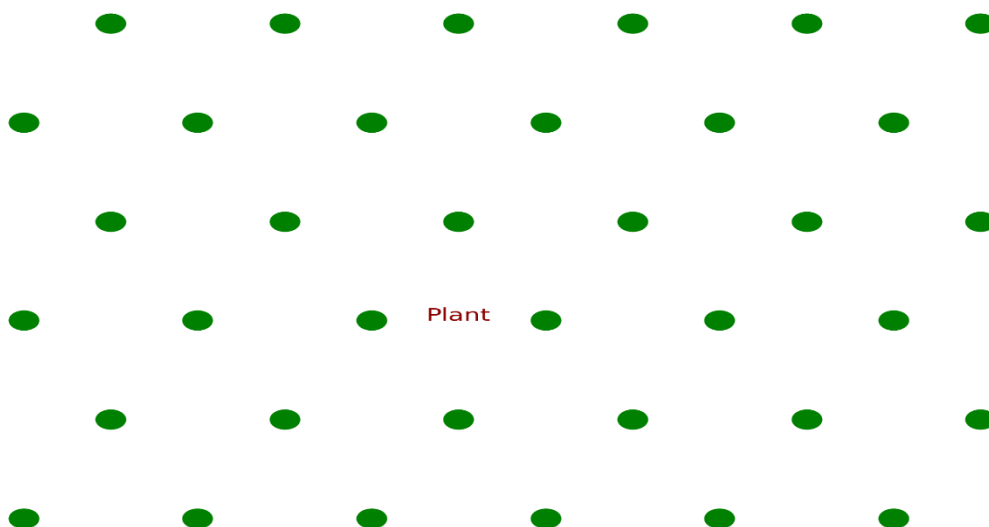
Honeycomb breeding was developed by **Dr. P. A. Fasoulas in Greece (1973)**. It is a method where plants are sown in a **hexagonal pattern** instead of the usual square or rectangular rows.

Why Hexagonal?

1. In a square pattern, plants compete more along rows and columns.
2. In a hexagonal pattern, **each plant is equidistant from its six nearest neighbors**.
3. This reduces uneven competition and allows a **fair comparison** of plants.

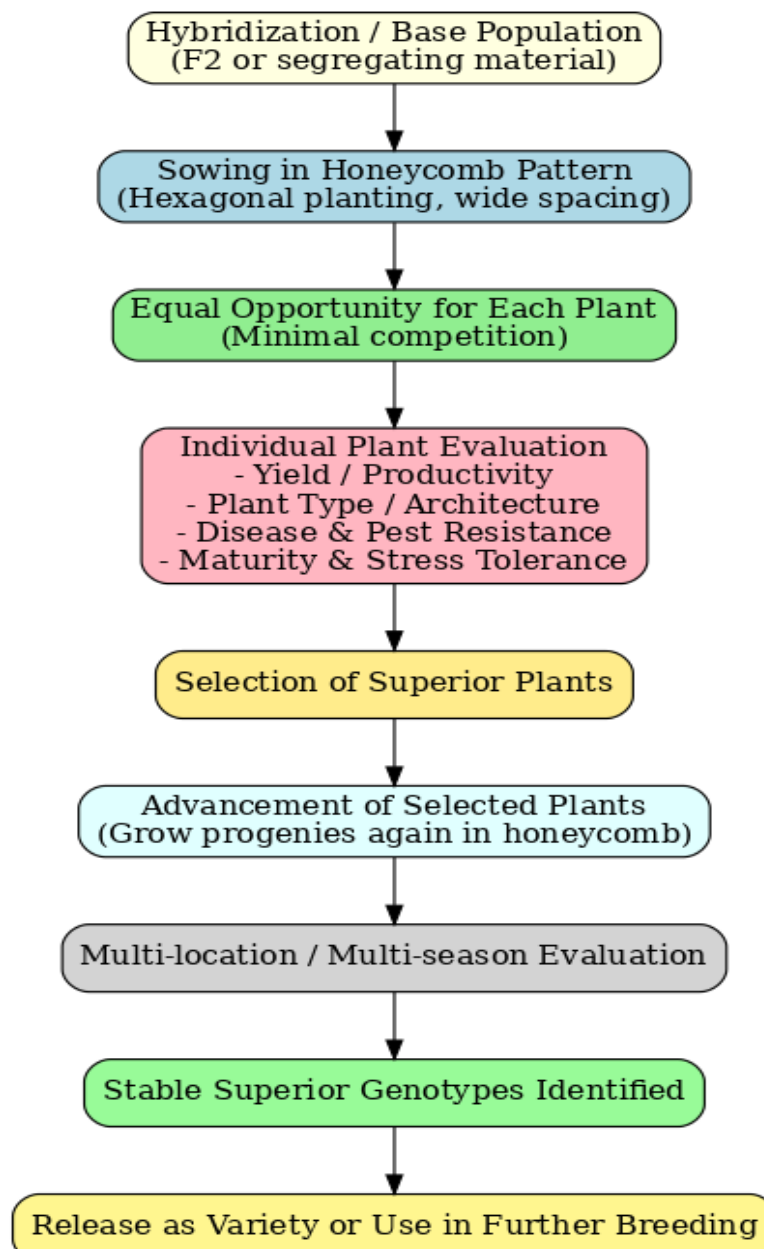
Thus, honeycomb breeding ensures that the observed differences among plants are due to **genetics, not competition**.

Honeycomb (Hexagonal) Planting Pattern



Stepwise Process of Honeycomb Breeding

- 1. Hybridization or Base Population** – Seeds from crosses or segregating material (like F₂ generation) are used.
- 2. Planting in Honeycomb Design** – Seeds are sown in wide spacing in a **hexagonal layout**.
- 3. Independent Growth** – Each plant grows freely without disturbance from neighbors.
- 4. Individual Evaluation** – Breeders record data like:
 - a. Grain/fruit yield per plant
 - b. Plant architecture (height, branching, leaf size)
 - c. Resistance to pests and diseases
 - d. Tolerance to drought or other stresses
 - e. Earliness or late maturity.
- 5. Selection of Superior Plants** – The best individuals are chosen.
- 6. Advancement** – Seeds of selected plants are again grown in honeycomb pattern for confirmation.
- 7. Testing in Multiple Locations** – Selected plants are evaluated across different fields and seasons.
- 8. Variety Release** – Stable and superior genotypes are released as **new crop varieties** or used in further breeding.



Advantages of Honeycomb Breeding

1. **Shows true potential** – Plants grow independently, so their performance reflects their genes, not their position.
2. **Accurate selection** – Breeders can identify real superior plants in early generations.
3. **High heritability** – Complex traits like yield can be improved with greater accuracy.
4. **Versatile method** – Works for both self-pollinated crops (like wheat, rice) and cross-pollinated crops (like gourds, sunflower).
5. **Useful for climate-smart farming** – Helps in developing varieties that can perform well in diverse conditions.

Limitations

1. Requires **more land area**, since plants are widely spaced.
2. **Labor intensive** – Each plant must be observed, measured, and recorded individually.
3. Not practical for handling **very large populations**, but excellent for testing elite lines.

Crops where it can be Used

1. **Cereals**: Wheat, barley, rice – for yield and stress tolerance.
2. **Pulses**: Chickpea, cowpea, soybean – for resistance and productivity.
3. **Oilseeds**: Sunflower, groundnut – for stable high yield.
4. **Vegetables**: Tomato, cucumber, bottle gourd, bitter gourd, okra – for fruit yield and quality.

Conclusion

Honeycomb breeding is like giving **each plant its own separate room** to grow, without quarrelling with neighbors. Just as bees build strong and efficient honeycombs, plant breeders use the honeycomb design to select **strong and efficient crop varieties**. This method ensures that varieties are selected on the basis of **their true genetic worth**. With the help of honeycomb breeding, farmers can get access to **better, high-yielding, disease-resistant, and climate-resilient crops** in the future. Thus, honeycomb breeding stands as a **smart, scientific, and farmer-friendly approach** to crop improvement.

Harnessing Python for the Life Sciences: A Comprehensive Exploration of Biopython's Tools, Applications, and Impact

Article ID: 72033

Harisha K¹, Karthik R¹, Gaganashree K P¹

¹Ph.D. Scholar, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad-580005.

Introduction

In the age of genomic revolution and data-driven research, biology is no longer confined to the microscope or petri dish. The digital age has transformed biology into a data-rich science, with massive volumes of information being generated through sequencing technologies, structural biology, and functional genomics (Cock *et. al.*, 2009). Making sense of this data requires not just biological knowledge but computational power and this is where **Biopython** steps in as a game-changer (Cornish *et. al.*, 2021).

BioPython

Biopython is an open-source collection of Python libraries and tools specifically designed for biological computation. Developed and maintained by an international community of scientists and programmers (Dewangan *et. al.*, 2025). Biopython allows users to efficiently handle biological data, automate routine bioinformatics tasks, and even perform complex molecular analyses (Doluca, 2024). The project began in the early 2000s as part of the wider Bio* projects (like BioPerl, BioJava, and BioRuby), which aim to provide programming support for bioinformatics across different languages. Among these, Biopython stands out due to Python's popularity, ease of use, and vast ecosystem of scientific libraries (Khodja *et. al.*, 2024).

Why Biopython Matters in Modern Biology

As biology increasingly intersects with data science, Biopython offers a vital toolkit for students, researchers, and professionals to analyze, manipulate, and visualize biological data. From DNA and protein sequences to phylogenetic trees and molecular structures, Biopython simplifies the complexities of bioinformatics (Kumari & Gupta, 2023). It supports common file formats like FASTA, GenBank, and PDB, making it easier to integrate biological data from multiple sources (Mohialden *et. al.*, 2023). Its user-friendly interface also ensures that even researchers with minimal programming experience can begin using it effectively (Sequeira *et. al.*, 2022).

Key Features and Functionalities

One of Biopython's greatest strengths is its versatility. With it, users can:

1. **Read, write, and analyze sequence data** using the Seq and SeqRecord objects.
2. **Fetch data from public databases** like NCBI, UniProt, or PDB via internet modules.
3. **Perform sequence alignments** using local and online tools.
4. **Handle 3D structures of proteins** with the Bio.PDB module.
5. **Parse results from bioinformatics tools** such as BLAST and ClustalW.
6. **Visualize data and compute statistics** with support from Matplotlib, NumPy, and Pandas. (Shajii *et. al.*, 2021)

Biopython can also integrate with other Python-based tools for machine learning, data mining, and statistical analysis, making it an ideal backbone for advanced bioinformatics pipelines.

Simple Yet Powerful: A Glimpse of Biopython in Action: To understand the elegance of Biopython, consider this simple example:

```
from Bio.Seq import Seq

my_seq = Seq("AGTACACTGGT")

print("Original Sequence:", my_seq)

print("Complement:", my_seq.complement())

print("Reverse Complement:", my_seq.reverse_complement())
```

Fig1. With just a few lines of code, Biopython can compute the complement and reverse complement of a DNA sequence—a task fundamental in molecular biology. This simplicity makes it ideal for automating repetitive lab tasks or exploring large datasets.

Applications Across the Life Sciences

Biopython is used extensively in areas like genomics, proteomics, transcriptomics, molecular evolution, and systems biology. In genomics, for example, it helps in reading genome annotation files, extracting gene regions, or aligning sequences to identify mutations (Mohialden *et al.*, 2023). Structural biologists can use Biopython to analyze protein-ligand interactions, compare PDB files, or visualize 3D molecular data (Kumari & Gupta, 2023). Even students working on biology projects can use Biopython to simulate PCR, translate DNA to protein, or model phylogenetic relationships (Doluca, 2024).

The Community and Ecosystem

The strength of Biopython lies not only in its functionality but also in its community. It is supported by a network of developers and users who actively contribute to its growth. The documentation is thorough and beginner-friendly, with tutorials, code examples, and detailed API references. Since its open-source, users are encouraged to contribute new modules, fix bugs, or suggest improvements making it a truly collaborative project (Khodja *et al.*, 2024).

Biopython in Education and Research

Many universities and bioinformatics training programs now include Biopython as part of their curriculum. Its intuitive syntax, integration with biological concepts, and real-world applications make it an excellent learning tool for students (Cornish *et al.*, 2021). Moreover, research labs across the globe use Biopython in their pipelines for tasks ranging from genome annotation to protein modelling, making it a practical choice for academic and industrial applications alike (Mohialden *et al.*, 2023).

Conclusion: The Future of Biology is Computational

Biopython represents the synergy of two powerful domains—biology and programming. It democratizes bioinformatics by making it accessible to anyone with basic coding skills and a passion for biology. In a future where biology will continue to generate more data than ever before, tools like Biopython will remain indispensable for unlocking the secrets hidden within DNA, RNA, and proteins. Whether you're a student, a professor, or a researcher, Biopython invites you to explore the living world through the lens of code.

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One Gene, Many Roles: Unravelling Pleiotropic QTLs in Crop Development

Article ID: 72034

Harisha K¹, Karthik R¹, Gaganashree K P¹

¹Ph.D. Scholar, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad-580005.

Introduction

In the field of plant genetics, researchers are increasingly discovering that genes rarely act in isolation. While earlier theories focused on the idea of “one gene controlling one trait,” modern science reveals a far more interconnected system. One fascinating genetic phenomenon is pleiotropy, in which a single gene affects two or more seemingly unrelated traits (Mangin *et.al.*, 1998). When this occurs within a quantitative trait locus (QTL), a region of DNA associated with variation in measurable traits, it is termed a pleiotropic QTL. These loci are incredibly valuable in crop science because they help explain how complex traits like yield, maturity, stress tolerance, and quality are often genetically linked (Ookawa *et.al.*, 2010). Understanding pleiotropic QTLs opens up exciting possibilities for accelerating plant breeding and improving crop performance.

Role of Pleiotropic QTL in Trait Expression

Pleiotropic QTLs play a central role in trait expression by functioning as “genetic hubs” or regulatory switches that influence multiple processes in the plant. These QTLs often house regulatory genes, such as transcription factors or hormone-related genes, which control various downstream targets involved in different biological pathways (Boehm *et.al.*, 2019). For instance, a single pleiotropic QTL might simultaneously affect flowering time, plant height, and grain yield, as seen with the *Ghd7* gene in rice (Smith, 2016). This happens because many traits are interconnected through shared developmental or physiological pathways. By regulating one central process, a pleiotropic QTL can set off a cascade of changes throughout the plant’s biology, shaping multiple traits together (Dwivedi *et.al.*, 2024).

Pleiotropy can be either beneficial or problematic in plant breeding when a pleiotropic QTL has positive effects on multiple traits. For example, improving both drought tolerance and early flowering, it becomes highly desirable. Such QTLs allow breeders to enhance multiple important traits in one selection cycle (Mackay & Anholt, 2024). However, the challenge arises with antagonistic pleiotropy, where improving one trait leads to an unintended reduction in another. A classic example is seen in wheat, where QTLs that increase grain protein content often reduce grain yield (Li *et.al.*, 2023). These trade-offs require careful consideration, as selecting for one trait may inadvertently cause a loss in another. Breeders must therefore aim to exploit positive pleiotropy while managing or decoupling negative interactions (Weng *et.al.*, 2022).

Mechanism of Trait Expression by Pleiotropic QTL

Several mechanisms explain how pleiotropic QTLs function. One common mechanism is the involvement of multi-functional genes, which encode proteins or enzymes that participate in multiple biological processes (Ookawa *et.al.*, 2010). Some pleiotropic effects occur because of hormones like auxins, gibberellins, and cytokinins influence various traits including root architecture, flowering, and leaf size. Other pleiotropic QTLs affect key transcription factors or signaling molecules that control multiple downstream genes (Boehm *et.al.*, 2019). In some cases, gene regulatory networks and chromatin-level interactions play a role, allowing one region of the genome to influence diverse pathways through co-expression or epistasis.

Identification of Pleiotropic QTL

Identifying pleiotropic QTLs requires advanced tools that can analyze multiple traits simultaneously. Traditional single-trait QTL mapping often misses these complex interactions. Instead, scientists now use multivariate QTL mapping, multi-trait GWAS (Genome-Wide Association Studies), and principal

component analysis (PCA)-based approaches to capture shared genetic signals (Smith, 2016). Software tools like TASSEL, R/qtl2, MTMM, QTLNetwork, and GEMMA enable such analyses by correlating marker data with trait datasets across multiple genotypes (Dwivedi *et.al.*, 2024). In practice, pleiotropic QTLs are identified when the same genomic region is consistently associated with more than one trait, and their effects are statistically validated through trait correlations and co-localization of QTL peaks (Mackay & Anholt, 2024).

A major challenge in pleiotropy research is distinguishing true pleiotropy from tight genetic linkage. In some cases, two different genes affecting different traits might lie very close to each other on the chromosome, giving the false appearance of pleiotropy (Li *et.al.*, 2023). To resolve this, researchers use high-resolution fine mapping, recombinant inbred lines (RILs), and gene expression (eQTL) analysis. Functional validation using mutants, overexpression lines, or CRISPR/Cas9 editing can further confirm whether a single gene is genuinely responsible for multiple phenotypic effects. Without such validation, pleiotropy remains a statistical inference (Boehm *et.al.*, 2019).

Factors influencing Pleiotropic QTL

Environmental interactions add another layer of complexity to pleiotropic QTL expression. Many QTLs show genotype $\times$ environment (G $\times$ E) interactions, meaning their effects vary across different conditions. A QTL may influence both yield and flowering time under drought stress but not under well-watered conditions. This is called context-dependent pleiotropy (Weng *et.al.*, 2022). Therefore, it is essential to test QTL effects across multi-environment trials (METs) and seasons. Understanding how pleiotropic QTLs behave under environmental variability allows breeders to select genotypes with stable performance under real-world conditions, particularly in the face of climate change (Mackay & Anholt, 2024).

Advantages of Pleiotropic QTL

The breeding value of pleiotropic QTLs is significant. In marker-assisted selection (MAS), identifying a QTL that improves multiple traits reduces the number of markers breeders need to track. In genomic selection (GS), pleiotropic effects are incorporated into prediction models that estimate breeding values for multiple traits simultaneously. In recent years, genome editing tools such as CRISPR/Cas9 have enabled precise modifications of pleiotropic genes either enhancing their beneficial functions or separating negative interactions (Dwivedi *et.al.*, 2024). This opens the door for ideotype breeding, where plants are designed with ideal trait combinations in mind, driven by a deep understanding of shared genetic controls.

Conclusion

Looking ahead, the integration of multi-omics data including genomics, transcriptomics, metabolomics, and phenomics will offer unprecedented insight into pleiotropic networks. With the help of machine learning and AI, it is now possible to predict potential pleiotropic relationships even before field trials. Meanwhile, pan-genomics across diverse cultivars is revealing how pleiotropic QTLs may vary across genetic backgrounds, offering new alleles for breeding. Ultimately, pleiotropic QTLs are not just curiosities of the genome — they are powerful tools in our quest to develop crops that are more productive, resilient, and sustainable.

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From Data to Decisions: The Role of Multivariate Analysis in Modern Plant Breeding

Article ID: 72035

Harisha K¹, Karthik R¹, Gaganashree K P¹

¹Ph.D. Scholar, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad-580005.

Introduction

Modern plant breeding is a complex science that deals with evaluating multiple traits simultaneously such as yield, height, flowering time, disease resistance, and drought tolerance (Ali *et.al.*, 2021). Since these traits often interact with each other and the environment, analysing them one at a time using univariate statistics may lead to misleading conclusions. This is where multivariate statistical techniques become essential. These techniques allow breeders to analyse, interpret, and visualize multiple variables together, helping to make more informed and holistic breeding decisions (Bedjaoui *et.al.*, 2022).

Multivariate Analysis in Plant Breeding

Unlike classical statistical methods that study one trait at a time, multivariate analysis explores how traits vary together. For instance, plant height and grain yield might be positively correlated, while early flowering might be negatively associated with biomass (Crossa *et.al.*, 2025). In such cases, breeders are not just interested in individual trait performance but in understanding trait relationships, genotype performance across multiple traits, and environmental interactions. Multivariate techniques enable the study of such complexities by reducing data dimensionality and revealing hidden patterns that are otherwise difficult to detect (Deepika *et.al.*, 2021).

Key Multivariate Techniques Used in Plant Breeding

In plant breeding, several multivariate statistical techniques are widely used to analyse complex trait data. **Principal Component Analysis (PCA)** reduces large datasets into a smaller number of principal components; preserving most of the variance and helping breeders identify key traits contributing to genetic diversity and visualize genotype-trait relationships (Ihsan *et.al.*, 2021). **Cluster Analysis** groups genotypes or traits based on similarity, aiding in the classification of genotypes into heterotic groups, identifying duplicates in germplasm collections, and managing breeding populations (Kumar *et.al.*, 2018). **Canonical Variate Analysis (CVA)** is useful for maximizing separation between predefined groups, allowing breeders to distinguish promising lines and evaluate environmental influences on trait expression (Padhi *et.al.*, 2023). **Discriminant Function Analysis (DFA)**, a supervised method, identifies the best combination of traits for group differentiation and is commonly used to classify genotypes based on traits like disease resistance or maturity class (Rocha *et.al.*, 2025). Lastly, **Multivariate Analysis of Variance (MANOVA)** assesses differences in group means across multiple traits simultaneously, enabling plant breeders to evaluate the combined effects of genotypes and environments, ultimately enhancing the precision of selection decisions (Kumar *et.al.*, 2018).

Real-World Applications in Breeding Programs

Multivariate techniques are widely applied across various stages of breeding programs. For example, in early-stage trials, PCA and cluster analysis can help select diverse parents for hybridization (Ihsan *et.al.*, 2021). In advanced trials, MANOVA and CVA help evaluate genotype stability and performance across multi-environment trials (METs). During variety release, discriminant analysis supports decision-making by identifying ideal ideotypes with superior trait combinations (Crossa *et.al.*, 2025). These methods also support molecular breeding by associating trait clusters with genetic markers in QTL mapping and genomic selection (Rocha *et.al.*, 2025).

Advantages over Traditional Methods

By using multivariate statistics, plant breeders gain several advantages:

- 1. Better trait integration:** Multiple traits are evaluated together, mimicking real-world conditions.
- 2. Improved selection accuracy:** Trait correlations are considered, reducing bias in genotype ranking.
- 3. Data simplification:** Large, complex datasets are reduced to meaningful components or clusters.
- 4. Visual insights:** Biplots, dendrograms, and canonical plots offer intuitive understanding of patterns.

This holistic approach ensures that selection is not just based on one trait like yield, but considers the overall agronomic profile of each genotype.

Challenges and Considerations

Despite their advantages, multivariate techniques require careful implementation. Data standardization and normalization are critical for fair comparisons. Also, trait interdependence must be considered when interpreting results some traits may dominate the analysis due to their scale or variance. Furthermore, breeders need basic statistical training to understand the assumptions and limitations of each technique. Open-source tools like R (packages like FactoMineR, ade4, Agricolae) and Python (libraries like scikit-learn, Pandas, Matplotlib) have made these methods more accessible to researchers.

Conclusion: A Statistical Revolution in Plant Breeding

In a world where breeding decisions must be made faster and more accurately, multivariate statistical techniques provide a scientific edge. They empower breeders to interpret complex data, discover trait relationships, and make data-driven selections. As modern breeding continues to integrate genomics, remote sensing, and AI, multivariate analysis will remain a cornerstone method for translating biological complexity into actionable insights. For today's and tomorrow's plant breeders, understanding multivariate statistics is not just a skill—it's a necessity.

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Artificial Intelligence Meets Agriculture: Transforming Phenotyping from Pixels to Predictions

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Harisha K¹, Karthik R¹, Gaganashree K P¹

¹Ph.D. Scholar, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad-580005.

Introduction

In the face of climate change, growing populations, and the urgent need for sustainable agriculture, plant scientists and breeders are racing against time to develop high-yielding, resilient crop varieties (Cardellicchio *et.al.*, 2023). However, the biggest bottleneck in modern crop improvement is not gene sequencing or breeding technologies but phenotyping. While genotyping has become fast and affordable, measuring how a plant actually performs in the field (its phenotype) remains slow, labor-intensive, and subjective (Cembrowska-Lech *et.al.*, 2023). This is where Artificial Intelligence (AI), paired with High-Throughput Phenotyping (HTP), is revolutionizing the landscape of plant science.

High-Throughput Phenotyping

High-throughput phenotyping refers to the automated measurement of plant traits at a large scale using sensors, imaging systems, drones, and robotics (Gill *et.al.*, 2022). It enables researchers to collect detailed information about plant growth, shape, canopy structure, leaf area, stress symptoms, and more rapidly and non-destructively (Khan *et.al.*, 2022). Platforms such as unmanned aerial vehicles (UAVs), ground-based rovers, and conveyor belt imaging systems are deployed in fields or greenhouses to capture vast amounts of data in real time (Koh *et.al.*, 2021).

The Role of AI in Phenotyping

Artificial Intelligence particularly its subfields of Machine Learning (ML) and Computer Vision provides the tools needed to analyse and interpret high-throughput phenotypic data (Mushtaq *et.al.*, 2024). AI algorithms can be trained to recognize patterns, quantify traits, classify plant types, and even predict future performance based on image and sensor data. For example, convolutional neural networks (CNNs) can distinguish between healthy and diseased leaves, while deep learning models can segment plant parts like stems, leaves, and flowers in a complex field image (Sheikh *et.al.*, 2024).

This automation eliminates human subjectivity, reduces time, and increases precision in phenotyping. Moreover, AI allows continuous monitoring of plant development under field conditions enabling researchers to study plant growth dynamics, drought responses, nutrient uptake, and more over time (Sharma & Shivandu, 2024).

Applications in Crop Improvement

The integration of AI and high-throughput phenotyping is already showing tangible benefits in plant breeding and stress physiology (Mushtaq *et.al.*, 2024). Breeders can now screen thousands of genotypes for traits like drought tolerance, heat resistance, or early vigour using automated image analysis pipelines (Khan *et.al.*, 2022). AI also helps in trait mining, where novel and subtle phenotypic expressions (e.g., early wilting, stay-green, leaf angle) are quantified in ways that were previously impractical (Gill *et.al.*, 2022).

In precision agriculture, AI-enhanced phenotyping enables real-time crop monitoring to guide irrigation, fertilization, and pest control. In controlled environment agriculture (like vertical farms), computer vision models can track every plant's growth and alert to anomalies—resulting in more consistent yield and better resource use (Koh *et.al.*, 2021).

From Pixels to Predictions: A New Era of Data-Driven Agriculture

The combination of imaging and AI transforms each plant into a data point with thousands of measurable features leaf colour, shape, texture, thermal response, canopy cover, etc (Sheikh *et.al.*, 2024). These features

can then be correlated with genetic data through Genome-Wide Association Studies (GWAS) or used in Genomic Selection to predict the breeding value of a plant. In this way, phenomics becomes a powerful bridge between genotype and phenotype, supporting next-generation crop improvement strategies (Cardellicchio *et.al.*, 2023).

Additionally, integrating AI with multi-sensor data fusion combining RGB, hyperspectral, thermal, LiDAR, and fluorescence imaging offers even richer insights into plant physiology and stress responses (Mushtaq *et.al.*, 2024). This multimodal data, once untapped, can now be mined using AI to uncover hidden trait combinations that define elite genotypes (Cembrowska-Lech *et.al.*, 2023).

Challenges and the Road Ahead

Despite its promise, AI-driven phenotyping also brings challenges. Data labelling for model training can be time-consuming, and field conditions such as varying light, wind, or background noise can introduce errors in image analysis. Furthermore, AI models trained in one environment may not generalize well across different crops, seasons, or geographies. Hence, model robustness and validation remain critical.

There is also a need for more open-source tools, shared datasets, and interdisciplinary collaboration between plant scientists, data engineers, and AI researchers. Platforms like PlantCV, PhenoDeep, and DeepPlantPheno are promising initiatives, but broader adoption will require user-friendly interfaces and scalable computing solutions (Zhang *et.al.*, 2025).

Conclusion: Cultivating Crops with Algorithms

Artificial Intelligence is transforming the way we look at plants not just through our eyes, but through cameras, sensors, and powerful algorithms. By enabling rapid, accurate, and scalable phenotyping, AI is accelerating crop research and making agriculture more data-driven than ever before. As we move forward, this fusion of biology, engineering, and computer science promises to unlock new frontiers in food security, climate resilience, and sustainable farming. In essence, we are cultivating not just plants, but intelligent systems that learn to grow with them.

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Ensuring Safe Drinking Water: Treatment Processes and Public Health Implications

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Anil Kumar Verma¹, Devendra Singh², Neelam Geat¹, Beerendra Singh³

¹Dr. B. R. Choudhary Agriculture Research Station, Mandor, Agriculture University Jodhpur, Rajasthan.

²ICAR- Central Arid Zone Research Institute, Jodhpur, Rajasthan.

³Department of Entomology, Rajasthan College of Agriculture, MPUAT, Udaipur.

Abstract

Access to safe drinking water is essential for human health and economic development. However, microbial contamination and the presence of harmful chemicals continue to pose serious public health risks, especially in developing regions. Drinking water treatment involves a series of processes aimed at removing physical, chemical, and biological contaminants to ensure water safety. These processes include sedimentation, coagulation and flocculation, filtration, and disinfection. Various disinfection methods such as chlorination, ozone treatment, and ultraviolet (UV) irradiation are employed to eliminate pathogens. Safe drinking water is a fundamental necessity, and improving treatment technologies remains a critical step in ensuring global public health.

Introduction

Access to safe drinking water is one of the fundamental prerequisites for a healthy life. However, waterborne diseases remain a major global concern due to the consumption of polluted and untreated water. The lack of access to clean drinking water poses a significant barrier to a country's progress, reflecting its economic and developmental challenges. It directly or indirectly impacts the workforce, thereby hindering national growth. The safety of drinking water is assessed based on national standards or international guidelines, with the WHO Guidelines for Drinking-Water Quality being among the most prominent. These guidelines are regularly updated and supported by comprehensive documents that elaborate on various aspects of water safety.

Microbial contamination of drinking water by pathogens responsible for waterborne diseases such as diarrhea and cholera remains a serious public health issue, particularly in developing regions. Similar to the 19th century outbreaks of cholera and typhoid in Europe and North America, these diseases continue to pose significant health risks. Preventing fecal contamination of water sources and ensuring effective treatment of drinking water to eliminate pathogens are essential to breaking the fecal–oral transmission cycle. Water purification is the process of removing unwanted chemicals, biological contaminants, suspended solids, and harmful gases that alter the natural composition of water. The primary objective of treatment is to make water safe for consumption. According to World Health Organization (WHO, 2003) report, 1.1 billion people lack proper access to safe drinking water. Additionally, 88% of the 4 billion annual cases of waterborne diseases are linked to unsafe water, inadequate sanitation, and poor hygiene. Approximately 1.8 million people die from diarrheal diseases each year, yet WHO estimates that 94% of these cases could be prevented through environmental improvements, including better access to clean water. Reducing deaths caused by waterborne diseases remains a key public health objective, particularly in developing nations.

Several simple yet effective household water treatment methods can significantly improve water quality. These include chlorination, filtration, and solar disinfection, among others, which will be discussed further.

Sedimentation

Sedimentation is the initial stage in the treatment of drinking water. In this process, raw water sourced from rivers, streams, or other bodies is pumped into a sedimentation tank or settling basin. Here, gravity facilitates the settling of suspended solid materials such as soil, sand, mineral particles, and other macroscopic debris at the bottom of the tank. The efficiency of sedimentation depends on the size and specific gravity of the suspended particles.

Coagulation and Flocculation

After sedimentation, water flows into a clarifier or coagulation basin, which contains inorganic materials like clay and silt and coagulants like aluminum sulfate or iron chloride. These coagulants neutralize negative charges on particle surfaces, causing suspended matter to precipitate and aggregate into larger masses called flocs. Floc formation can occur naturally or be enhanced by flocculation. Mixing devices in flocculation basins improve water clarity.

Filtration

Once coagulation and flocculation are complete, the clarified water enters the filtration system, where a series of filters remove residual suspended particles, organic solutes, and microorganisms. Various filtration methods are employed, including:

Rapid Sand Filters: Commonly used in water purification systems. Water passes through sand, with an upper layer of activated carbon that removes organic compounds, improving taste and odor. Some treatment plants use pressure filters, which function similarly but rely on rapid gravity filtration.

Advantages:

- a. Effective at removing fine particles and sand.
- b. Allow smooth and rapid water flow.
- c. Strong structure, capable of withstanding high pressure.
- d. Can be backflushed and reused.

Slow Sand Filters: Water moves gradually through layers of sand. Constructed using graded sand layers, with the coarsest sand at the bottom and the finest at the top. A Zoogloal layer (biofilm) on the surface aids biological treatment. Unlike rapid sand filters, these cannot be cleaned through backflushing.

Membrane Filtration: Used for both potable water and sewage filtration. Can remove particles larger than 0.2 µm, including pathogens such as Giardia and Cryptosporidium.

Disinfection

The final step in water treatment involves eliminating disease-causing microorganisms through disinfection. This is achieved by adding disinfectants that kill harmful pathogens before the water is stored and distributed. A residual disinfectant dose remains in the system to prevent microbial regrowth during storage.

Common waterborne pathogens include:

- a. Bacteria: Salmonella, Vibrio cholerae, Campylobacter, Shigella.
- b. Protozoa: Giardia lamblia, Cryptosporidium spp. (Clasen et al., 2008).

Chloramine disinfection: Chlorination is a widely used disinfection method, where chlorine-based compounds such as chloramine or chlorine dioxide are added to the water. Chlorine, a strong oxidant, effectively eliminates most harmful microorganisms within 30 minutes at sufficient doses. It also reacts with organic compounds, enhancing water taste and odor. However, chlorine treatment is less effective against cyst-forming protozoa such as Giardia lamblia and Cryptosporidium (Nabeela et al., 2014). After disinfection, water is temporarily stored in contact tanks to allow complete pathogen elimination before distribution. Disinfection using other Chlorine compounds like Chlorine dioxide disinfection. As compared to elemental chlorine the chlorine compound *i.e.* chlorine dioxide is a fast disinfectant however its use is limited as it creates excessive amounts of chlorite.

Drawback of Chlorination

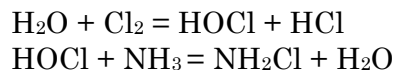
One drawback of using chlorine as disinfectant is that it reacts with organic compound present in the water thereby forming harmful chemical by products like trihalomethanes (THM) and halo acetic acid (HAAs), both are carcinogenic in nature and leaves residual chlorine. Maximal THM limit in drinking water is 100 µg/l and to keep the THM levels within this limit in traditional chlorine disinfection process, the organic compounds must be removed from water through sand filtration, however, this is an costly and impractical affair.

Concept of Residual Chlorine

Chlorine gets consumed in the process of reacting with organic compounds present in the water and leaves no residual chlorine for the next disinfection process to carry out. Therefore, sufficient amount of chlorine *i.e.* 0.2-0.6 µg/ml should be maintained added to effectively kill the harmful microorganisms.

Maintenance of Residual Chlorine Throughout the Distribution System

Chlorine gas even when dissolved in water is extremely volatile in nature, due to its volatility it disappeared within an hour from the chlorinated water. So to maintain the residual chlorine levels up to 0.2 -0.6 micrograms per ml throughout the distribution system, most of the water treatment plants introduce ammonia as with the chloride to form the stable, non-volatile chlorine containing compound *i.e.* chloramines.



Ozone disinfection: Ozone has been widely used for water disinfection in Europe and USA as it is a broad-spectrum disinfectant. Also, ozone layers is a powerful oxidizing agent, so it is toxic and effective against cyst forming protozoa. Ozone is generated by passing oxygen through ultraviolet light or a "cold" electrical discharge.

Advantages of Using Ozone as Disinfection

It produces less dangerous by-products and removes the taste and odor problem and also, leaves no residual effect in the treated water.

Ultraviolet disinfection: Ultraviolet light (UV) is used as an effective means for the inactivation of cysts in low turbid water. However, effectiveness of UV light disinfection decreases with increase in turbidity of water. This UV light is generated from mercury vapor lamps.

Advantages of using UV light over the chlorination process:

- Firstly, UV irradiation is a physical process so there is no involvement of any chemicals.
- Second, operative cost is lower than chlorination.
- There is no generation of byproducts.

Conclusion

Ensuring safe drinking water through effective treatment methods is crucial for public health and economic stability. While sedimentation, coagulation, filtration, and disinfection play key roles in water purification, each method has its limitations. Chlorination remains the most widely used disinfection method but has drawbacks, including the formation of carcinogenic by-products. Alternative methods such as ozone and UV disinfection offer effective solutions without harmful residues. The maintenance of residual disinfectant levels in water distribution systems is also essential to prevent microbial regrowth. As waterborne diseases continue to be a global challenge, improving treatment technologies and expanding access to clean drinking water remain critical priorities for sustainable development and public health protection.

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Natural Farming Methods for Soil Health Improvement: A Systematic Review

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Abhishek Ranjan¹, Shivam Pathak², Ramunaidu P. V. S.³, Soumya Roy Chowdhury⁴,
Gowthamchand N. J.⁵

¹²³Ph.D Research Scholar, Department of Agronomy, PGCA, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar.

⁴Department of Soil Science, PGCA, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar.

⁵Assistant Professor, Department of Soil Science, PGCA, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar.

Summary

Natural farming represents an integrated set of agroecological practices that reduce dependence on synthetic fertilizers and pesticides while enhancing the biological and ecological functioning of soils. These methods—cover cropping, mulching, organic amendments (compost, manure, biochar), crop diversification, minimal or zero tillage, and the use of microbial inoculants—collectively contribute to restoring soil fertility, improving ecosystem services, and mitigating climate change. A growing body of evidence highlights their role in enhancing soil organic carbon (SOC), improving soil structure, moderating microclimatic conditions, and fostering microbial and faunal activity. Importantly, natural farming is not a one-size-fits-all solution; outcomes are influenced by agroecological conditions, management intensity, and duration of adoption. This systematic review synthesizes evidence from global meta-analyses and long-term field studies to evaluate soil health outcomes of natural farming methods. Robust analyses demonstrate consistent SOC sequestration benefits from cover cropping, significant carbon pool increases from biochar applications, and enhanced soil quality with comparable or superior crop yields under whole-system natural farming trials in South India. The findings underscore the transformative potential of natural farming, while also pointing to the need for context-specific adaptation and supportive policy frameworks.

Introduction

Soil health is the backbone of a thriving ecosystem, playing a pivotal role in sustaining plant, animal, and human life. It is intricately linked to food production, ecosystem stability, and climate regulation. However, decades of conventional agriculture practices have taken a toll on soil health, leading to degradation, nutrient imbalances, declining organic matter, and loss of biodiversity. In contrast, natural farming emerges as a beacon of hope, offering a holistic approach that promotes ecological balance, biodiversity, and efficient use of resources. By harnessing the power of ecological processes, natural farming not only improves soil fertility but also reduces greenhouse gas emissions, enhances biodiversity, and strengthens farmers' economic resilience, thereby contributing to a more sustainable and climate-resilient agricultural system.

This review aims to synthesize the existing body of evidence on the impact of natural farming practices on soil health, focusing on key indicators such as soil organic carbon, soil structure, water-holding capacity, biological activity, and nutrient cycling. Drawing from systematic reviews, meta-analyses, and high-quality field studies, including pivotal research by Poeplau & Don (2015) on cover cropping, Chagas et al. (2022) on biochar, and Duddigan et al. (2023) on natural farming in India, this evaluation seeks to provide a comprehensive understanding of the benefits and potential of natural farming in promoting soil health and sustainable agriculture.

By exploring the intersection of ecological principles and agricultural practices, this review aims to inform strategies for improving soil health, reducing environmental degradation, and promoting sustainable agricultural systems that support both human well-being and ecosystem health.

Soil Health Indicators

The effectiveness of natural farming is best understood through measurable indicators:

- 1. Soil Organic Carbon (SOC):** Critical for nutrient storage, cation exchange, and long-term carbon sequestration.
- 2. Soil Structure:** Stable aggregates resist erosion, facilitate aeration, and enhance water retention.
- 3. Hydrological Function:** Improved infiltration and water-holding capacity buffer crops against droughts and floods.
- 4. Biological Functioning:** Diverse microbial communities and soil fauna drive nutrient transformations and suppress pathogens.
- 5. Nutrient Cycling:** Natural systems enhance N fixation, P solubilization, and micronutrient availability.

Evidence Synthesis by Practice

- 1. Cover Cropping and Green Manures:** Cover crops contribute continuous organic inputs to soil. Poeplau & Don (2015) found global SOC gains averaging **0.32 Mg C ha⁻¹ yr⁻¹** across 139 observations. Additional benefits include improved aggregate stability, microbial proliferation, and erosion control. Challenges include water competition in semi-arid zones and labor requirements for management.
- 2. Mulching and Residue Retention:** Mulches stabilize soil temperatures, reduce evaporation, and support soil fauna like earthworms. Residue retention maintains organic cover, which acts as a physical barrier against erosion while gradually contributing to organic matter.
- 3. Compost, Manure, and Organic Amendments:** Long-term application of compost and farmyard manure boosts SOC, enhances nutrient exchange, and enriches microbial populations. When combined with minimal tillage and cover crops, compost acts synergistically to restore degraded soils.
- 4. Biochar:** Chagas et al. (2022) demonstrated significant and durable increases in SOC pools with biochar additions. Its porous structure improves cation exchange, water retention, and microbial colonization. Results are most pronounced in sandy or acidic soils but depend strongly on pyrolysis conditions and feedstock type.
- 5. Reduced or Zero Tillage:** Low-disturbance systems preserve soil aggregates, reduce erosion, and sustain microbial habitats. Benefits are amplified when paired with cover crops and residue retention. However, SOC sequestration under tropical conditions often requires additional organic amendments to offset rapid decomposition.
- 6. Crop Rotations and Diversification:** Diversified rotations, especially those incorporating legumes, enhance nutrient cycling, increase microbial functional diversity, and break pest and disease cycles. Deep-rooted crops also redistribute nutrients from subsoil layers to the rhizosphere.
- 7. Biological Inputs:** Rhizobia, mycorrhizal fungi, and phosphate-solubilizing bacteria boost nutrient availability and root architecture. Their effectiveness depends on site-specific compatibility and integration with organic soil management.
- 8. Whole-System Natural Farming (e.g., Zero Budget Natural Farming):** Field evaluations in India show that ZBNF increases earthworm populations, SOC, and nutrient availability while maintaining or enhancing crop yields (Duddigan et al., 2023). The practice reduces external input dependence, particularly beneficial for smallholders, but requires knowledge-intensive training and strong community networks.

Mechanisms Linking Practices to Soil Health

- 1. Carbon Inputs:** Cover crops, compost, and biochar enrich SOC pools.
- 2. Microclimate Moderation:** Mulching stabilizes temperature and moisture dynamics.
- 3. Biological Enhancement:** Reduced disturbance sustains microbial diversity and soil fauna.
- 4. Erosion Control:** Residue cover and live roots protect against water and wind erosion.
- 5. Nutrient Cycling:** Legumes fix atmospheric nitrogen; microbes mobilize phosphorus and micronutrients.

Context-Dependence and Limitations

The performance of natural farming varies across contexts:

- 1. Temporal Dynamics:** SOC improvements may take 5–10 years to materialize (Poeplau & Don, 2015).
- 2. Soil-Specific Variability:** Biochar responses differ by soil texture and baseline fertility (Chagas et al., 2022).
- 3. Socioeconomic Barriers:** Labor intensity and knowledge requirements may deter adoption.
- 4. Ecological Trade-offs:** Cover crops can compete for soil moisture in dry regions.
- 5. Scaling Challenges:** Whole-system transitions such as ZBNF demand extensive farmer training (Duddigan et al., 2023).

Policy and Practical Recommendations

- 1. Capacity Building:** Farmer training on composting, cover crop management, and biochar application.
- 2. Incentives:** Payments for ecosystem services, particularly carbon sequestration and biodiversity conservation.
- 3. Infrastructure:** Establish decentralized composting and biochar production units.
- 4. Monitoring Frameworks:** Standardized soil health indicators for tracking long-term improvements.
- 5. Integration with Climate Policy:** Recognize natural farming as a carbon sequestration strategy within national climate commitments.

Conclusion

Natural farming offers a scientifically validated pathway to regenerate soil health, enhance ecosystem resilience, and secure agricultural productivity. Evidence demonstrates measurable benefits of cover crops (Poeplau & Don, 2015), biochar (Chagas et al., 2022), and whole-system approaches like ZBNF (Duddigan et al., 2023). While results vary by agroecological and socioeconomic context, the overarching trend affirms that soil-based solutions can bridge the goals of sustainable agriculture and climate change mitigation. Scaling these practices requires adaptive management, supportive policies, and long-term farmer engagement.

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The Impact of Climate Change on Sustainable Agriculture: A Review of Adaptation and Mitigation Strategies

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Shalu Kumar¹, Soni Kumari²

¹Assistant Professor, School of Agriculture, Aarni University, Kathgarh, Kangra, Himachal Pradesh.

²Project manager, EKO Guarantee Division of ENCON.

Summary

Climate change is one of the most pressing challenges confronting modern agriculture. Rising global temperatures, erratic rainfall, frequent extreme weather events, and shifting pest and disease dynamics are already threatening agricultural productivity, soil fertility, and food security worldwide. Agriculture, in turn, contributes substantially to greenhouse gas (GHG) emissions, intensifying climate change. This dual role of agriculture—as both a victim and driver of climate change—necessitates urgent action through integrated adaptation and mitigation strategies. Adaptation measures such as climate-resilient crop varieties, conservation agriculture, agroforestry, and improved water management are critical for sustaining productivity under uncertain climates. Mitigation measures, including carbon sequestration, optimized fertilizer use, livestock emission reduction, and agroforestry, can significantly reduce agriculture's environmental footprint. The review emphasizes the need for synergies between adaptation and mitigation, while addressing socio-economic barriers, institutional frameworks, and policy instruments. Evidence from recent reviews highlights both the opportunities and trade-offs in implementing climate-smart practices. A coordinated approach involving farmers, policymakers, researchers, and international institutions is imperative to ensure sustainable agriculture in a changing climate.

Introduction

Agriculture lies at the core of human survival and sustainable development, yet it is profoundly vulnerable to climate change. Increasing atmospheric CO₂, rising temperatures, altered precipitation regimes, and climate extremes directly affect crop yields, livestock performance, and soil health (IPCC, 2022). Beyond physical impacts, smallholder farmers—especially in developing nations—are disproportionately vulnerable due to limited adaptive capacity, poor infrastructure, and market constraints (Rao et al., 2024). Simultaneously, agriculture contributes around 20–30% of global GHG emissions, primarily through enteric fermentation, rice cultivation, fertilizer use, and land-use change (FAO, 2013). Hence, building sustainable agriculture requires simultaneous adaptation and mitigation strategies that ensure resilience and reduce emissions.

Impacts of Climate Change on Agriculture

1. Temperature rise and crop productivity: Higher temperatures reduce yields in heat-sensitive crops such as wheat, maize, and rice by shortening growth cycles and damaging reproductive stages. Livestock are similarly affected through heat stress, leading to reduced fertility, weight gain, and milk yield (IPCC, 2022).

2. Water availability and irrigation demand: Climate change alters hydrological cycles, intensifying droughts in arid regions while increasing flood risks in humid areas. Irrigation demand is projected to rise as evapotranspiration increases, putting additional stress on water resources (FAO, 2013).

3. Extreme weather and pest outbreaks: Cyclones, floods, and prolonged droughts disrupt agricultural systems, often causing irreversible soil and crop damage. Warmer temperatures also expand the geographical range of insect pests and diseases, increasing yield losses (Barbieri et al., 2024).

4. Soil degradation and nutrient cycles: Soil erosion, organic matter loss, and nutrient imbalances are worsened by heavy rainfall and higher mineralization rates. Such processes reduce soil fertility and weaken ecosystem services critical for sustainable farming.

Adaptation Strategies

1. Genetic and crop-based solutions:

- Development of drought-tolerant, heat-resistant, and saline-tolerant varieties through modern breeding and biotechnological approaches.
- Diversified cropping systems, including intercropping and crop rotations, to reduce vulnerability to climate variability.

2. Agronomic and soil-water management:

- Conservation agriculture (minimum tillage, residue retention, crop rotation) to enhance soil organic carbon and water retention.
- Rainwater harvesting, drip irrigation, and efficient irrigation scheduling to optimize water use.
- Integrated pest management (IPM) strategies to manage emerging pest threats (Rao et al., 2024).

3. Agroforestry and biodiversity approaches:

- Agroforestry improves microclimates, provides alternative income, and sequesters carbon.
- Biodiversity-based approaches (cover crops, buffer strips) enhance ecological resilience.

4. Institutional and financial mechanisms:

- Climate information services and early warning systems enable farmers to plan proactively.
- Crop insurance and index-based weather insurance provide risk management tools.
- Farmer cooperatives and participatory extension improve adoption of climate-smart practices (Bamniya et al., 2024).

Mitigation Strategies

1. Soil and crop management:

- Soil carbon sequestration through reduced tillage, cover crops, and organic amendments.
- Biochar application for long-term carbon stabilization.
- Precision fertilizer application and nitrification inhibitors to reduce N₂O emissions.

2. Livestock management:

- Improved feed quality and additives (e.g., tannins, 3-NOP) reduce enteric methane.
- Manure management through anaerobic digesters captures methane for renewable energy.

3. Rice and water systems: Alternate wetting and drying (AWD) in paddy fields reduces methane emissions without yield penalties.

4. Agroforestry and reforestation: Large-scale agroforestry systems sequester significant carbon while improving farm resilience.

5. Demand-side interventions: Shifting towards sustainable diets and reducing food loss and waste are critical to lowering food system emissions (Barbieri et al., 2024).

Synergies and Trade-Offs

Some strategies, such as agroforestry and conservation agriculture, offer both adaptation and mitigation benefits. However, trade-offs exist: irrigation expansion for adaptation may worsen water scarcity, and carbon sequestration practices may initially reduce yields. Spatial targeting and multi-criteria assessment are essential for designing context-specific solutions (Barbieri et al., 2024).

Policy and Institutional Support

1. Policy instruments: Carbon pricing, subsidies for climate-smart technologies, and green credit schemes encourage adoption.

2. Institutional frameworks: Land tenure security, farmer organizations, and inclusive governance systems strengthen collective resilience.

3. Finance: Climate funds and public–private partnerships can mobilize resources for large-scale adoption (Rao et al., 2024).

Research Gaps and Future Directions

1. Long-term empirical studies to measure adaptation–mitigation synergies.
2. Low-cost monitoring and verification methods for soil carbon and emissions.
3. Social innovations (e.g., farmer collectives) for scaling adoption.
4. Stronger integration of climate resilience into national agricultural policies (Bamniya et al., 2024).

Conclusion

Agriculture is at the frontline of climate change impacts, facing profound risks but also offering major opportunities for climate action. Adaptation is essential for safeguarding food security, while mitigation reduces agriculture's contribution to climate change. Integrating both strategies through context-specific, inclusive, and evidence-based approaches is vital for achieving sustainable agriculture. Policies, institutions, and financial mechanisms must align to scale adoption, ensuring that agriculture contributes both to resilience and global climate goals.

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Sweet Alternatives: Understanding the Benefits and Drawbacks of Sugar Replacers

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Vidhi K. Patel¹

¹Ph.D. Research Scholar, Nutrition and Dietetics, Department of Applied Science, Parul University, Vadodara.

Introduction

Sugar has been an inseparable part of human diets for centuries, providing energy and enhancing the taste of foods. However, the modern lifestyle, marked by reduced physical activity and increased consumption of processed foods, has triggered a rise in health concerns linked to excessive sugar intake. The World Health Organization (WHO, 2023) recommends limiting free sugar intake to less than 10% of total energy consumption to reduce the risk of obesity, type 2 diabetes, and dental caries. In response, the food industry and nutrition researchers have developed and promoted sugar replacers—substances that mimic the sweetness of sugar while offering fewer or no calories.

Sugar replacers, also called sweeteners, fall into two main categories: nutritive sweeteners (such as sorbitol, xylitol, and other sugar alcohols) that provide some calories, and non-nutritive sweeteners (such as stevia, sucralose, aspartame, and saccharin) that deliver little to no calories. Their growing use reflects both consumer demand for healthier choices and the food industry's innovation to reduce sugar without compromising taste.

Despite their popularity, sugar replacers are not free from debate. While they offer potential benefits such as weight management, blood sugar control, and reduced risk of tooth decay, concerns persist regarding their long-term safety, metabolic effects, and potential overconsumption. Thus, understanding their types, advantages, and disadvantages is crucial for informed dietary decisions.

Types of Sugar Replacers

Sugar replacers can be grouped into **three broad categories**:

1. Natural Non-Nutritive Sweeteners:

- a. **Stevia** – Plant-derived, 200–300 times sweeter than sugar, zero calories.
- b. **Monk Fruit (Luo Han Guo)** – Contains mogrosides, very sweet, calorie-free.

2. Artificial (Synthetic) Non-Nutritive Sweeteners

- a. **Aspartame** – 200 times sweeter than sugar, low calorie, not heat stable.
- b. **Sucralose** – 600 times sweeter, calorie-free, heat stable (good for baking).
- c. **Saccharin** – 300–400 times sweeter, calorie-free, metallic aftertaste.
- d. **Acesulfame potassium (Ace-K)** – Often blended with other sweeteners.

3. Sugar Alcohols (Polyols)

- a. **Xylitol** – 2.4 kcal/g, similar sweetness to sugar, prevents tooth decay.
- b. **Sorbitol** – 2.6 kcal/g, lower sweetness, may cause bloating.
- c. **Maltitol, Erythritol, Mannitol** – Fewer calories, widely used in sugar-free products.

Comparison of Common Sugar Replacers

Sweetener	Sweetness (vs Sugar)	Calories (per g)	Key Benefits	Main Limitations
Sugar (sucrose)	1x (reference)	4 kcal	Natural taste, energy source	High calories, raises blood sugar, dental caries

Stevia	200–300x	0 kcal	Natural, zero calories, safe for diabetics	Bitter aftertaste, costly
Monk Fruit	150–200x	0 kcal	Natural, antioxidant properties, no effect on blood sugar	Expensive, less available
Aspartame	200x	4 kcal (very low in use)	Widely used, low calorie	Not heat stable, unsuitable for people with PKU
Sucralose	600x	0 kcal	Heat stable, widely accepted	May alter gut microbiota (debated)
Saccharin	300–400x	0 kcal	Oldest sweetener, inexpensive	Metallic aftertaste, safety concerns in past
Xylitol	1x	2.4 kcal	Tooth-friendly, diabetic safe	Can cause bloating/diarrhea in excess
Sorbitol	0.6x	2.6 kcal	Low glycemic impact, used in gums	Laxative effect in high intake
Erythritol	0.7x	0.2 kcal	Very low calorie, well tolerated	May cause bloating in some

Benefits of Sugar Replacers

1. Weight Management and Calorie Reduction: One of the major benefits of sugar replacers is their low or negligible calorie content. Replacing sugar with non-nutritive sweeteners helps reduce total caloric intake, which can aid in weight control. Studies suggest that switching from sugar-sweetened beverages to those with artificial sweeteners may help prevent weight gain in adults (Peters et al., 2016).

2. Blood Sugar Regulation: For individuals with diabetes, sugar replacers provide a way to enjoy sweet flavors without causing sharp spikes in blood glucose. Sweeteners like stevia and sucralose are widely considered safe for diabetic use, making them useful in managing glycemic control (Lohner et al., 2017).

3. Dental Health: Unlike sugar, which promotes bacterial growth and acid formation leading to cavities, sugar alcohols such as xylitol reduce the risk of tooth decay. The American Dental Association recognizes xylitol as beneficial for oral health (ADA, 2022).

4. Food Industry Innovation: Sugar replacers enable the creation of "diet," "low-calorie," and "sugar-free" products that cater to health-conscious consumers. They expand options in beverages, baked goods, dairy products, and confectionery without losing the sweet taste consumers crave.

Disadvantages of Sugar Replacers

1. Gastrointestinal Issues: Certain sugar alcohols, such as sorbitol and maltitol, are poorly absorbed in the intestine, leading to bloating, diarrhea, or abdominal discomfort when consumed in excess (Livesey, 2003).

2. Possible Metabolic Concerns: Some studies suggest that frequent consumption of artificial sweeteners may alter gut microbiota and potentially affect metabolism, raising questions about long-term impacts on glucose tolerance and obesity risk (Suez et al., 2014).

3. Taste and Aftertaste: Not all sugar replacers mimic the natural sweetness of sugar perfectly. Stevia, for example, has a slightly bitter aftertaste, and some artificial sweeteners leave a metallic flavor, which can affect product acceptability.

4. Overconsumption and “Health Halo” Effect: Because products labeled “sugar-free” are perceived as healthy, consumers may overindulge, potentially negating calorie savings. This psychological effect, known as the **compensation phenomenon**, has been observed in dietary behavior research (Bellisle, 2015).

5. Safety Concerns and Public Perception: Although regulatory agencies such as the U.S. Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA) have declared approved sweeteners safe within acceptable daily intake levels, skepticism and misinformation persist among consumers regarding possible links to cancer or other chronic diseases.

Conclusion

Sugar replacers represent a valuable tool in modern nutrition, offering the sweetness people enjoy while helping reduce calorie intake, manage diabetes, and promote dental health. However, they are not a perfect solution. Overconsumption, gastrointestinal side effects, and uncertainties around long-term health effects highlight the need for moderation and balanced use. Instead of treating sugar replacers as a magic bullet, they should be seen as one part of a broader strategy that emphasizes whole foods, balanced meals, and mindful eating.

For policymakers, healthcare providers, and consumers alike, the key lies in **responsible integration**—using sugar replacers wisely while continuing to address the underlying drivers of poor diets. A thoughtful approach ensures that these sweet alternatives contribute positively to overall health and well-being.

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Low-Cost Protein Sources in Rural Diets: Power from Local Foods

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Vidhi K. Patel¹

¹Ph.D. Research Scholar, Nutrition and Dietetics, Department of Applied Science, Parul University, Vadodara.

Introduction

Protein, often called the “building block of life,” is crucial for growth, tissue repair, and immune health. Yet, a large proportion of rural households in India and other developing countries remain protein-deficient. According to the Indian Council of Medical Research (ICMR), the recommended dietary allowance (RDA) for adults is **0.8–1 g of protein per kg body weight per day**, but surveys show that many rural families fall short of this requirement (ICMR-NIN, 2020).

The irony is that rural communities often have **access to diverse local foods rich in protein**, but economic constraints, cultural food practices, and lack of awareness prevents their optimal use. This article explores **affordable and locally available protein-rich foods** and their potential to transform rural nutrition.

The good news is that rural India already has access to a wide variety of **low-cost, locally available protein-rich foods**. With the right knowledge and simple adaptations in diets, families can meet their protein needs without expensive supplements or imported foods. This article highlights the power of affordable protein sources, their health benefits, and practical strategies to integrate them into daily meals for better nutrition and well-being.

Why Protein Matters in Rural Diets?

- 1. Growth and Development:** Protein supports the growth of children and adolescents.
- 2. Immunity Boost:** Adequate protein strengthens the immune system, protecting against infections.
- 3. Muscle Strength:** Protein maintains muscle health, especially important for rural populations engaged in physical labor.
- 4. Women’s Health:** Protein is vital for maternal health, supporting pregnancy, lactation, and recovery.
- 5. Healthy Aging:** Older adults require sufficient protein to prevent weakness and muscle loss.

A balanced diet with adequate protein can transform community health outcomes, reducing malnutrition and increasing productivity.



Understanding the Protein Gap in Rural Areas

The National Family Health Survey-5 (NFHS-5) reveals that despite economic progress, **stunting and wasting** among children remain high, particularly in rural India (MoHFW, 2021). Much of this can be attributed to protein-energy malnutrition.

Key reasons include:

1. **Economic limitations:** Families prioritize bulk cereals like rice and wheat.
2. **Food habits:** Animal-based foods are often considered luxury items.
3. **Market access:** Poor infrastructure restricts availability of pulses and dairy.
4. **Awareness gap:** Protein-rich foods are often undervalued compared to calorie-rich staples (FAO, 2019).

Plant-Based Low-Cost Protein Sources

1. **Pulses and Legumes:** India is the largest producer and consumer of pulses, yet per capita availability has declined over decades due to rising demand (FAOSTAT, 2020). Lentils, chickpeas, pigeon peas, green gram, and black gram provide **20–25% protein**.

- **Example:** Roasted gram flour (*sattu*) in Bihar and Jharkhand is an inexpensive protein staple (Kumar et al., 2019).

2. **Millets and Pseudo-Cereals:** Millets such as ragi, bajra, and foxtail millet are **nutri-cereals** recognized by the FAO for their resilience and nutritional value. They provide **8–12% protein**, along with iron and calcium (ICRISAT, 2018).

- **Example:** Bajra rotla in Gujarat remains a protein-supportive staple for rural families.

3. **Oilseeds and Nuts:** Groundnuts, sesame, and sunflower seeds are traditional crops with **20–25% protein** (USDA, 2020). Roasted peanuts are a low-cost snack for children in many states.

4. **Green Leafy Vegetables:** Though less protein-dense, drumstick leaves, amaranth, and spinach supply **3–4% protein** along with vitamins and minerals, enhancing diet diversity (Gopalan et al., 2012).

Animal-Based Low-Cost Protein Sources

1. **Eggs:** Eggs provide **6–7 g of high-quality protein** per egg. WHO recognizes them as a “reference protein” for their digestibility (WHO, 2007).

Backyard poultry farming ensures affordability and self-sufficiency in rural areas.

2. **Dairy Products:** Milk, curd, and buttermilk contribute **3.2 g protein per 100 ml** along with calcium. In villages with livestock, dairy serves as a readily available protein source (ICMR-NIN, 2020).

Traditional and Forgotten Protein-Rich Foods

1. **Sattu drinks:** Rich in protein and energy, commonly consumed in Bihar.
2. **Khichdi:** Combines cereals and pulses, offering a complete amino acid profile.
3. **Fermented foods (idli, dosa):** Increase protein digestibility (Ghosh et al., 2019).
4. **Sprouted legumes:** Improve nutrient absorption and quality of protein.

Strategies to Promote Protein from Local Foods

1. **Nutrition education** through schools, anganwadis, and self-help groups.
2. **Kitchen gardens and backyard poultry** to promote self-reliance.
3. **Women empowerment programs** teaching low-cost protein recipes.
4. **Inclusion in public feeding programs** like Mid-Day Meal and ICDS.
5. **Extension services and community radio** to spread local food knowledge.

Socio-Economic Benefits

1. Enhances **diet diversity** and reduces malnutrition.
2. Supports **local livelihoods** (farmers, fishers, poultry rearers).
3. Reduces **household food costs** by depending on self-produced foods.
4. Strengthens **community resilience** against market price fluctuations.

Challenges and Way Forward

1. **Cultural barriers** around meat/egg consumption in certain regions.
2. **Perceived status** of pulses as “poor man’s food.”
3. **Climate variability** impacting production of pulses and millets.

Way forward includes:

- a. **Policy support** for millet and pulse promotion.
- b. **Affordable pricing** for protein foods under the Public Distribution System (PDS).
- c. **Community-level interventions** to increase acceptance and awareness.

Conclusion

Rural diets often remain **carbohydrate-heavy and protein-poor**, leading to invisible malnutrition. Yet, the solution lies in **revalorizing local, affordable protein sources** like pulses, millets, groundnuts, dairy, fish, and eggs. These foods are culturally familiar, economically feasible, and nutritionally rich.

By educating communities, supporting local production, and integrating protein-rich foods into public nutrition programs, we can bridge the **protein gap in rural diets**.

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Nutrition Myths vs Facts: Clearing the Confusion

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Vidhi K. Patel¹

¹Ph.D. Research Scholar, Nutrition and Dietetics, Department of Applied Science, Parul University, Vadodara.

Introduction

In today's fast-paced, information-driven world, people are constantly exposed to nutrition advice from multiple sources—social media platforms, online influencers, family traditions, cultural practices, friends, and even aggressive food marketing. While some of this advice is backed by scientific research, much of it is based on misconceptions, half-truths, or commercial interests. This overflow of mixed information creates confusion and can influence individuals to adopt unhealthy practices. Nutrition myths, when followed blindly, may result in nutrient deficiencies, weight management issues, digestive discomforts, and even long-term lifestyle diseases such as diabetes, hypertension, and cardiovascular disorders (World Health Organization, 2021; Goyal & Kaur, 2020).

For individuals and families striving to build sustainable eating habits, it is important to separate fact from fiction and rely on evidence-based knowledge. Misconceptions such as “all fats are harmful,” “skipping meals reduces weight,” or “fruits should not be eaten at night” are deeply rooted in cultural and social narratives, but they do not hold strong scientific backing (Harvard T.H. Chan School of Public Health, 2022). Instead of blindly eliminating foods or following restrictive patterns, it is essential to understand the role of balance, portion control, and nutrient diversity in maintaining overall health (National Institute of Nutrition, 2020).

Myth 1: Eating Rice at Night Causes Weight Gain

The Belief: Many people avoid rice in the evening, assuming it leads to fat accumulation.

The Fact: Rice itself is not inherently fattening. What matters is the portion size and overall calorie balance throughout the day. Complex carbohydrate options like brown rice or millets provide steady energy and do not automatically result in weight gain. Eating heavy portions of fried rice or combining rice with oily curries late at night, however, can contribute to indigestion and excess calorie intake.

Practical Tip: Choose a moderate portion of plain rice or millet with vegetables and lentils for dinner, ensuring a balanced meal without heaviness.

Myth 2: All Fats Are Bad for Health

The Belief: People often eliminate oils and fats completely, fearing obesity and heart disease.

The Fact: The body requires healthy fats for hormone production, brain function, and absorption of vitamins A, D, E, and K. Unsaturated fats from sources such as groundnut oil, mustard oil, sesame seeds, flaxseeds, and nuts are protective for the heart. What should be avoided are trans fats and excessive deep-fried foods.

Practical Tip: Use moderate amounts of cold-pressed oils and include nuts or seeds daily, while limiting packaged fried snacks.

Myth 3: Sugar Substitutes Are Always Safe

The Belief: Artificial sweeteners and sugar-free products are harmless alternatives to sugar.

The Fact: While sugar substitutes can help reduce calorie intake, overconsumption may affect gut health and cravings. Some artificial sweeteners have been linked with bloating and digestive discomfort. Natural sweeteners like jaggery, dates, or honey (in moderation) provide micronutrients along with sweetness.

Practical Tip: Use natural sweeteners sparingly and gradually reduce dependence on overly sweet foods.



Myth 4: Skipping Meals Helps in Weight Loss

The Belief: Missing breakfast or lunch helps reduce calorie intake and results in faster weight loss.

The Fact: Skipping meals often backfires, leading to overeating later in the day and slowing metabolism. Regular meals with balanced nutrients stabilize blood sugar levels and maintain energy throughout the day.

Practical Tip: Instead of skipping meals, practice portion control and choose high-fiber, high-protein foods to stay full longer.

Myth 5: Fresh Fruits Should Not Be Eaten at Night

The Belief: Fruits consumed in the evening or at night are difficult to digest.

The Fact: Fruits can be eaten at any time of day. They provide vitamins, fiber, and hydration that are beneficial for the body. However, consuming them immediately before bedtime may cause mild discomfort in some individuals due to acidity.

Practical Tip: Eat fruits as an evening snack or at least one hour before sleeping for best digestion.

Myth 6: Milk and Curd Should Not Be Consumed Together

The Belief: Traditional beliefs suggest that milk and curd should not be eaten in the same meal.

The Fact: Both milk and curd are dairy products rich in calcium and protein. Eating them together does not cause harm; it is safe and nutritionally beneficial. The concern arises only if someone has lactose intolerance or digestive sensitivity.

Practical Tip: Include curd during lunch and milk at night for better digestion and sound sleep.

Myth 7: Eating Bananas Causes Cold and Cough

The Belief: Many people avoid bananas in winter or during illness, assuming they produce mucus.

The Fact: Bananas are rich in potassium, vitamin B6, and fiber, which support digestion and immunity. Scientific studies do not confirm that bananas cause colds or worsen coughs. Only individuals with existing respiratory allergies may feel increased discomfort.

Practical Tip: Eat bananas as part of a balanced diet; those with respiratory issues can consume other fruits like guava, papaya, or apple.

Myth 8: Detox Diets and Juices Cleanse the Body

The Belief: Detox juices, teas, or diets are essential for removing toxins from the body.

The Fact: The human body already has natural detoxification systems—the liver, kidneys, lungs, and skin. Extreme detox diets can deprive the body of essential nutrients and cause weakness. Fresh fruits, vegetables, whole grains, and adequate water intake are enough to support natural detoxification.

Practical Tip: Focus on a diet rich in seasonal produce and adequate hydration instead of relying on costly detox products.

Myth 9: Packaged Foods Fortified with Nutrients Are Always Healthy

The Belief: Products labeled as “fortified with vitamins and minerals” are automatically good for health.

The Fact: While fortification can address nutrient deficiencies, many packaged foods also contain excess sugar, salt, or unhealthy fats. Relying solely on these products may increase the risk of lifestyle diseases.

Practical Tip: Read nutrition labels carefully; prioritize whole foods and use fortified products only when necessary.



Myth 10: Traditional Remedies Are Always Safe

The Belief: Home remedies passed down through generations are free from side effects.

The Fact: While many traditional foods and herbs (like turmeric, ginger, or fenugreek) are beneficial, overconsumption without guidance can cause harm. For example, excessive turmeric may irritate the stomach, and too much fenugreek can affect blood sugar levels.

Practical Tip: Use traditional remedies in moderation and consult professionals if you have existing health conditions.

Conclusion

Nutrition myths are widespread and often influence daily food habits. By relying on evidence-based facts, individuals can make informed decisions about their diet and health. Eating rice at night, consuming bananas, or including healthy fats should not be feared, while practices like portion control, hydration, and balanced meals should be encouraged. Clearing confusion around food myths empowers people to adopt simple, sustainable, and healthy eating practices.

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Eat Right, Feel Better: A Guide to Menstrual Well-Being

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Vidhi K. Patel¹

¹Ph.D. Research Scholar, Nutrition and Dietetics, Department of Applied Science, Parul University, Vadodara.

Introduction

Menstruation is an essential part of women's reproductive health, recurring almost every month for approximately four decades of life. Despite being a natural biological function, menstruation is often accompanied by discomfort, cramps, bloating, headaches, fatigue, and emotional fluctuations. These symptoms can vary from mild to severe, affecting daily productivity and mental well-being.

While pain-relieving medications and rest are often considered first-line solutions, nutrition plays a far more significant role than is usually acknowledged. The food we consume before and during menstruation directly affects energy levels, hormone regulation, and emotional stability. A nutrient-dense, well-balanced diet can help reduce menstrual discomfort, restore vital nutrients lost during bleeding, and promote long-term reproductive health.

This article explores the role of nutrition in menstrual well-being—highlighting essential nutrients, food recommendations, dietary patterns, and cultural practices that can ease the monthly cycle and enhance quality of life.

Nutritional Needs during Menstruation

The menstrual cycle involves hormonal fluctuations, uterine muscle contractions, and blood loss, all of which create increased nutritional demands. Certain vitamins, minerals, and macronutrients can support the body's natural processes and reduce discomfort.

1. Iron: Menstrual blood loss lowers iron levels, increasing the risk of anemia. Symptoms such as fatigue, weakness, and low concentration are directly linked to iron deficiency. Plant-based sources such as spinach, jaggery, lentils, and black sesame seeds, when paired with vitamin C-rich foods (oranges, lemon), enhance iron absorption.

2. Magnesium: This mineral supports muscle relaxation, reduces cramping, and helps regulate mood by interacting with neurotransmitters like serotonin. Foods such as pumpkin seeds, sunflower seeds, and legumes are excellent sources.

3. Calcium and Vitamin D: These nutrients work together to ease uterine muscle contractions, reduce bloating, and support bone health. Dairy products, ragi, fortified cereals, and adequate sunlight exposure are beneficial.

4. Vitamin B6 and Other B Vitamins: B6 in particular supports neurotransmitter synthesis, reducing irritability, mood swings, and water retention. Whole grains, chickpeas, and bananas are rich in B6.

5. Omega-3 Fatty Acids: Known for anti-inflammatory properties, omega-3s in flaxseeds, walnuts, and fatty fish help reduce menstrual cramps and inflammation.

6. Hydration: Adequate water intake prevents bloating, headaches, and fatigue. Herbal teas and water-rich fruits can be more soothing than plain water during menstruation.

Foods to Eat During Periods

Choosing the right foods can help ease symptoms and improve comfort.

Iron-rich foods:

- Dark leafy greens (spinach, moringa leaves, fenugreek)
- Jaggery and dates (traditional Indian remedies for weakness)
- Legumes (chickpeas, black gram, lentils)
- Nuts and seeds (black sesame, almonds)

Magnesium-rich foods:

- a. Pumpkin and sunflower seeds
- b. Cashews, peanuts, and soy products
- c. Whole grains like millets and quinoa

Complex carbohydrates:

- a. Brown rice, oats, and barley help maintain stable blood sugar and reduce irritability.
- b. Sweet potatoes provide sustained energy and are rich in potassium.

Protein sources:

- a. Pulses, lentil soups, and paneer (cottage cheese) aid tissue repair.
- b. Yogurt provides probiotics, easing digestion and bloating.
- c. Soy milk and tofu are good plant-based options.

Hydrating fruits and vegetables:

- a. Watermelon, cucumber, and oranges combat dehydration.
- b. Berries provide antioxidants that reduce oxidative stress.

Herbal teas:

- a. **Ginger tea:** Relieves nausea and improves blood circulation.
- b. **Chamomile tea:** Reduces anxiety and helps with sleep.
- c. **Tulsi (Holy Basil) tea:** Boosts immunity and relieves mild cramps.


Foods to Limit or Avoid

While cravings often increase during menstruation, some foods may worsen discomfort:

1. **Salty foods:** Chips, pickles, and packaged snacks worsen water retention and bloating.
2. **Refined sugar:** Cakes, pastries, and sodas cause energy crashes and mood fluctuations.
3. **Caffeine:** Strong coffee or energy drinks increase dehydration, irritability, and breast tenderness.
4. **Fried foods:** Deep-fried pakoras, samosas, and fast food slow digestion and intensify cramps.
5. **Highly processed foods:** Instant noodles and preserved meats often contain additives that disrupt hormonal balance.



Lifestyle and Dietary Tips

Nutrition works best when combined with lifestyle strategies:

1. Eat small, frequent meals to prevent blood sugar fluctuations.
2. Drink warm water or herbal infusions to ease bloating.
3. Engage in light yoga postures like child's pose or cat-cow stretch for pain relief.
4. Aim for 7–8 hours of quality sleep to restore energy.
5. Practice mindful eating to connect with hunger cues and avoid overeating.

Traditional and Cultural Practices

Across India and many cultures, women are offered special foods during menstruation to provide warmth and energy.

1. **Jaggery and sesame seeds laddoo:** Believed to boost iron and relieve cramps.
2. **Turmeric milk:** Traditionally consumed to reduce inflammation and promote healing.
3. **Herbal infusions:** Decoctions made with ginger, ajwain (carom seeds), or methi (fenugreek) are common home remedies for cramps.

While some practices are cultural, many are supported by modern science. Spices like ginger and turmeric are proven anti-inflammatory agents, while jaggery is a natural source of iron and minerals.

Psychological Well-being and Food

The connection between food and mood is especially important during menstruation. Serotonin levels drop before periods, leading to irritability and mood swings. Foods high in tryptophan (bananas, nuts, oats) support serotonin production, while complex carbohydrates maintain brain energy. Avoiding excessive caffeine and sugar can help stabilize mood.

Social and emotional comfort also matter—warm, home-cooked meals, supportive environments, and cultural rituals provide not just nutrition but also psychological relief.

Conclusion

Menstrual well-being is not solely about enduring discomfort—it is an opportunity to care for one's body through thoughtful nutrition and lifestyle. Eating iron-rich foods restores vitality, magnesium and omega-3s reduce cramps, while hydration and herbal teas soothe discomfort. Avoiding processed, salty, and sugary foods further supports hormonal balance.

Traditional practices, combined with modern nutritional science, create a holistic approach to menstrual health. With the right dietary strategies, menstruation can shift from being viewed as a burden to being respected as a natural cycle of renewal, strength, and self-care.

Eating right during this phase not only eases physical pain but also enhances emotional resilience, confidence, and overall well-being.

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Healthy Soils, Healthy Harvests: The Foundation of Sustainable Agriculture

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Km Susmita¹, Vineet Kumar¹, Uzma Manzoor¹

¹School of Agriculture, Galgotias University.

Summary

Soil is the fundamental natural resource for food, fodder, and fiber production, supporting nearly 95% of global food supply (FAO, 2017). Unlike other resources, soil formation is a slow process, developing just 1 cm of topsoil can take 200–400 years (Lal, 2015). Healthy soils are characterized by balanced nutrients, organic matter content, good structure, and biological activity. They not only sustain crops but also contribute to water regulation, carbon sequestration, and climate resilience (Dominati et al., 2010).

However, modern agricultural practices have placed enormous pressure on soil resources. Excessive tillage, indiscriminate use of fertilizers and pesticides, overgrazing, and deforestation accelerate erosion, salinization, and nutrient depletion (Singh et al., 2015). According to FAO (2015), 33% of the world's soils are degraded, threatening global food security. In India, soil fertility decline and organic matter loss are major issues, particularly in intensively cultivated regions such as the Indo-Gangetic Plains (Bhattacharyya et al.). Thus, the path to sustainable agriculture begins with restoring and conserving soil health.

Introduction

Soil is not merely a medium for plant growth but a dynamic, living system that underpins agricultural productivity, biodiversity, and ecosystem balance. It acts as a reservoir of nutrients and water, provides a habitat for billions of microorganisms, and regulates biogeochemical cycles that sustain life on earth (FAO, 2017).

Globally, soil contributes to more than 95% of food production, making it indispensable for food and nutritional security. Beyond food, soils provide raw materials for fodder, fuel, fiber, and a range of ecosystem services including water purification, climate regulation, and carbon sequestration (Dominati et al., 2010). However, the ability of soil to perform these functions depends on its health, defined by its physical structure, chemical balance, organic matter content, and biological diversity (Lal, 2015).

The rapid intensification of agriculture during the Green Revolution improved food security but also caused widespread soil degradation. Practices such as excessive tillage, heavy use of synthetic fertilizers and pesticides, monocropping, and unscientific irrigation have led to erosion, salinization, nutrient mining, and organic matter depletion (Singh et al., 2015). In India, the problem is particularly acute in the Indo-Gangetic Plains where high cropping intensity has caused severe fertility decline (Bhattacharyya et al., 2015). According to FAO (2015), one-third of the world's soils are already degraded, posing a major challenge to sustainable development.

Thus, ensuring soil health is no longer a matter of choice but a necessity. Sustainable agricultural practices that conserve, restore, and enhance soil functions are urgently needed to secure the future of farming and ensure resilient food systems. The following sections highlight key strategies that can be adopted to maintain soil health and ensure healthy harvests.

Strategies for Maintaining Soil Health

1. Organic and Conservation Farming: Incorporating compost, farmyard manure, crop residues, and biofertilizers enhances soil organic matter and microbial diversity. Conservation agriculture characterized by minimum tillage, permanent soil cover, and crop rotation reduces erosion and improves soil structure (Hobbs et al., 2008).

2. Agroforestry Systems: Tree-based farming improves soil fertility through leaf litter and nitrogen fixation, reduces erosion, and provides diversified farm income. Agroforestry also contributes to climate mitigation by sequestering atmospheric carbon (Kumar and Nair, 2011).

3. Crop Rotation and Cover Crops: Legume-based rotations replenish nitrogen naturally, while cover crops such as clover and rye prevent nutrient leaching, suppress weeds, and enhance soil biota (Drinkwater et al., 1998).

4. Integrated Nutrient Management (INM): Combining organic manures, crop residues, biofertilizers, and judicious fertilizer use maintains soil fertility, reduces input costs, and improves nutrient-use efficiency (Yadav and Sidhu, 2016).

5. Engineering and Structural Solutions: Physical measures such as contour bunding, terracing, and check dams conserve soil moisture, reduce runoff, and prevent erosion in hilly and semi-arid regions (Verma, 2020).

Conclusion

Healthy soils are the bedrock of sustainable agriculture. By integrating organic matter management, crop diversification, agroforestry, and soil conservation measures, farmers can achieve higher productivity while preserving resources for future generations. Soil health is not just a farmer's concern but a shared responsibility, connecting consumers, researchers, and policymakers in the global pursuit of sustainable food systems. The principle of "Healthy Soils, Healthy Harvests" must guide agricultural transformation for long-term food and environmental security.

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Biodegradable Packaging: A Greener Path for Fresh Fruits and Vegetables

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Aman Kumar¹, Deepak Kumar², Amit Prasad³

PhD research scholar

¹Agricultural processing and food engineering

²Farm machinery and power engineering

³Soil and water conservation engineering

ICAR- Central institute of Agricultural engineering, Bhopal, Madhya Pradesh.

Abstract

Plastic packaging has long been the dominant choice for fresh fruits and vegetables due to its low cost, durability, and convenience. However, the environmental consequences of plastic waste—ocean pollution, land degradation, and threats to human health—have made it unsustainable. As global awareness of climate change and environmental protection grows, the focus has shifted to biodegradable packaging. Derived from renewable biological resources such as starch, cellulose, proteins, and natural polymers, biodegradable packaging materials can decompose naturally without harming ecosystems. This article provides a detailed exploration of biodegradable packaging for fruits and vegetables, discussing its definition, types, functional importance, advantages, innovations, challenges, and future outlook. It highlights how these packaging solutions not only protect perishable produce but also contribute to sustainability and a circular economy.

Introduction

Fruits and vegetables are essential components of a healthy diet. Rich in vitamins, minerals, antioxidants, and fiber, they are consumed globally in increasing amounts. However, their high perishability makes them vulnerable to rapid quality loss, microbial spoilage, and mechanical damage. Packaging plays a crucial role in reducing postharvest losses, ensuring food safety, and improving consumer convenience.

Traditionally, plastics such as polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) have been widely used. They offer excellent strength, flexibility, and barrier properties. Yet, these materials are non-biodegradable, persisting in the environment for centuries and causing massive ecological harm. Landfills, waterways, and oceans are now flooded with plastic debris, threatening marine and terrestrial life.

This unsustainable scenario has driven scientists, industries, and policymakers to search for **eco-friendly** alternatives. Biodegradable packaging, derived from natural and renewable resources, emerges as a sustainable solution that aligns food preservation with environmental conservation.

What is Biodegradable Packaging?

Biodegradable packaging refers to materials that break down naturally through the action of microorganisms, converting into harmless end-products such as carbon dioxide, water, methane, and biomass. The breakdown process usually takes weeks to months, depending on environmental conditions like temperature, humidity, and microbial activity.

Unlike plastics that remain in the environment for hundreds of years, biodegradable materials complete their life cycle within a short span, reducing long-term waste accumulation.

Sources of Biodegradable Packaging

Biodegradable packaging can be derived from a variety of natural materials. The major sources and their applications are summarized in Table 1.

Table 1. Sources of biodegradable packaging and their applications in fruits and vegetables:

Source	Examples & Characteristics	Applications
Polysaccharides	- Starch (corn, potato): flexible films, needs blending for strength - Cellulose (wood, plant fibers): transparent coatings - Chitosan (shrimp/crab shells): antimicrobial properties	Coatings for apples, cucumbers; shelf-life extension in strawberries, mushrooms
Proteins	- Soy protein, gluten: edible films, moisture-sensitive - Casein, whey protein: excellent oxygen barriers	Wrapping fresh produce
Biopolymers	- Polylactic acid (PLA): derived from corn/sugarcane, already in market - Polyhydroxyalkanoates (PHAs): bacterial fermentation products	Trays, wraps, films
Plant Extracts	- Aloe vera gel: delays spoilage - Essential oils: antimicrobial effect - Anthocyanins: freshness indicators	Coatings, active films, smart indicators

Why Do Fruits and Vegetables Need Biodegradable Packaging?

Fruits and vegetables are biologically active even after harvest. They continue to respire, lose water, and undergo biochemical changes. Without proper packaging, they quickly lose freshness and marketability.

Key Reasons for Packaging

1. Moisture Regulation: Fresh produce easily loses water, leading to wilting, shriveling, and weight loss. Biodegradable films can act as semi-permeable barriers that retain optimal moisture.

2. Gas Exchange Control: Fruits and vegetables respire by taking in oxygen and releasing carbon dioxide. Excess oxygen accelerates ripening, while poor ventilation leads to spoilage. Biodegradable films can be engineered to allow controlled gas exchange, slowing down ripening.

3. Barrier Protection: During handling and transportation, produce is vulnerable to dust, pathogens, and physical damage. Biodegradable trays and wraps provide cushioning and cleanliness.

4. Eco-Safety: Unlike plastics, which leave behind microplastics that enter the food chain, biodegradable materials decompose harmlessly, making them safer for consumers and the environment.



Fig. 1. White button mushroom in biobased-biodegradable packaging (Kumar et al., 2024)

Advantages of Biodegradable Packaging for Fruits and Vegetables

The benefits of biodegradable packaging extend beyond environmental protection. They directly contribute to food quality and consumer acceptance.

Table 3. Advantages of biodegradable packaging for fruits and vegetables:

Advantage	Key Points
Environmental Sustainability	Reduces dependence on fossil fuels, decomposes naturally, lowers landfill waste.
Shelf-Life Extension	Active films with antimicrobials delay microbial growth; smart packaging reduces premature disposal.
Food Safety	Non-toxic, chemical-free, edible coatings reduce need for preservatives.
Consumer Appeal	Eco-friendly packaging increases trust and preference.
Circular Economy	Compostable packaging returns nutrients to soil, creating a sustainable loop.

Innovative Trends in Biodegradable Packaging

1. Edible Coatings: Thin edible films of starch, chitosan, or proteins are applied directly to fruits and vegetables. These coatings:

- Reduce water loss.
- Delay ripening.
- Can be safely consumed or washed off.

Example: Aloe vera gel coatings for grapes significantly extend storage life.

2. Active Packaging: Films are embedded with natural additives like essential oils (oregano, thyme, cinnamon), organic acids, or plant extracts. They inhibit microbial growth and delay spoilage.

Example: Chitosan films with cinnamon oil reduce fungal infections in strawberries.

3. Smart Packaging: Natural pigments (e.g., anthocyanins, lac dye) are used in biodegradable labels that change color when they produce spoils. These serve as freshness indicators.

Example: Anthocyanin-based labels that shift from purple to green in response to pH changes caused by mushroom spoilage.

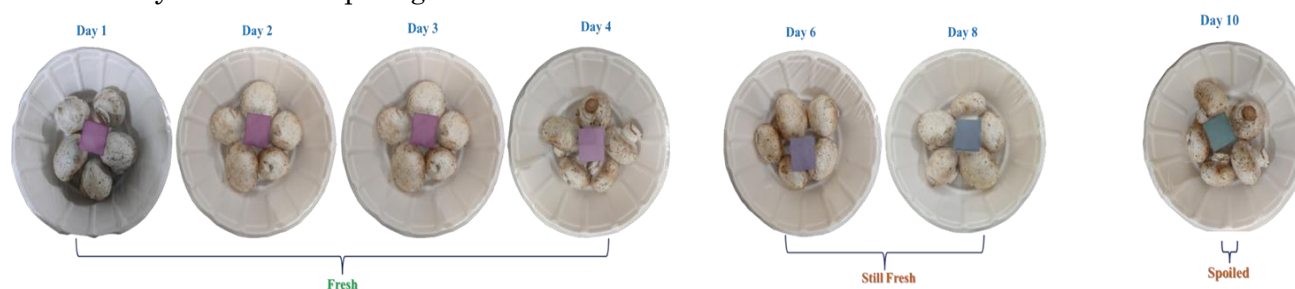


Fig 2. Button mushroom freshness evaluation according to the color change of on package freshness indicator at $5\pm 1^\circ\text{C}$ (Kumar et al., 2025)

4. Compostable Containers: PLA-based trays, sugarcane bagasse clamshells, and molded pulp containers are gaining popularity in supermarkets. They replace plastic trays used for apples, berries, and mushrooms.

Challenges and Limitations

1. Cost Factor: Biodegradable materials are still more expensive than conventional plastics, limiting their widespread adoption.

2. Barrier Properties: Some biopolymers have poor resistance to moisture and oxygen, making them less effective in humid environments.

3. Shelf Stability: Natural coatings may degrade quickly during storage or transportation.

4. Consumer Awareness: Many consumers are unaware of how to properly dispose of biodegradable packaging, sometimes mixing it with plastics.

5. Industrial Scalability: Large-scale, cost-effective production remains a challenge, especially for developing countries.

Future Outlook

The future of biodegradable packaging lies in technological innovation and global collaboration. Research is focusing on:

1. Reinforcing biodegradable films with nanomaterials (e.g., nanocellulose, clay nanoparticles) to improve strength and barrier properties.
2. Combining active and smart packaging to not only extend shelf life but also inform consumers of freshness.
3. Developing cost-effective methods for large-scale production to compete with plastics.
4. Government incentives and stricter regulations on plastics will accelerate the shift toward biodegradable options.

In the next decade, biodegradable packaging is expected to become mainstream, reshaping food retail and reducing the environmental burden of plastic pollution.

Conclusion

Biodegradable packaging for fruits and vegetables is more than a technological advancement—it is a sustainability revolution. By protecting perishable produce, enhancing shelf life, ensuring food safety, and addressing environmental concerns, it bridges the gap between consumer needs and ecological responsibility. Despite challenges such as cost and scalability, continuous innovations and growing eco-awareness ensure that biodegradable packaging will play a central role in shaping the future of food systems and environmental health.

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Digital Farmer – AI The Agricultural Turning Point

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M. Lakshmanan¹, G. Rasikha², P. Shakthisri³, J. Rhitika⁴

¹UG Scholar, B. Sc (Hons) Agriculture, school of Agriculture sciences, Takshashila university Tamil Nadu, India.

^{2,3,4}B. Sc (Hons) Agriculture, School of Agriculture sciences, Takshashila university, Tamil Nadu, India.

Introduction

Agriculture is the one of the oldest method of human activities for production of agriculture product for own consumption and improves the livelihood and improves the economy of a person or an family, Agriculture is important for crop cultivating and livestock's which gives the standard income to our life at beging the Agriculture sector contribute and GDP of 17%for an Indian economy alone, when the years are changes the evolution of IT(Information Technology) is increased rapidly and the farming activities are completely reduced. At now the agriculture faces lot of problems at the 21 st century so as the evolution of information the agriculture needs some help from the AI artificial intelligence makes an huge role in developing the farming the using mordern and innovative approaches like drones, sensors, smart irrigation system, pest and disease monitoring and some of app are develop to help the farmers, the Machinery for different field operation in agriculture can be evolved at this time only . By analyzing the large of data and gives the correct solutions to the farmers problems, so AI is the powerful emerging tool to boost the Agriculture into the Future.

Precision Farming

Precision is the method of using low-cost inputs instead of using the high-level equipment to reduce the cost of farmers.AI Significantly plays a major role in agriculture; by adding the effective resources management and analysing the databases in large source, Precision farming is more suitable for the small and marginal farmers in India and Tamil Nadu, who has small land holdings. In short manner the precision farming is termed as to reduce the cost of Input sources in agriculture like (Seeds, Fertilizer, Machinery, Pesticides and other chemicals which are used in agriculture field)

5 R concepts of precision Farming: 5R concept in precision farming deals with the 5 principles that should be followed in precision farming, they are

- a. Right input
- b. Right amount
- c. Right place
- d. Right Time
- e. Right manner.

Are the different principles in precision farming. (Nafchi et. al 2022)

In general, instead of high-level Technology in agriculture we may use the soil testing results, and GPS Mapping like this for enhancing the productivity.

Smart Irrigation Systems

AI in smart irrigation system: AI are also involved in watering a crops in a field as plant protector by applying the sufficient irrigation of water to the plants and the crops by using several radars, sensors are used to push the process as earlier one, about 70% of water is used (sharma 2021) now a days all the large scale farmers use the AI based sensors for irrigating the field by switching the motor from home it self and some sensors may automatically starts by passing the signal or an message from the user. In agriculture it may the irrigation operation as very easy to the farmers and some sensors detects the soil moisture and giving the correct amounts of water to the plants in an right manner. Some of AI systems of irrigation are soil and (crop monitoring, predictive sensors for early detection and whether forecasting irrigation systems.

Pest and Disease Management and Monitoring

Pest and disease are the main and major problems in agriculture which they will affects the crop yield into half of the yield in some situation it may cause even famine as **Pest and Disease outbreak** it is conditions where the uncontrolled population is rapidly increased world-wide at some areas, so over come from this problem chemicals like pesticides, Fungicides are used to control the pest. By using these chemicals in the field, it may also result in phytotoxicity in plant and soil infertility in soil. So, use of AI can give solutions to all the problems. They will work by Capturing the by using drones or by an sensors then the data is transferred to the monitoring systems where they can use to identify the symptoms like rust, leafspots for disease and bore holes and defoliation by insects and gives the warning to the farmers by analysing the previous damages caused by the pest and disease and it will also recommend the chemicals to the farmers. It will easily identify the newly emerging pest and disease in the field.

Yield Predictions and Monitoring

Prediction of yield before harvesting is some tough topic , in this way the AI is insert as the tool to predicts the yield by using systems called (GPS AND GIS) an systems called as Remote sensing Remote sensing is the method of predicting the growth of crops by passing the signal directly on to the plant leaf surface or from any vegetative parts and it's will receive the data the field and in some cases Drones are also used to identify the density of the canopy in a plants or crops and some of the application are IBM Watson , GOOGLE +TATA AI and Agro stars are some mobile application where they can use AI for predicting the yield.

Automation

At the development of agriculture in 21 st century is not sufficient we wants more and more machinery and implement so at now all the young graduate are moving towards the IT field so the farming faces the insufficient in Labours(Ahamed, T. (2023)and right now we needs the automation in agriculture in developing countries the automation has come in USA by John Deere tractors and and drones with AI powered camera are used in many countries India is now at the starting stages so we need even more development implementing AI in agriculture.

Chat Bots

Chat bots are the tools used to give the information and database to the farmers at present lot of chat bots are available to help farmers to identify the problems like pest, disease and deficiency and also the fertilizer recommendations for crops, the chat bots works has in 24*7 so at any time we can ask the question and get answers from it some chat bots are plantix for pest and disease identify, kisan and Agribots are some of the bots used for Agriculture.

Conclusion

From the above topic we have concluded the Agriculture is the backbone of our country , we need to protect and improves the growth and development of agriculture by using the modern technology like using AI in agriculture is good development to compete with the rapidly increasing global population by using IOT like precision farming use of GPS and GIS, and also the sensors and the Automation even more also the chat bots for helping the farmers and guide the farmers for growth and promotes their income level in the society , also this contribution to export of agriculture product and improves the Indian Economy.

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Adulterations and Substitutions in Medicinal Plants

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M. R. Prajapati¹, Mayur Ram¹, B. S. Desai¹, V. B. Patel¹, M. B. Tandel¹, V. M. Prajapati¹

¹Ph.D. Scholar Dept. of Silviculture and Agroforestry, College of Forestry, NAU, Navsari, Gujarat- 396450, India.

Introduction

Ayurveda is an Indian traditional system of medicine. It is a science of life and believed to be prevalent for last 5000 years in Indian Sub-continent. It is one of the most noted systems of medicine in the world (Kokate *et al.*, 2014). In Ayurvedic system of medicine, treatment is based on *Chikitsa Chatuspad* (Tetrapod of treatment) and for success of treatment, all these pods most contain special qualities. *Aushadh* (Drugs) is one of the major pods, and for success of treatment potent drugs are the primary requirement. Medicinal plants are the major source of drugs in Ayurveda. Due to such a high demand and less availability of natural sources and unavailability of crude genuine drugs, practices of substitution and adulteration are increasing day by day. Similarly, a large percentage of plants used in herbal industries are subject of controversy. At present the adulteration and Substitution of the herbal drugs is the burning problem in herbal industry and in Ayurvedic practices (Dixit, 2011). Due to adulteration, faith in herbal drugs has declined and led to one of the greatest drawbacks in promotion of Ayurveda and Herbal products. Adulterants are also creating health hazards or adverse events (Keshari, 2021).

Controversial plants or Sandigdha-dravyas is a term used for medicinal plants having controversial botanicals as sources; appear in the Ancient Indian Literature as for e.g. *Ephedra* species and Safed Musli which is described as *Asparagus adscendens* in Ayurveda and one that is used are species of the genera *Chlorophytum*.

Drug Adulteration

Adulteration is a practice of substituting original crude drug partially or wholly with other spurious substances, but the latter is either free from or inferior in chemical and therapeutic properties. It means deterioration, admixture, sophistication, substitution, inferiority and spoilage are methods of adulteration. Deterioration is impairment in the quality of drug, while admixture is addition of one article to another due to ignorance or carelessness or by accident. It is a type of unintentional adulteration. Sophistication is the intentional or deliberate type of adulteration. Substitution occurs when some totally different substance is added in place of original drug, inferiority refers to any substandard drug, and spoilage is due to attack of microorganisms and aflatoxin. Adulteration in market samples is one of the major bottle necks in processing of herbal products (Kokate *et al.*, 2014).

Major Intentional Types of Adulteration (Mitra and Kannan, 2007; Kokate *et al.*, 2014; Poonam, 2016)

1. Substitution with substandard commercial varieties: This is the most common type of adulteration in which low standard drugs are mixed which are morphologically, chemically and therapeutically resembles to the original crude drugs. For example, Arabian senna and Dog senna are used instead of Indian senna, *Strychnous nux-blanda* in place of *S. nux-vomica*, *Capsicum minimum* replaced by *C. annum*, Medicinal ginger replaced by its inferior varieties *viz.* African, Japanese and Cochin ginger.

2. Using superficially similar inferior drugs: In this type of adulteration adulterants are superficially similar in appearance but may or may not having any chemical or therapeutic value as the original crude drugs. For example, papaya seeds are adulterated with *Piper nigrum*, saffron is admixed with dried flowers of *Carthamus tinctorious*, Belladonna leaves are substituted with Ailanthus leaves, Mother cloves and clove stalks are mixed with clove, Bee wax substituted by Japan wax.

3. Using artificially manufactured substance: In this type of adulteration artificially manufactured substances resemble to original crude drugs, are adulterated. This type of adulteration is done for costlier

drugs. For example, Calcium carbonate compounds are used by name of Vansha lochan, Paraffin wax made yellow coloured and substituted for beeswax properly cut and shaped basswood for nutmeg.

4. Using exhausted drug: This type of adulteration is usually done for those drugs which contain volatile oil. For example, fennel, clove, coriander and caraway etc. fennel, clove, coriander, caraway etc. In this type of same crude drug is adulterated but after extracting major chemical constituents, e.g. Volatile oil is extracted from bud of Lavanga (clove) and exhausted buds are adulterated. In this case sometimes extra additives are used to make the exhausted drugs attractive. Exhausted gentian made bitter with aloes, Artificial colouring of exhausted saffron.

5. Using synthetic chemicals to enhance natural character: Synthetic chemicals are used as adulterant which enhances the natural characteristics of original drug. For example, Addition of Benzyl benzoate to balsam of Peru, Citral is added in citrus oil like oil of lemon or orange oil.

6. Presence of vegetative matter of same plant: Instead of proper used parts of crude drugs other parts of same species or miniature species grown around the large species are mixed with genuine crude drugs. This type of adulteration occurs in both intentional and unintentional adulteration. For example, Instead of root of Bala (*Sida cordifolia*) stem or whole parts of plant is used, the lower plants like moss, liver worts and epiphytes growing on bark portion are mixed with Cinchona, the stem portion are mixed along with leaf drug like *Datura stramonium*, Lobelia and senna.

7. Harmful adulterants: For increasing weight of crude drugs for commercial profit, some harmful substances are added with genuine crude drugs. For example, Stone pieces and sand particles mixed in Guggul (gum of *Commiphora mukul*), pieces of amber coloured glass in colophony, limestone in asafoetida, lead shot in opium, Rodent faecal matter to cardamom seed is a very harmful.

8. Adulteration of powders: The drugs which are commonly found in powder forms are adulterated with powder of other substances resembling the same. For examples, Dextrin in ipecacuanha and Kampillak (*Mallotus philippensis*) powder is adulterated with Annatto dye (*Bixa orellana* Linn.), powdered gentian admixed with powdered olive stones, Red sandar wood in capsicum.

Quality Assurance and Quality Control as Stated by WHO

1. World Health Organization (WHO), in its publication on quality standards for medicinal plant materials, recommends rejecting any batch of raw material, which has more than 5% of any other plant part of the same plant (e.g. stem in leaf drugs), nevertheless if they are derived from the authentic plant.
2. Based on these standards, adulteration whether, intentional or unintentional, should be rejected.
3. Also, suppliers and traders should be educated about the authentic sources.

Reason for Adulteration (Kokate *et al.*, 2014)

1. Confusion in vernacular names and Sanskrit name: Ayurveda, Parpatta refers to *Fumaria parviflora*. In Siddha, 'Parpadagam' refers to *Mollugo pentaphylla*. *Mollugo pentaphylla* as Parpatta/Parpadagam and the North Indian suppliers supply *F. parviflora*. *Aerva lanata* (source of Pashanbhedha in south) adulterated as *Bergenia ligulata*.

2. Lack of Knowledge About Authentic Sources: Nagakesar is one of the important drugs in Ayurveda. The authentic source is *Mesua ferrea*. However, market samples are adulterated with flowers of *Calophyllum inophyllum*.

3. Similarity in Morphology: *Mucuna pruriens* is adulterated with other similar Papilionaceae seeds having similarity in morphology. *M. utilis* (sold as white variety) and *M. deeringiana* (sold as bigger variety) are popular adulterants. *M. cochinchinensis*, *Canavalia virosa* and *C. ensiformis* are also sold in Indian markets. Authentic seeds are up to 1 cm in length with shining mosaic pattern of black and brown colour on their surface. *M. deeringiana* and *M. utilis* are bigger (1.5-2 cm) in size. While *M. deeringiana* is dull black and *M. utilis* is white or buff coloured.

4. Lack of Authentic Plant: *Hypericum perforatum* is cultivated and sold in European markets. In India, availability of this species is very limited. However, the abundant Indo-Nepal species *H. patulum*, sold in the name of *H. perforatum*. Market sample is a whole plant with flowers, and it is easy to identify them taxonomically. Anatomically, transverse section of *H. perforatum* stem has compressed thin phloem, hollow

pith and absence of calcium oxalate crystals. Whereas *H. patulum* has broader phloem, partially hollow pith and presence of calcium oxalate crystals.

5. Similarity in Colour: 'Ratanjot' is a recent day example. According to the suppliers and non-timer forest product (NTFP) contractors, in the past, roots of *Ventilago madraspatana* were collected from Western Ghats, as the only source of 'Ratanjot'. However, that has not been practiced now. It is clearly known that *Arnebia euchroma vareuchroma* is the present source. Similarity is in yielding a red dye, *A. euchroma* substitutes *V. madraspatana*. Recently *V. madraspatana* is not found in market. Whatever is available in the market, in the name of Ratanjot is originated from *A. euchroma*.

6. Careless Collections: Some of the herbal adulterations are due to the carelessness of herbal collectors and suppliers. *Parmelia perlata* is used in Ayurveda, Unani and Siddha. It is also used as grocery. Market samples showed it to be admixed with other species (*P. perforata* and *P. cirrhata*). Sometimes, *Usnea* sp. is also mixed with them. Authentic plants can be identified by their thallus nature.

7. Improper storage: Due to improper storage physical factors such as air (oxygen), humidity, light and temperature can bring about deterioration directly or indirectly and use of such type of drug acts as adulterant.

8. Imperfect preparation: Some of crude drugs should be processed before marketing, during such processing improper technique may destroy active constituents e.g. over drying of crude drugs, removal of cork from zinger etc.

Table.1: List of substitute drugs (herbs) mentioned in Bhavaprakash Nighantu:

Original Drug			Substitution Drug	
#	Sanskrit Name	Botanical Name	Sanskrit Name	Botanical Name
1.	Chitrak	<i>Plumbago zeylanica</i> L.	Danti	<i>Baliospermum montanum</i> (Willd.) Müll. Arg.
2.	Dhanyaghas	<i>Fagonia cretica</i> L.	Pavasak	<i>Alhagi pseudalhagi</i> (M.Bieb.) Desv. ex Wangerin
3.	Tagar	<i>Valeriana wallichii</i> DC.	Kustha	<i>Saussurea lappa</i> (Falc.) Lipsch.
4.	Nilkamal	<i>Nelumbo nucifera</i> Gaertn.	Kumudpushpa	<i>Nymphaea stellata</i> Willd.
5.	Murva	<i>Clematis gouriana</i> Roxb. ex DC.	Manjistha	<i>Rubia cordifolia</i> L.
6.	Bakul	<i>Mimusops elengi</i> L.	Nilkamal	<i>Nelumbo nucifera</i> Gaertn.
7.	Chameli pushpa	<i>Jasminum officinale</i> L.	Laving	<i>Syzygium aromaticum</i> (L.) Merr. & Perry.
8.	Pushakarmool	<i>Inula racemosa</i> Hook. f.	Kustha	<i>Saussurea lappa</i> (Falc.) Lipsch.
9.	Snuhi	<i>Euphorbia neriifolia</i> L.	Kustha	<i>Saussurea lappa</i> (Falc.) Lipsch.
10.	Chavya	<i>Piper cubeba</i> L. f.	Pipali	<i>Piper longum</i> L.
11.	Daru haridra	<i>Berberis aristata</i> DC.	Haridra	<i>Curcuma longa</i> L.
12.	Bharangi	<i>Clerodendrum serratum</i> (L.) Moon.	Talispatra	<i>Taxus baccata</i> L.
13.	Yasti madhu	<i>Glycyrrhiza glabra</i> L.	Dhatakpuspa	<i>Woodfordia fruticosa</i> (L.) Kurz.
14.	Rajavriksha	<i>Cassia fistula</i> L.	Chukra	<i>Rumex vesicarius</i> L.
15.	Draksha	<i>Vitis vinifera</i> L.	Gambhari phal	<i>Gmelina arborea</i> Roxb. ex Sm.
16.	Gambhari	<i>Gmelina arborea</i> Roxb. ex Sm.	Madhuka pushpa	<i>Madhuca indica</i> J.F.Gmel.

17.	Chinikabab	<i>Piper cubeba</i> L. f.	Chameli pushpa	<i>Jasminum officinale</i> L.
18.	Karpur	<i>Cinnamomum camphora</i> (L.) J. Presl.	Nagarmusta	<i>Cyperus rotundus</i> L.
19.	Kesar	<i>Crocus sativus</i> L.	Kusum phool	<i>Carthamus tinctorious</i> L.
20.	Sweta chandan	<i>Santalum album</i> L.	Karpur	<i>Cinnamomum camphora</i> (L.) J. Presl.
21.	Sweta chandan	<i>Santalum album</i> L.	Rakta chandan	<i>Pterocarpus santalinus</i> L. f.
22.	Rakta chandan	<i>Pterocarpus santalinus</i> L. f.	Ushir	<i>Vetiveria zizanioides</i> (L.) Nash.
23.	Haritaka	<i>Terminalia chebula</i> Retz.	Amalki	<i>Emblica officinalis</i> Gaertn
24.	Ativish	<i>Aconitum ferox</i> Wall. ex Ser.	Nagarmustak	<i>Cyperus rotundus</i> L.
25.	Nagkesar	<i>Mesua ferrea</i> L.	Kamal kesar	<i>Nelumbo nucifera</i> Gaertn.
26.	Bhallatak	<i>Semicarpus anacardium</i> Linn. f.	Chitraka	<i>Plumbago zeylanica</i> L.
27.	Danti	<i>Baliospermum montanum</i> (Willd.) Müll. Arg.	Chitrak	<i>Plumbago zeylanica</i> L.
28.	Meda	<i>Polygonum glabrum</i> Willd.	Shatavari	<i>Asparagus racemosus</i> Willd.
29.	Mahameda	<i>Polygonum verticillatum</i> (L.) All.	Shatavari	<i>Asparagus racemosus</i> Willd.
30.	Jivaka	<i>Microstylis wallichii</i> Lindl.	Vidari kand	<i>Pueraria tuberosa</i> (Roxb. ex Wild.) DC.
31.	Rhushabhak	<i>Microstylis muscifera</i> (Lindl.) Ridl.	Vidari kand	<i>Pueraria tuberosa</i> (Roxb. ex Wild.) DC.
32.	Kakoli	<i>Rosa procera</i> L.	Ashwagandha	<i>Withania sonchifera</i> L. Dunal
33.	Kshirkakoli	<i>Lilium polyphyllum</i> D. Don.	Ashwagandha	<i>Withania sonchifera</i> L. Dunal
34.	Rudhhi	<i>Habenaria intermedia</i> D. Don.	Varahikand	<i>Dioscorea bulbifera</i> L.
35.	Vrudhhi	<i>Habenaria spp.</i>	Varahikand	<i>Dioscorea bulbifera</i> L.

Source (Desai *et al.*, 2007)

Substitution

Substitution is a replacement of equivalent drugs in place of original drugs on the basis of similar pharmacological actions and therapeutic uses. In Ayurveda, substitution is described by the name of *Abhava Pratinidhi Dravya*. During *Samhita* Period concept of adulteration and substitution had not existed but later on these practices come in existence. But *Vagbhatta* has mentioned that the *dravya* having similar Ras (taste), Guna (characteristic), Veerya (potency) and Vipaka should be used in absence of each other. So *Abhava Pratinidhi Dravya* is a replacement of original drug basically having similar Rasa, Guna, Veerya, Vipaka and mostly on Karma. Description of *Abhava Pratinidhi Dravya* are mentioned in *Bhavaprakash Nighantu*, *Yogratnakar* and *Bhaishajya-Ratnawali* (Bhava Mishra, 2002; Shastri, 2005). There are 47 drugs of plant origin (*Sthavar Dravya*), 2 drugs of animal origin (*Jangam Dravya*), 7 drugs Minerals-Metals origin (*Bhoumya Dravya*) and 5 food materials (*Ahara Dravya*) mentioned for *Abhava Pratinidhi Dravya* in *Bhavaprakash Nighantu* (Joshi *et al.*, 2012).

Need for Substitution (Mitra and Kannan, 2007; Poornima, 2010; Joshi *et al.*, 2012; Poonam, 2016)

1. Non-availability of the drug: Some drugs mentioned in Ayurvedic lexicon are not available nowadays, so those drugs are substituted by other drugs having similar therapeutic value. For example, most of drugs from Astavarga are not easily available so those drugs are substituted by other ones e.g. Meda and Mahameda are substituted by Shatavari.

2. Uncertain identity of the drug: The drugs which are mentioned in Ayurvedic classics, but their botanical identity is not clear those are substituted by known one e.g. for the herb Lakshmana, different species such as *Arlia quinquefolia*, *Ipomoea sepiaria* etc. are considered.

3. Cost of the drug: Kumkuma (*Crocus sativus*) is more costly, so it is substituted by less expensive Kusumbha (*Carthamus tinctorius* Linn.).

4. Geographical distribution of the drug: Rasna (*Pluchea lanceolata*) is used in Northern India while in southern parts *Alpinia galanga* is used as Rasana and *Vanda roxburghii* is considered as source in Bengal.

5. The adverse reaction of the drug: Vasa (*Adhatoda vasica*) is good Rakta-Pittahara (antihemorrhagic) drug, but having abortifacient activity, so instead of this drug Laksha (*Lacifer lacca*), Ashoka (*Saraca asoka*) etc. are used in pregnant women for the same purpose.

6. Seasonal availability of drug- Punarnawa (*Boerhaavia diffusa*) is commonly not found throughout the year so for that *Trianthema portulacastrum* (Varshabhu) can be used as substitute, which is found throughout the year.

Types of Substitution (Joshi *et al.*, 2012; Poonam, 2016)

1. Substitution with totally different drug- Use of Danti (*Baliospermum montanum*) as a substitute of Chitraka (*Plumbago zeylanica*)

2. Substitution of species belonging insame family - *Datura metal* is substituted by *Datura stramonium*.

3. Using different species having Common Sanskrit name - Two types of Gokshura are used, they are *Tribulus terrestris* (Laghu Gokshur) and *Pedalium Murex* (Brihat Gokshura)

4. Using different parts of same plant - Instead of root of *Sida cordifolia* whole plants of *Sida cordifolia* is used

5. Due to similar action - Aamalki (*Emblica officinalis*) is taken instead of Bhallatak (*Semecarpus anacardium*) for Rasayana karma (rejuvenation and overall health tonic).

Table.2: Adulterants Used (Desai *et al.*, 2007)

#	Name of the drug	Plants and other material used for adulteration/Adulterants
1.	Arjun chhal (Bark) <i>Terminalia arjuna</i>	Baheda, Krishna arjun, Harde, Deshi Almond and bark of other species.
2.	Ashok chhal (Bark of <i>Saraca asoca</i>).	Shal, Trayrnan, Asopalav (<i>Polyalthia longifolia</i>) and Kanchar Chhal (<i>Bauhinia spp</i>).
3.	Guggal gum (<i>Commiphora wightii</i>)	Balsam, Usak Loban, Hirabol, Bhammarchhal, (<i>Hymenodictyon orixense</i>), Shallaki (<i>Boswellia serrata</i>) and other gum. Sand and soil are also be mixed.
4.	Hing (<i>Ferula asafoetida</i>)	Resin with smell , painted gum, gum of babool (<i>Acacia nilotica</i>), brown soil, corn flour.
5.	Kesar	<i>Nyctanthus spp.</i> painted corn style, <i>Calendula officinalis</i> , <i>Carthamus tinctorius</i> . Stamen and other flowers can be mixed.
6.	Ativish	Vakhmo and bulb of <i>Cryptocoryne retrospiralis</i>
7.	Kasturi	Animal blood, liver pieces, dry peas, wheat - barley mixture. Also, Amretta seed, Angelia root, <i>Guaria grandiflora</i> bark etc. Plants that give smell like Kasturi, Nabhi of other animals is also used as Kasturinabhi.

8.	Jayphal (<i>Myristica fragrans</i>)	Other fruits without oil e.g, <i>Myristica malabarica</i> are pushed in.
9.	Laving (<i>Piper longum</i>)	Original laving without oil, which gives less smell.
10.	Elaichi	Original Elaichi without oil.
11.	Taj (<i>Cinnamomum tamala</i>)	Bark of other plants and original Taj without oil.
12.	Brahmi (<i>Centella asiatica</i>)	Undarkani's panchang (<i>Merremia emarginata</i> Whole plant).
13.	Vidari kand (<i>Pueraria tuberosa</i>)	Cycas-Kangutad's root pieces.
14.	Ganthoda (Piper root)	Branches and pieces of other plants like different species of Piper.
15.	Shal parni	<i>Alysicarpus tetragonolobus</i> (Samervo) and other genus.
16.	Patol (<i>Trichosanthes cucumerina</i>)	Panchang of Karela and other cucurbitaceous climbers (<i>Momordica charantia</i>).
17.	Vanskapoor	Tungakehari (<i>Curcuma angustifolia</i>), root pieces and synthetic vanskapoor.
18.	Lindi piper (<i>Piper longum</i>)	Big thick fruits of Piper spp.
19.	Masparni (jangli adad) (<i>Phaseolus aureus</i>)	Climbers of magamathi (<i>Rhynchosia minima</i>)
20.	Kapilo (<i>Mallotus phillippensis</i>)	Dust of brick, red soil, colour etc.
21.	Nagkesar	Stamen of any other plants and undeveloped Puspkalika of Surpunakh (<i>Ochrocarpus longifolia</i>), Seeds of Mehndi (<i>Lawsonia spp</i>).
22.	Kasth-uplet	Plant of tulsiphoool (<i>Ocimum spp</i>), <i>Salvia lanata</i> and <i>Costus speciosus</i> . Also Puskarmool is useful.
23.	Swet chandan (<i>Santalum album</i>)	Pieces of innerwood and pith of other plants.
24.	Mochras	Gum of simlo, red soil, chhal (bark) of other plants.
25.	Kakda singi	Round, oval, flat formations on plants made by insects, i. e. insect galls.
26.	Tamalpatra (<i>Cinnamomum tamala</i>)	Leaves of Taj , Laving and <i>Cinnamomum spp</i> .
27.	Rasna (<i>Pluchea lanceolata</i>)	Damvel, Ishwari, Kulijan, Puskarmool, Vaisuri, Kaknuj , <i>Viscum articulatum</i> .
28.	Bharangimool (<i>Clerodendrum multiflorum</i>)	Pieces of other plant branches. Bark of <i>Picrorrhiza quassioides</i> .

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Ashwagandha (*Withania somnifera* (L.) Dunal): A High Valued Medicinal Plant

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M. R. Prajapati¹, Mayur Ram¹, V. M. Prajapati¹, M. R. Parmar¹, V. B. Patel¹, B. S. Desai¹

¹Ph.D. Scholar Dept. of Silviculture and Agroforestry, College of Forestry, NAU, Navsari,

Gujarat- 396450, India.

Introduction

Ashwagandha consists of dried mature roots of *Withania somnifera* (L.) Dunal (Family- Solanaceae), a perennial shrub, found in waste lands, cultivated fields and open grounds throughout India. Roots are collected in winter, washed and cut into short pieces. It is indigenous to India and is also distributed across Spain, Egypt, Israel, Jordan, Sudan, Iran, Afghanistan, Morocco, Baluchistan, Pakistan, Sri Lanka and Mediterranean regions of East Africa. In India, it is the main medicinal crop that is grown on wider scale in states of Madhya Pradesh, Gujarat, Rajasthan, Maharashtra, Punjab and Karnataka. It is called Indian Ginseng and is potential alternative to Chinese Ginseng. The raw root if broken smells like hay of horse and hence the name Ashwagandha (Deshpande, 2005).

Habitat

Throughout the drier and sub-tropical parts of India.

Classification

Kingdom: Plantae

Division: Angiosperma

Class: Dicotyledons

Order: Solanales

Family: Solanaceae

Genus: *Withania*

Species: *somnifera*

Therapeutic Action

Roots- used as an anti-inflammatory drug for swellings, tumours, scrofula, rheumatism, as a sedative and hypnotic in anxiety neurosis. Leaf- anti-inflammatory, hepatoprotective, antibacterial. Fruits and seeds- diuretic. Withanine- sedative, hypnotic. Withaferin A- major component of biologically active steroids; as effective as hydrocortisone dose for dose. Antibacterial, antitumour, antiarthritic, significantly protective against hepatotoxicity in rats (Khare, 2007).

Morphology

It is a medium sized, erect, herbaceous, evergreen, under shrub attaining a height of 60-120 cms. Stem is profusely branched, and both are covered with star shaped hairs. The leaves are simple ovate, alternate, entire, glabrous, thin, entire, in pairs, pubescent, with cuneate base and lower end of leaf is covered with hairs. The leaves are 5-10 cms long and 3.0-5.0 cms broad. The flowers are axial, in clusters forming a umbellate cyme, either sessile or sub sessile, pedicel 1.0 cm long and are greenish yellow in colour. Calyx 5 mm long, tomentose, teeth 2.5 mm long, linear, acute; corolla 8 mm long, divided up to middle, lobes lanceolate, acute, pubescent outside; filaments 3 mm long; anthers broadly elliptic, 1.25 mm long; ovary 4 celled, glabrous; style glabrous, stigma capitate. Flowering initiated after 90-110 days old plants and fruits matures on 180-190 days old plants and is continuous process. Fruit is berry turning reddish yellow or orange red, on maturity, globose, enclosed in the inflated membranous calyx. The seeds are reniform and yellow in colour (Ganvit, 2015).

Soil and Climatic Requirements

It grows well in good drained sandy loam or loamy soil with good organic matter and drainage. A soil pH range of 7.5 to 8 is ideal. It grows well in subtropical climates. It is planted during the late rainy season and prefers dry weather for its successful growth. In these conditions, 1-2 late winter rains are enough for its roots to develop fully. Places which receive 660-750 mm of rainfall are suitable for its cultivation (Deshpande, 2005).

Propagation

Seeds propagate it, either by direct sowing or raising a nursery seedling and transplanting them in field. The seeds are sown 45 days before onset of monsoon or after maximum monsoon is over (Rajeswara Rao *et al.*, 2012).

Grading of Roots

The dried roots are beaten with a club to remove adhering soil and to break off thin, brittle, lateral rootlets. Lateral branches, root crown and stem remain are carefully trimmed with a knife. Root pieces are then sorted out into following grades. (Shinde *et al.*, 2015)

- 1. Grade A:** Root pieces up to 7 cm in length, 1-1.5 cm in diameter, solid cylindrical with smooth external surface and pure white from inside.
 - 2. Grade B:** Root pieces up to 5 cm in length, 1 cm or less in diameter, solid, brittle and white from inside.
 - 3. Grade C:** Solid root pieces up to 3-4 cm in length, 1 cm or less in diameter.
 - 4. Lower grade:** Small root pieces, semisolid or hollow, very thin, yellowish inside and < 1 cm in diameter.
- Note: of late farmers are grading the roots into 7 or more grades.

Yield

The crop produces 400-1200 kg/ha dried roots and 200-500 kg seeds/ha. Good quality roots are selling at a price of Rs. 100-150/kg and seeds at Rs. 40-100/kg. The cost of cultivation works out to Rs. 15000-25000/ha. The net profit ranges from Rs. 25000-155000/ha. Additional returns can be earned by selling seeds and leaves (Shinde *et al.*, 2015).

Phyto Chemical Constituents

The roots contain 0.15% to 0.31% alkaloids in which 18 are major as - Withanine, Withananine. Pseudo-withanine, Pseudotropine, Tropine, Nicotine, Somnine, Somniferine, Somniferinine, Choline, Anaferine, Cusculohygrine, 3A-tigloyloxytropine, Iso-pelletine, tricine, Withasomine, Visamine and Withasomnine. Besides these Withanolides are also present. The roots are fractionally distilled to separate the contents, which give value additions. Besides above, Tropenol, Pseudo-tropenol, Anahygrine, Isopelline and Analides are also present in traces. The roots also contain free amino acids along with Aspartic acid, Glycine, Tyrosine, Alanine, Proline tryptophan, Glutemic acid and Cysteine. The roots also contain Starch, Sugars, Glycosides, Hentriacontane, Dulcitol and Withanicil. The leaves contain 12 Withanolides out of which Withaferin A, 27-deoxywithaferin A, 27-deoxy-14-hydroxywithaferin A, are major constituents. The green berries contain amino acids as Proline, Valine, Tyrosine, Alanine, Glycine, Hydroxyproline, Aspartic acid, Cystine, Cysteine along with Protolytic enzymes-chamase (Deshpande, 2005).

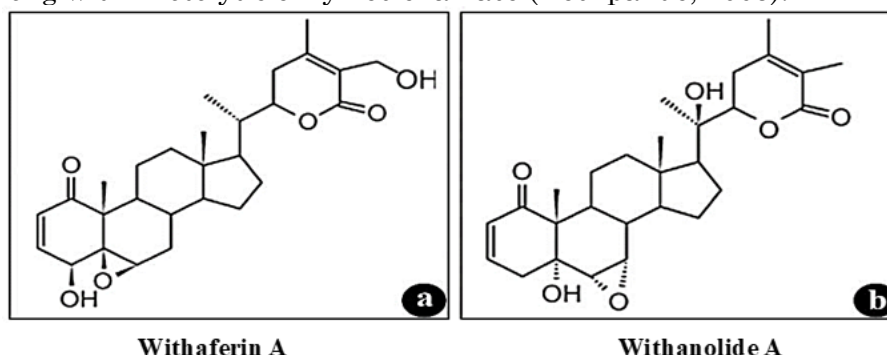


Fig.1: Structures of important Withanolides (Khare, 2007)

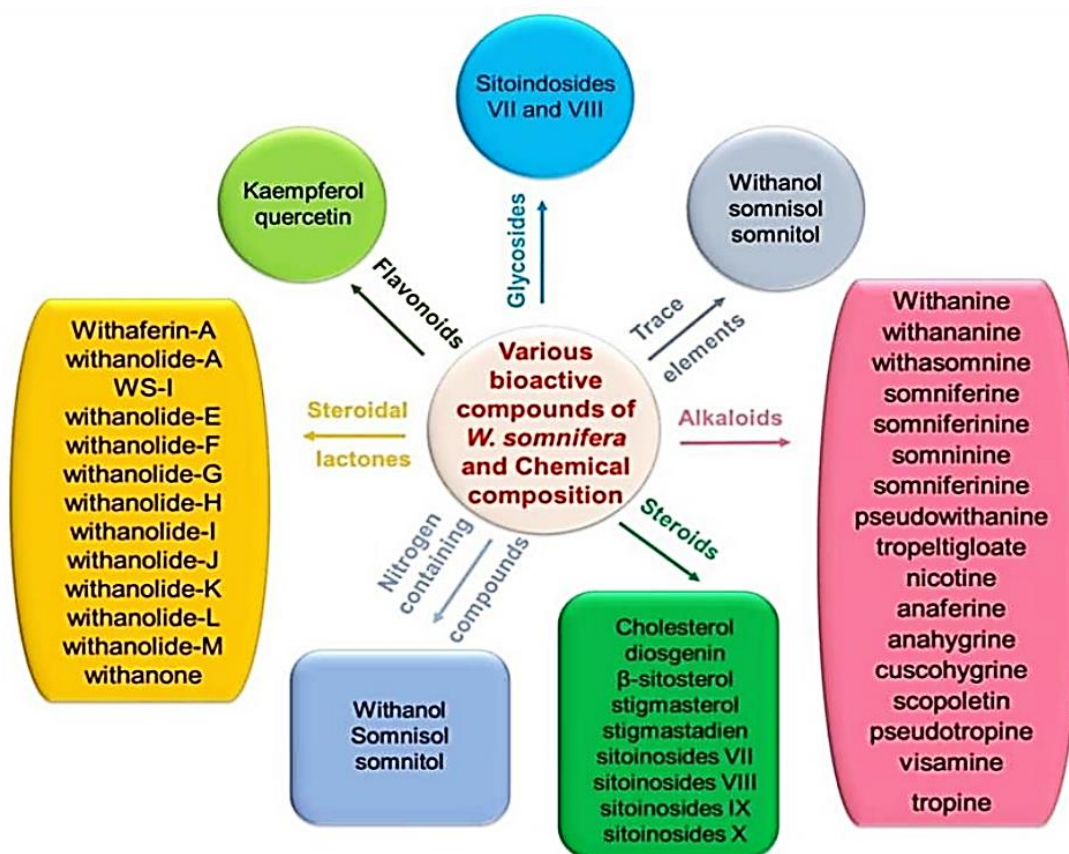


Fig.2: Various phytochemicals present in Ashwagandha (Srivastav *et al.*, 2024)

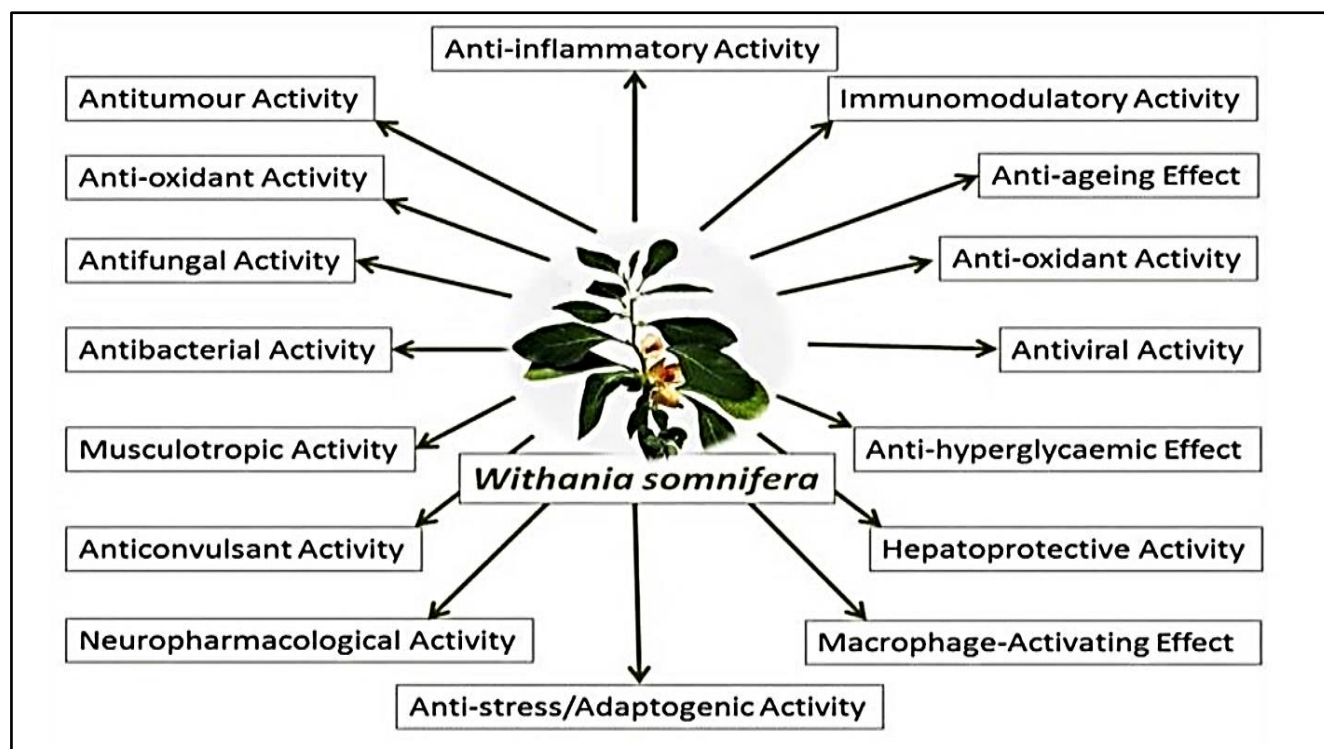


Fig.3: Pharmacological activities of Ashwagandha (Srivastav *et al.*, 2024)

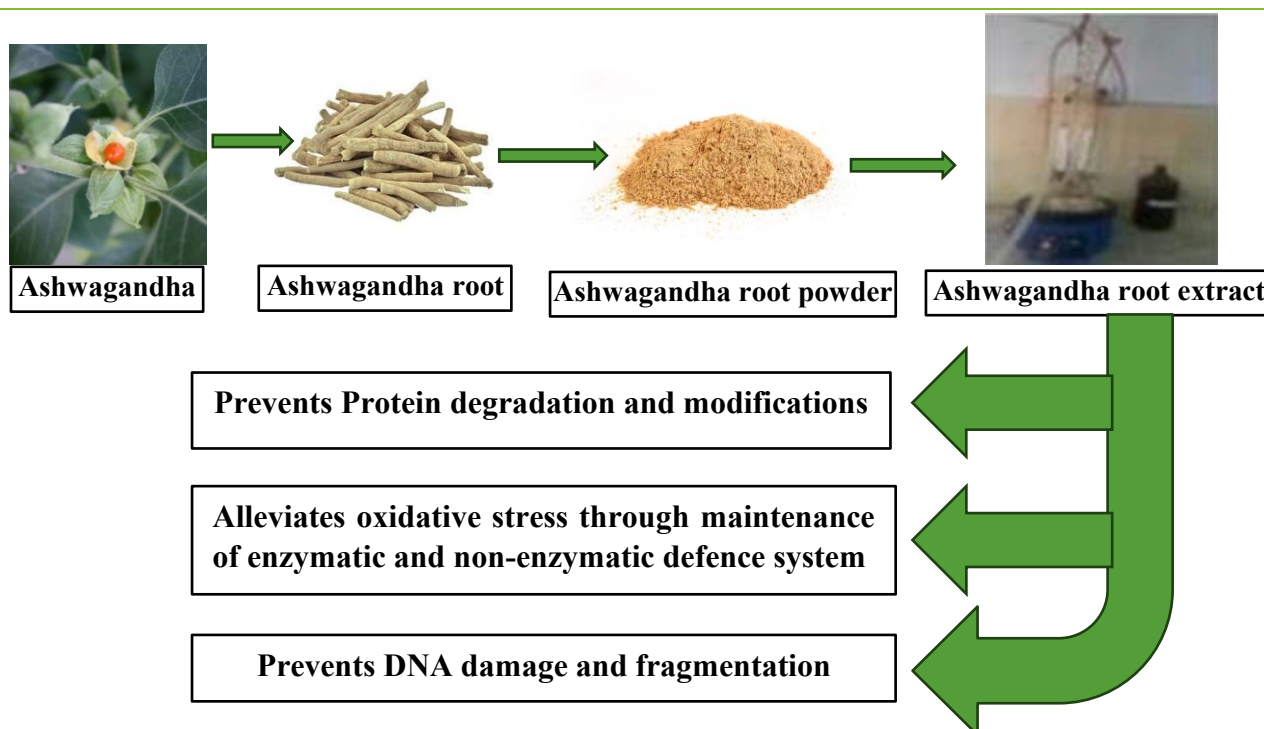


Fig.4: Flow Chart of Ashwagandha Root Extraction Process (Javaid and Akhtar, 2015)

Value Addition

Value added products from Ashwagandha include root powder, capsules, root extract, herbal beer etc. in addition to the traditional drugs made from this plant. Health drinks, herbal tea, functional foods, nutraceuticals and cosmeceuticals are some of the value-added products on which enterprises can be set up (Rajeswara Rao *et al.*, 2012).

Traditional Uses

According to the Wealth of India, it is difficult to accept *Withania somnifera* as the source of classical Ashwagandha (of Charaka and Sushruta). Charaka divided plant substances in fifty groups according to physiological actions of their decoctions. Ashwagandha of his period was included in Vaajikarana (aphrodisiac) group but was not mentioned in Jivaniya (promoter of longevity), Vayasthaapana (age-sustainer) and Rasaayana (rejuvenator) groups. Sushruta also did not include Ashwagandha in Rasaayana (rejuvenating) group. Ashwagandha and Kapikacchuu (*Mucuna pruriens*) were included by Charaka in the same group of (Vaajikaran) herbs, specific “sex drugs” for promoting virility. Ashwaka of Sushruta (Dalhan) is now being equated with *Mucuna monosperma* DC. It is quite possible that Ashwagandha of Charaka and Sushruta period was a related species of *Mucuna*. During the 7th century, *Withania somnifera* was included as Ashwagandha among twenty age-sustaining compound preparations of Ashtaanga Hridaya.

By the 16th century, *W. somnifera* entered more than fifteen formulations of Shaarangadhara Samhitaa. It was considered spermatogenic and libido-stimulant. Externally it was applied to stimulate the growth of the penis; also to relaxed vagina for restoring its original shape. Ashwagandhadi Tailam, also known as Linga-varadhana Tailam, is still available over the counter. (It contains extracts of *Withania somnifera* and *Mucuna prurita*). In Bhaavaprakasha, Ashwagandha was incorporated in more than twenty compound preparations and ten medicinal oils, for cough, asthma, consumption, emaciation, haemothermia, hyperacidity, cardiac affections, anxiety neurosis, mental and neurological disorders, muscular atrophy, oedema, gout, arthritis, spermaturia, diseases of the female genital tract, menstrual disorders and sterility. The powder of Ashwagandha root, with milk or jaggery or purified butter, was prescribed as a nourishing, rejuvenating and restorative tonic, for promoting virility in men and fertility in women (Ashtaanga Hridaya, Raaja Maarttanda). To promote intellect, life span and virility, Manduukaparni (*Centella asiatica*), Shankha pushpi (*Convolvulus pluricaulis*) and Shatavari (*Asparagus racemosus*) were added to Ashwagandha (Ashtaanga Hridaya). For cough and consumption, Pippali (*Piper longum*) was added (Vrindamaadhava). When prescribed as a cardiac tonic, Bibhitaka (*Terminalia bellirica*) was added. Single

drug, mixed with sugar and purified butter, was prescribed for insomnia (Bangasena). For arthritis, purified butter cooked with the decoction and paste of Ashwagandha along with milk, was prescribed. Ashwagandha Ghrita of Vrindaamaadhava was specific for arthritis and debilitated conditions. Among over-the-counter drugs, Ashwagandha-haarishtha (Bhaishajya Ratnaavali) is prescribed for anxiety neurosis; Ashwagandha Churna (Bhaav aprakaasha) for stress, fatigue and rundown conditions. Balaa-Ashwaganadha-Lakshaadi Taila (Sahasrayoga) is prescribed internally as well as externally as a nervine tonic and restorative. Amukkuraa (Ashwagandha) Churnam of Siddha medicine is prescribed in rheumatic diseases, sexual insufficiency and spermatorrhoea. In Unani medicine, Habb-e-Asgandh is prescribed as a supporting aphrodisiac and nervine tonic. Paste of the root is applied to penis for toning up erectile tissues; mixed with mother's milk a paste of the root is applied to sagging breasts. Majoon-e-Saalab is for sexual debility and attenuated semen, Majoon-e-Baladur for neurasthenia, dementia, amnesia (Khare, 2004).

Important Formulations (API Vol. I)

Asvagandhadyarista, Asvagandhadi Leha, Balasvagandha Laksadi Taila.

Properties and Action (API Vol. I)

Rasa: Tikta, Kasaya

Guna: Laghu

Virya: Usna

Vipaka: Madhura

Karma: Rasayana, Vatakapahapa, Balya, Vajikarana.

Therapeutic Uses (API Vol. I)

Sotha, Ksaya, Daurbalya, Vataroga, Klaibya.

Dose (Khare, 2004; API Vol. I)

Root powder 3-6 g, ash 1-2 g.

Chemotype and Varieties (Khare, 2004)

1. Chemotype I (Israeli): Contains Withaferin A as major constituent. Minor constituents are Withanolides N and O.

2. Chemotype II (Israeli): Contains Withanolide D as a major constituent. Withanolide G, 27-hydroxywithanolide D, 14-alpha-hydroxywithanolide D and 17-alpha-hydroxywithanolide D are present in trace amounts.

3. Chemotype III (Israeli): Contains Withanolides E-M. Leaves of offspring F₃ (from crossing of chemotype I and III), contain Withanolides Q and R. Withanolides P and S are also present in leaves. The plants raised in Israel from Jamnagar (Gujarat) seeds contained only three Withanolides: Withaferin A, 5-alpha-17-alpha-dihydroxy-1-oxo-6-alpha-7alpha-epoxy-witha-2, 24-dienolide and a minor Withanolide.

Table: Varieties are developed for Alkaloid and Root production:

Alkaloid content	Root production (Dry root yield)
Ws- 90-117	Jawahar-31
Ws-90-127 (0.46%)	Jawahar-20
Jawahar-31	Jawahar-134
Ws-90-105 (0.27%)	Jawahar Asgand -20 (5 to 6 q/ha)
Ws-20-120 (0.26%)	Jawahar Asgand-134 (4 to 6 q/ha)
Gujarat Anand Ashwagandha-1	Raj Vijay Ashwagandha-100 (6 to 7 q/ha)

(Shinde *et al.*, 2015; Khatri *et al.*, 2025)

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Flow Behaviour of Dragon Fruit Pulp for Food Processing Applications

Article ID: 72049

Anindita Karmakar¹, Sandeep Yadav²

^{1,2}Department of Post Harvest Engineering, Faculty of Agricultural Engineering, BCKV, Mohanpur, 741252, West Bengal, India.

Abstract

Dragon fruit (pitaya), valued for its vibrant color and nutritional richness, has gained popularity in India due to its early yield and economic potential. Despite of its several health benefits, its short shelf life poses challenges for processing and storage. This study investigates the flow behavior of dragon fruit pulp at varying total soluble solid (TSS) concentrations (10%, 20%, 30%) and temperatures (25°C, 35°C, 45°C). Using an Anton Paar rheometer (MCR 92), the flow behavior was analyzed across shear rates ranging from 20 to 200 s⁻¹. The pulp exhibited non-Newtonian, pseudoplastic behavior across all conditions. Both the Power Law and Herschel–Bulkley models fit the experimental data well ($R^2 > 0.90$). Apparent viscosity decreased with increasing temperature, particularly at lower shear rates. Activation energy, determined using the Arrhenius model, varied with concentration, with the highest value (2.1458 kJ/mol) observed at 30 °Brix. These findings provide essential insights for optimizing processing parameters, improving equipment design, and enhancing product quality in dragon fruit-based food applications.

Keywords: *Dragon fruit, Flow behavior, Pseudoplastic fluid, Total soluble solids (TSS), Apparent viscosity, Activation energy.*

Introduction

Dragon fruit (*Hylocereus undatus*), also known as pitaya or pitahaya, is a tropical fruit with vibrant colour and rich nutritional profile. The health benefits of dragon fruit are attributed to its abundance of bioactive phytochemicals, including flavonoids, phenols, anthocyanins, and betalains (Chen *et. al.*, 2024). These bioactive compounds have anti-inflammatory, anti-cancer, anti-microbial and antioxidant qualities. The fruit is also a good source of fiber, polysaccharides, fats enriched with essential fatty acids, vitamins (B₁, B₂, B₁₂, C, and E), and minerals (Fe, Ca, P, K, Mg, Zn, etc.) (Kumari *et. al.*, 2025).

Dragon fruit is becoming popular among Indian farmers, entrepreneurs and both rural and urban consumers. This perennial fruit crop yields fruit from the first year after planting and reaches peak production in three to five years. However, dragon fruit has a short shelf life. Due to its high susceptibility to spoilage, dragon fruit can develop problems due to oxidative reactions, microbial contamination, softness and nutrient loss (Khatun *et. al.*, 2024). Despite the fact that the majority of dragon fruits are sold fresh, some amounts are turned into juice or purees to increase their value, prolong their shelf life, and make the finished goods year-round.

Understanding rheological/flow properties is crucial for developing new products, controlling and optimizing process variables, designing and evaluating equipment such as pumps, pipes, heat exchangers, and mixers, as well as ensuring food quality control and consumer acceptability (Nindo *et. al.*, 2007). The flow behavior of food fluids is complex and is affected by various factors, including shear rate, temperature, solids concentration, moisture content, thermal history and applied shear stress. The aim of this study was to evaluate the effect of temperature and solid concentrations on flow behavior of dragon fruit pulp for different processing applications.

Materials and Methods

Dragon fruits were obtained from Horticulture Department of Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, India. Following, washing, sorting and slicing, the dragon fruit was blended with a domestic blender for approximately 5 minutes to obtain dragon fruit pulp (Fig.1). Then seeds were separated from the pulp by strainer. The pulp was dried at a temperature of 60°C for a very short period to obtain three

different concentrations of 10%, 20% and 30% total soluble solid contents (TSS). Rheological/flow properties were measured using Anton Paar Rheometer (MCR 92) (Fig.2) at three different temperatures of 25, 35 and 45°C and shear rates varying between 20 and 200 s⁻¹. Two different models namely power law (Equation 1) and Herschel-Bulkley (Equation 2) were applied to the rheological data in order to find the best fit model. Arrhenius model (Equation 3) was used to describe the effect of temperature on apparent viscosity and to determine the activation energy.

$$\tau = K\gamma^n \quad (1)$$

$$\tau = \tau_0 + K\gamma^n \quad (2)$$

$$\mu = Ae^{-\frac{E_a}{RT}} \quad (3)$$

where,

τ = Shear stress (Pa), μ = Apparent viscosity (Pa·s), n = Flow behaviour index, τ_0 = Yield stress (Pa), γ = Shear rate (s⁻¹), A = Arrhenius constant, E_a = Activation energy, R = Universal gas content, T = Absolute Temperature (K), k = consistency coefficient (Pa·s ^{n}).



Fig.1. Dragon Fruit Pulp



Fig.2. Anton Paar Rheometer

Results and Discussion

The rheograms in Fig.3 (a, b, c) illustrate the experimental relationship between shear stress and shear rate for dragon fruit pulp at three different concentrations. The dragon fruit pulp showed non-Newtonian pseudoplastic behavior for all three concentrations. For pseudoplastic fluid, viscosity decreases with increasing shear rate.

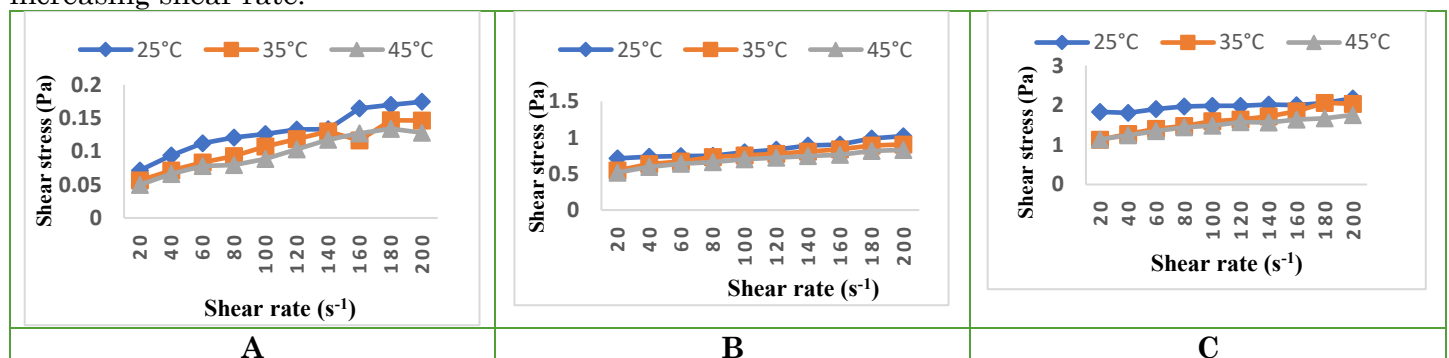


Fig.3. Shear stress versus shear rate (a) 10°Brix, (b) 20° Brix (c) 30° Brix

This is also evident from the viscosity graphs presented in Fig.4 (a, b, c). At lower shear rates viscosity decreased with increasing temperature. However at higher shear rates temperature did not have much influence on viscosity. All the experimental data from the shear stress versus shear rate curve were fitted to Power Law model and Herschel-Bulkley model. Both the models showed good fit to the experimental data with $R^2 > 0.90$ in most of the cases.

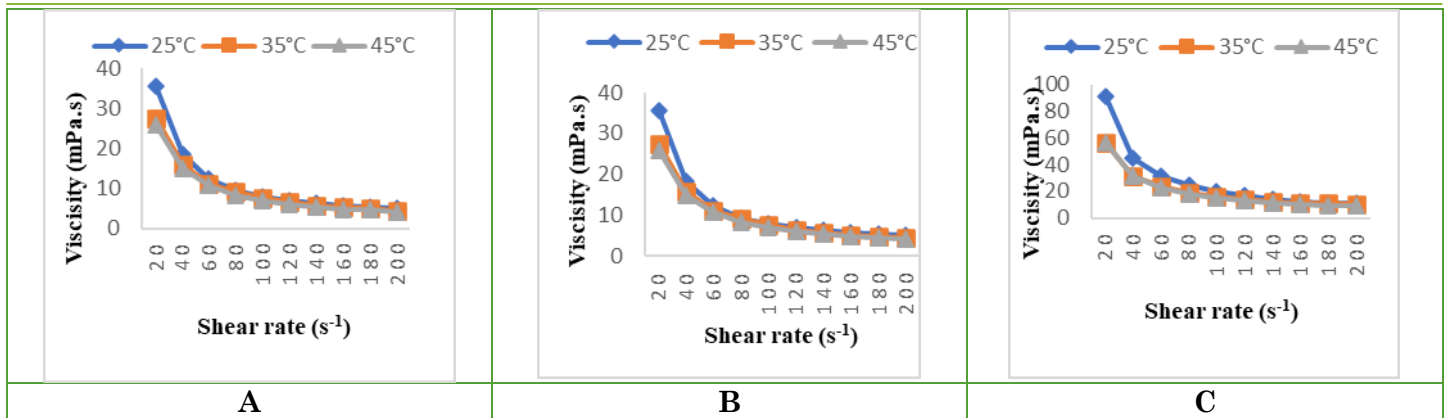


Fig.4. Viscosity versus shear rate (a) 10°Brix, (b) 20° Brix (c) 30° Brix

Variations in activation energy with concentration were inconsistent (Table 1). The higher activation energy was observed for 30°Brix concentration. Activation energy is important for chemical reactions, and during processing operations, food material can undergo chemical changes.

Table 1. Arrhenius constant and activation energy at different concentrations:

C(°Brix)	A(Pa.s)	E _A (kJ.mol ⁻¹)
10	0.00927	1.9512
20	0.09361	1.5888
30	0.2705	2.1458

Conclusion

Dragon fruit pulp showed pseudoplastic shear thinning behavior. Both the models, power law and Herschel-Bulkley showed good fit to the experimental data. Highest activation energy was found for the pulp of 30°Brix. The knowledge of flow properties of dragon fruit pulp will help the processors in selecting the appropriate pump, improving the processing efficiency, design better products, maintaining better quality and reducing production costs.

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Optimizing Fruit Crop Yield and Soil Health in Arid Zones through Integrated Nutrient Management

Article ID: 72050

K. Venkata Ramudu¹

¹Horticulture Assistant, Department of Horticulture, Andhra Pradesh.

Abstract

Excessive application of chemical pesticides and improper nutrient management degrade plant health, soil microbial diversity, and environmental quality, prompting the adoption of integrated nutrient management to sustain soil fertility and enhance crop productivity.

Introduction

India, home to 1.38 billion people—about 17.5% of the world's population packed into just 2.4% of the Earth's surface—is facing the critical challenge of feeding its rapidly growing population, expected to reach 9.6 billion globally by 2050. Despite progress, India ranks 101 out of 116 countries on the Global Hunger Index, highlighting widespread malnutrition that hampers socio-economic development. The United Nations' Sustainable Development Goals aim to tackle these issues by 2030 with a holistic approach. Increasing demand for nutrient-rich fruits has surged, especially amid the COVID-19 pandemic, emphasizing balanced diets for better immunity and health. While major crops like mango, banana, and citrus dominate, native underutilized fruits, rich in nutrients and adaptable to harsh climates, offer untapped potential. Climate change intensifies challenges—raising temperatures and causing extreme events that worsen salinity and pest pressures. However, limited research, poor awareness, and scarce quality planting materials hinder wider cultivation of these resilient fruits. With initiatives like India's Mission on Integrated Development of Horticulture, there's renewed focus on boosting such crops sustainably, complemented by Integrated Nutrient Management to reduce reliance on costly and harmful chemical fertilizers. This integrated approach promises to enhance productivity, soil health, and fruit quality, securing nutrition and livelihoods amid evolving environmental pressures.

Integrated Nutrient Management

Integrated Nutrient Management (INM) combines inorganic fertilizers, organic manures, and biological resources to provide balanced, efficient crop nutrition, sustain soil fertility, improve soil physico-chemical properties, and ensure environmentally safe and economically viable agricultural productivity. The integrated approach maximizes the use of all available nutrient sources judiciously to maintain long-term soil health and optimum crop yields.

Objectives of Integrated Nutrient Management (INM)

The primary objectives of Integrated Nutrient Management (INM) are to reduce reliance on chemical fertilizers and minimize input costs by efficiently utilizing locally available nutrient resources. INM aims to sustain crop productivity over the long term without compromising soil health or fertility. It seeks to enhance fertilizer use efficiency while leveraging the benefits of green manures, leguminous crops, and biofertilizers. Additionally, INM strives to prevent environmental degradation and address the social and economic needs of farmers. By adopting this holistic approach, the practice promotes sustainable agriculture while conserving natural resources essential for ongoing crop production.

Drivers for Implementing Integrated Nutrient Management

The requirement for Integrated Nutrient Management (INM) arises due to several factors, including the decline in crop productivity caused by deficiencies in secondary and micronutrients, the rising costs and unavailability of chemical fertilizers, and the adverse environmental effects of their continuous overuse. Additionally, ongoing nutrient depletion in soils highlights the necessity of combining chemical fertilizers with organic sources to achieve optimal crop production. Since fertilizer production in the country falls

short of demand, incorporating organic manures and biofertilizers as alternative nutrient sources is essential to bridge this gap. This integrated strategy not only sustains soil health and productivity but also enhances farmers' profitability. INM thus involves multiple components working together to promote balanced and efficient nutrient use in agriculture.

Organic Manures

Organic manures are natural materials derived from plant and animal sources used to enhance soil fertility and productivity. These manures primarily contain a large amount of organic matter and smaller quantities of plant nutrients. Their main role is to improve soil's physical, chemical, and biological properties, which in turn boosts crop growth. Common examples include farmyard manure (FYM), vermicompost, compost, oil cakes, and green manure.

Green Manure

Green manure consists of decomposed plant material, usually grown specifically as crops from leguminous plants, which are incorporated into the soil to enrich it. Green leaves collected from wastelands, fields, or forests can also serve as green manure. Crop residues like stalks, leaves, and seed pods left after harvest contribute significantly to organic matter in the soil and can be fed to animals or used in fish feed after processing.

Biofertilizers

Biofertilizers consist of beneficial microorganisms such as nitrogen-fixing bacteria (e.g., *Rhizobium*, *Azotobacter*), phosphorus-solubilizing bacteria, and mycorrhizal fungi, which enhance the availability of nutrients to plants through biological processes.

Chemical Fertilizers

Chemical fertilizers are commercially produced substances containing essential nutrients in chemical forms to supply crops with one or more nutrients quickly.

Problematic Soils

Problematic soils like saline, alkali, acidic, or waterlogged soils reduce productivity and must be managed regularly using amendments such as gypsum, lime, or organic/inorganic materials based on soil tests to restore fertility.

Finally, efficient irrigation water management using techniques like drip or sprinkler irrigation is crucial. Proper moisture enables plants to absorb dissolved nutrients effectively, and managing water supply reduces wastage and enhances nutrient availability, especially in arid regions.

Following the systematic steps of Integrated Nutrient Management ensures optimal utilization of available nutrient resources, leading to improved crop yield, enhanced soil health, and sustainable agricultural productivity. Regular monitoring and adjustment of nutrient application further maintain soil fertility and crop quality over time, ultimately supporting environmental conservation and increasing farmer profitability.

Summarized Table of Various Treatments and their Measured Plant Variables Based on the Information Provided

Crop	Treatment Description	Measured Plant Variables	Reference
Custard Apple	50% recommended fertilizer + 50% N through vermicompost + biofertilizers	Photosynthetic rate, transpiration rate, stomatal conductance, internal CO ₂ , leaf temperature, vapor pressure deficit	Asheesh Sharma <i>et al.</i> , (2014)
Custard Apple	50% RDN from Urea + 25% RDN poultry manure + <i>Azotobacter</i>	Total soluble solids, reducing sugar, non-reducing sugar, total sugar, ascorbic acid	Jangid <i>et al.</i> , (2021)

Custard Apple	2.5 kg vermicompost + 50 ml Azotobacter + 50 ml PSB + 75% RDF	Plant height, canopy spread, fruit weight, fruit length, fruit girth, yield per tree	Rikshita <i>et al.</i> , (2023)
Lemongrass	Organic manures + green manuring + vermicompost + Azotobacter	Growth, yield attributes, oil composition, soil nutrients, microbial populations, economics	Anjali Massey <i>et al.</i> , (2021)
Phalsa	FYM + 75% NPK + Azotobacter + PSB + ZnSO ₄	Plant growth, fruit yield, fruit size, juice percentage, pulp/stone ratio, TSS, ascorbic acid, sugars, acidity	Verma <i>et al.</i> , (2014)
Bael	Organic, inorganic fertilizers, biofertilizers + foliar boron spray	Fruit length, width, weight, volume, maturity, yield, TSS, acidity, ascorbic acid	Bael Singh <i>et al.</i> , (2014)
Aonla	50% RDN chemical + 25% vermicompost + biofertilizers	Fruit weight, size, volume, pulp/stone ratio, yield, TSS, ascorbic acid, shelf life	Aal <i>et al.</i> , (2020)
Pomegranate	50% N through FYM + 25% N castor cake + 25% N Urea	Fruit weight, length, retention, yield	Hiwale, (2009)
Manila Tamarind	50% NPK + vermicompost + FYM + phosphobacteria	Fruit weight, length, girth, peel weight, number and weight of arils, yield	Arthi <i>et al.</i> , (2023)

Conclusion

Several research studies conducted on various arid zone fruits clearly demonstrate that the combined application of biofertilizers and organic manures along with the recommended dose of chemical fertilizers significantly enhances overall plant growth, yield, and fruit quality. This integrated nutrient approach not only boosts fertilizer use efficiency but also promotes long-term ecological safety by maintaining soil health. Therefore, Integrated Nutrient Management (INM) serves as a sustainable and effective strategy to improve productivity and environmental sustainability in arid zone fruit crops.

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Empowering Farmers through Value-Added Agricultural Products

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J. B. Vasave¹, R. R. Sisodiya², Jyoti Valvi³

¹Assistant Professor, Polytechnic in Agriculture, NAU, Vyara.

²Assistant Professor, NMCA, Dept. of Soil Sci. and Ag. Chem, NAU, Navsari.

³Junior Executive, National Co-operative Dairy Federation of India Limited, Anand.

Abstract

Agriculture continues to be the primary source of livelihood for a majority of rural populations across the world, particularly in developing countries. However, the farming community often struggles with fluctuating market prices, post-harvest losses and low profitability when commodities are sold in raw form. Value addition in agriculture has emerged as an effective strategy to address these challenges by enhancing the economic worth of agricultural commodities through processing, packaging, branding and innovative marketing. The value-added agricultural products empower farmers by improving income, reducing wastage, creating rural employment, diversifying market opportunities and promoting entrepreneurial development. Successful examples of value-added products, government interventions, institutional support and future opportunities. At the same time, critically examines the constraints faced by farmers in adopting value addition, including infrastructure gaps, financial limitations and lack of awareness.

Keywords: Value addition, farmer empowerment, agro-processing, agricultural products, rural development, food security and entrepreneurship.

Introduction

Agriculture is the backbone of many economies, particularly in agrarian nations such as India, China, Nigeria and Brazil. While agricultural production has increased significantly due to technological innovations like high-yielding varieties, mechanization and improved irrigation facilities, farmers' income levels have not shown proportional growth. The paradox is clear: higher yields often do not guarantee higher profits. This problem stems from the over dependence on raw commodity sales, seasonal market fluctuations and post-harvest losses that reduce the farmer's share of profit.

Value addition in agriculture offers a revolutionary solution. By transforming raw commodities into consumer-ready or processed products, farmers can capture a larger share of the value chain. The global food industry demonstrates that processed and branded agricultural products fetch much higher prices than their raw counterparts. For example, a kilogram of raw mango may fetch only a modest sum for the farmer, while the same mango, once processed into juice, pickle or dried slices, can bring significantly higher returns.

The idea of empowering farmers through value addition is not limited to economics alone. It has wider implications for rural development, employment creation, food security and women's empowerment.

Concept and Definition of Value Addition

Value addition in agriculture refers to activities that **increase the economic value and consumer appeal of agricultural commodities**. It goes beyond mere processing to include innovations in packaging, branding, certification and marketing strategies.

Types of Value Addition

1. Primary Processing: Basic transformation of raw commodities, e.g., milling of rice, grinding of wheat into flour.

2. Secondary Processing: Advanced processing into products like bread, biscuits, yogurt, cheese, ketchup and snacks.

3. Packaging and Branding: Use of attractive packaging and unique branding to capture consumer attention.

4. Nutritional and Functional Enhancement: Development of fortified foods, nutraceuticals and functional beverages.

5. Certification and Labelling: Organic certification, fair-trade labelling and geographical indications (GIs) that enhance trust and marketability.

By adopting these strategies, farmers can move from being primary producers to becoming entrepreneurs and stakeholders in the food processing industry.

Importance of Value Addition for Farmers

1. Increasing Farmers' Income: The most direct benefit of value addition is improved profitability. Selling processed products allows farmers to retain a greater portion of consumer expenditure. For instance, turning raw milk into cheese or ghee can double or even triple earnings.

2. Reducing Post-Harvest Losses: Perishable crops such as fruits, vegetables, and milk account for significant post-harvest losses in developing countries sometimes up to 30-40%. Processing into long-lasting products like juices, jams, powders or dried goods minimizes these losses.

3. Market Diversification: Value-added products enable farmers to tap into urban, export and niche markets. For example, millet-based health foods are gaining popularity in international markets, providing new opportunities for farmers cultivating traditional grains.

4. Employment Generation: Agro-processing units require skilled and semi-skilled labour, thus creating rural employment. Women's self-help groups (SHGs) have particularly benefited by producing pickles, papads and spice powders for local markets.

5. Consumer-Centric Agriculture: Modern consumers demand convenience, nutrition and quality. Value addition allows farmers to meet these preferences by offering ready-to-cook mixes, organic foods, fortified products and innovative beverages.

6. Entrepreneurial Development: Value addition transforms farmers from passive cultivators into "Agripreneurs." They acquire skills in processing, marketing and brand management, thereby diversifying their income streams.

Examples of Value-Added Agricultural Products

1. Fruits and Vegetables: Mango pulp, tomato ketchup, dehydrated onion flakes, banana chips, fruit jams and pickles.

2. Dairy Products: Paneer, cheese, yogurt, flavored milk, ice cream and ghee.

3. Cereals and Millets: Millet flour, ready-to-cook mixes, breakfast cereals, biscuits and energy bars.

4. Spices and Condiments: Curry powders, masala blends, essential oils and herbal teas.

5. Livestock and Fisheries: Sausages, dried fish, meat pickles and leather goods.

6. Organic and Herbal Products: Herbal medicines, organic jaggery and eco-friendly packaging.

Successful Value Addition Example

1. Amul Dairy Cooperative: Amul transformed India's dairy sector by organizing farmers into cooperatives and processing milk into butter, cheese and other products. Today, millions of farmers benefit from higher incomes and stable markets.

2. Millet-Based Enterprises: In India, start-ups focusing on millet-based health foods have not only revived traditional crops but also increased incomes for small millet farmers. Products like millet cookies, noodles and energy bars are gaining urban and global demand.

3. Tropical Fruit Processing in Latin America: Countries like Brazil and Mexico have developed export-oriented industries around processed mango, pineapple and avocado products, significantly raising farmers' incomes.

Role of Government and Institutions

Government Interventions:

- a. Subsidies and Incentives:** Financial assistance for setting up food processing units.
- b. Skill Development Programs:** Training farmers in agro-processing and entrepreneurship.
- c. Research Support:** Development of improved processing technologies through agricultural universities.
- d. Market Linkages:** Platforms like e-NAM (National Agricultural Market) connect farmers with buyers across India.
- e. Export Promotion:** Agencies like APEDA (Agricultural and Processed Food Products Export Development Authority) promote Indian agro-products abroad.

Institutional Support:

- a. Cooperatives:** Dairy and fruit cooperatives empower farmers by pooling resources.
- b. Self-Help Group:** Women-led SHGs have successfully created micro-enterprises in food processing.
- c. NGOs and Start-ups:** Organizations support farmers with training, branding, and e-commerce platforms.

Challenges in Adopting Value Addition

- 1. Infrastructure Gaps:** Lack of cold storage, processing facilities, and transport.
- 2. Financial Barriers:** High initial investment and limited access to credit.
- 3. Awareness and Training:** Farmers often lack knowledge of value addition technologies.
- 4. Quality Standards:** Meeting food safety and export requirements is difficult for small farmers.
- 5. Market Competition:** Competing with established food corporations can be challenging.
- 6. Policy Gaps:** Policies often focus more on primary production than on agro-processing.

Future Prospects of Value-Added Agriculture

- 1. Technological Integration:** Artificial intelligence, blockchain and smart packaging can enhance quality assurance and traceability.
- 2. Export Growth:** Rising demand for organic, ethnic and healthy foods provides opportunities for global trade.
- 3. Women Empowerment:** Value-added enterprises are ideal for women-led SHGs, enhancing gender equality.
- 4. Agro-Tourism:** Farmers can combine product sales with experiential tourism to attract urban consumers.
- 5. Sustainability and Climate Resilience:** Eco-friendly packaging, plant-based foods and renewable energy-driven processing will shape the future.

Policy Recommendations

- 1. Investment in Rural Infrastructure:** Cold chains, warehouses and processing clusters.
- 2. Access to Finance:** Special credit lines for farmer-producers and SHGs.
- 3. Capacity Building:** Training programs in food processing, branding and digital marketing.
- 4. Public-Private Partnerships:** Collaboration between government, corporates and farmer groups.
- 5. Support for Startups:** Incubation centers for agro-based innovations.
- 6. Research and Development:** Focus on low-cost processing technologies suitable for small farmers.

Conclusion

Value addition in agriculture is a transformative approach that empowers farmers by bridging the gap between production and consumption. By moving beyond raw commodity sales, farmers can enhance their income, reduce wastage and establish themselves as entrepreneurs in the agribusiness sector. Government

support, institutional collaboration and technological innovation are crucial for scaling up value addition. Successful cooperatives, startups and SHGs demonstrate that value-added agriculture is not just a theoretical concept but a practical pathway toward rural prosperity.

As global food demand grows and consumer preferences shift toward healthy, organic and convenient products, farmers have a unique opportunity to harness value addition as a tool for empowerment. When farmers become active participants in the value chain, agriculture transitions from subsistence to enterprise-ushering in a new era of sustainable and inclusive rural development.

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Microgreens as a Superfood

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J. B. Vasave¹, R. R. Sisodiya², Jyoti Valvi³

¹Assistant Professor, Polytechnic in Agriculture, NAU, Vyara.

²Assistant Professor, NMCA, Dept. of Soil Sci. and Ag. Chem, NAU, Navsari.

³Junior Executive, National Co-operative Dairy Federation of India Limited, Anand.

Abstract

Microgreens, the young seedlings of vegetables and herbs, have gained global recognition as a novel “superfood” due to their remarkable nutrient density and bioactive compounds. Harvested within 7-21 days of germination, these miniature greens are richer in vitamins, minerals, antioxidants and phytochemicals compared to their mature plant counterparts. It also emphasizes their role in disease prevention, immune system enhancement, and promoting a sustainable food future. Microgreens can serve as a powerful tool in addressing modern dietary deficiencies, lifestyle-related diseases and global food security challenges. Ultimately, microgreens exemplify how small-scale innovations in nutrition and agriculture can make a significant impact on human health and sustainability.

Keyword: Microgreen, superfood, immune system and human health.

Introduction

The pursuit of healthy and sustainable food has become a defining theme of the 21st century. With rising health issues such as obesity, diabetes, cardiovascular diseases and micronutrient deficiencies, society is increasingly shifting toward functional foods and superfoods. Among these microgreens tiny but nutrient-packed vegetable seedlings-have captured attention for their exceptional health benefits and ease of cultivation.

Although once restricted to gourmet kitchens and upscale restaurants, microgreens are now being embraced by households, health enthusiasts, nutritionists and even policymakers as an answer to both dietary needs and sustainability challenges. Despite their small size, microgreens contain **4 to 40 times higher concentrations** of vitamins, minerals and antioxidants compared to their mature counterparts. This makes them an efficient source of essential nutrients, even when consumed in small amounts.

The comprehensive overview of microgreens as a superfood. It explores their origin, cultivation methods, nutritional profile, health benefits, culinary versatility, market potential, and their role in a sustainable future.

What are Microgreens?

Microgreens are **young edible seedlings** of vegetables, herbs and legumes harvested shortly after germination, when the first pair of true leaves emerge. They are larger than sprouts but smaller than baby greens. Typically, they are harvested within **7-21 days after sowing**, depending on the plant species.

Some of the most common microgreens include:

- 1. Cruciferous vegetables:** Broccoli, mustard, cabbage and radish.
- 2. Leafy vegetables:** Spinach, lettuce and beet greens
- 3. Legumes:** Green gram, Fenugreek and Pea
- 4. Herbs:** Basil and dill.
- 5. Specialty crops:** Sunflower, amaranth and coriander

Microgreens are appreciated for their intense flavours, vibrant colours and delicate textures. Beyond aesthetics, their nutrient density sets them apart as a functional food.

Historical Background of Microgreens

The concept of eating young greens is not new. Ancient civilizations often consumed **sprouted grains and legumes** for health benefits. However, the modern microgreen movement began in the late 20th century.

Chefs in California during the 1980s experimented with young greens to enhance visual appeal and taste in gourmet dishes.

Over time, nutritionists discovered that these greens were **nutritionally superior** to their mature plant forms. By the early 2000s, microgreens had transitioned from niche restaurants to farmers' markets and household kitchens. Today, they are recognized globally as a **superfood** that combines culinary elegance with nutritional excellence.

Nutritional Profile of Microgreens

Numerous scientific studies have validated that microgreens are nutrient-dense. Compared to mature plants, they often contain significantly higher concentrations of essential nutrients.

Key Nutrients in Microgreens:

a. Vitamins:

- i. Vitamin C: Strengthens immunity and collagen synthesis.
- ii. Vitamin E: Functions as an antioxidant, protecting cells from oxidative damage.
- iii. Vitamin K: Supports blood clotting and bone health.
- iv. Beta-carotene (Vitamin A precursor): Essential for eye health and immune function.

b. Minerals:

- i. Iron: Supports haemoglobin formation and oxygen transport.
- ii. Magnesium: Regulates muscle function and metabolism.
- iii. Zinc: Vital for immunity and wound healing.
- iv. Potassium: Maintains heart and muscle function.
- v. Calcium: Essential for strong bones and teeth.

c. Antioxidants & Bioactive Compounds:

- i. Polyphenols: Reduce inflammation and prevent chronic diseases.
- ii. Carotenoids: Improve vision and protect against oxidative stress.
- iii. Sulforaphane (in broccoli microgreens): Known for anti-cancer potential.

Health Benefits of Microgreens

1. Immune System Support: Vitamin C, zinc and antioxidants in microgreens help strengthen the immune system, making the body more resistant to infections and seasonal illnesses.

2. Cardiovascular Health: Nutrients like potassium and magnesium regulate blood pressure, while antioxidants reduce inflammation in blood vessels. Studies suggest microgreens can lower LDL (bad cholesterol) and improve overall heart health.

3. Anti-Cancer Properties: Cruciferous microgreens like broccoli and mustard are rich in glucosinolates and sulforaphane, compounds that activate detoxification enzymes and reduce cancer risk.

4. Digestive Health: High fiber content supports healthy gut microbiota, prevents constipation, and improves nutrient absorption.

5. Skin and Eye Health: Beta-carotene and vitamin E slow down skin aging, reduce wrinkles, and protect against UV damage. They also support retinal function, preventing age-related vision loss.

6. Diabetes Management: Low glycemic index and bioactive compounds in microgreens help regulate blood sugar levels, making them beneficial for diabetic patients.

7. Weight Management: Low in calories yet high in nutrients, microgreens promote satiety, reduce overeating, and assist in weight control.

Cultivation and Sustainability of Microgreens

1. Growing Conditions: Microgreens require minimal resources-small trays, soil or hydroponic media, water and light. They are typically harvested in 1-3 weeks, making them one of the fastest-growing food crops.

2. Indoor and Urban Farming: Due to their short life cycle, microgreens are ideal for urban farming, rooftop gardening and hydroponic systems. They do not require fertilizers or pesticides, reducing environmental impact.

3. Water and Space Efficiency: Microgreens use **90% less water** compared to traditional farming and can be grown in compact spaces, making them a sustainable solution for food production in cities.

4. Economic Opportunities: Small-scale farmers and entrepreneurs can benefit from microgreen cultivation, as they fetch high market prices due to their premium status in culinary and health markets.

Culinary Applications of Microgreens

Microgreens are versatile in flavour-ranging from sweet, tangy and nutty to spicy and earthy. They are used in:

1. Fresh salads and smoothie bowls.
2. Garnishes for soups, pizzas and curries.
3. Sandwiches, wraps and burgers.
4. Smoothies and juices for added nutrition.
5. Gourmet dishes for visual appeal.
6. Their ability to combine nutrition with taste and aesthetics makes them popular among chefs and home cooks alike.

Microgreens in Food Security and Public Health

With global malnutrition and micronutrient deficiencies affecting billions, microgreens offer a low-cost, nutrient-dense solution. They can be grown even in resource-poor settings, providing vulnerable populations with access to fresh nutrition.

Moreover, integrating microgreens into school meals, hospitals and community nutrition programs can help tackle deficiencies in iron, vitamin A and zinc, particularly in developing countries.

Market Trends and Global Popularity

The global microgreens market has grown significantly in the last decade. Health-conscious consumers, vegan diets and plant-based food trends have fuelled demand. According to market reports, the microgreens industry is expected to expand by over 10% annually, driven by urban farming start-ups, restaurant demand and home cultivation kits.

Challenges and Limitations

Despite their benefits, microgreens face challenges such as:

1. Short shelf life (3-5 days).
2. Limited awareness in rural and low-income populations.
3. High costs compared to conventional vegetables.
4. Lack of standardized cultivation practices.

Conclusion

Microgreens have emerged as a nutritional powerhouse and sustainable superfood. With their exceptional nutrient density, antioxidant capacity and bioactive compounds, they offer tremendous health benefits ranging from disease prevention to enhanced immunity. Their cultivation requires minimal resources, making them an eco-friendly solution for urban and rural populations alike. By integrating microgreens into daily diets, public health programs and sustainable agriculture systems, society can address modern challenges of malnutrition, chronic diseases, and environmental degradation. Though small in size, microgreens embody the principle that **“big health benefits can come in small packages.”** In the future, microgreens may become a **mainstream dietary component** and a cornerstone of food security strategies worldwide, bridging the gap between health, nutrition and sustainability.

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The Colour of Money: How Apple Hue Dictates Farmer Income in Kinnaur

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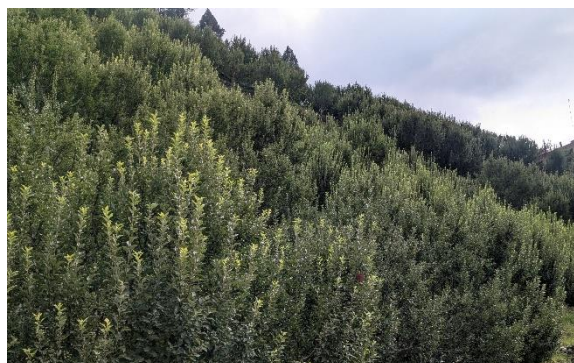
Arun Kumar¹

¹Krishi Vigyan Kendra Kinnaur and Regional Horticultural Research & Training Station Sharbo Kinnaur, H.P. 172107 India.



Introduction

Apple (*Malus domestica* Borkh.) cultivation is the backbone of horticultural livelihoods in Kinnaur district of Himachal Pradesh, where the crop contributes significantly to household income, employment generation, and regional identity. Since its introduction in the mid-20th century, apple farming has transformed the socio-economic landscape of the high-altitude valleys, with most households depending on orchards as their primary source of income. In the lower regions of Kinnaur, including Bari village (2,100 m a.m.s.l.), apple orchards are typically 20–25 years old and established under traditional systems of wide spacing (4.5 × 4.5 m). While these orchards were originally planted to ensure soil conservation on sloping terrain and to allow ease of management, their ageing canopies now pose structural and physiological constraints. High rainfall in the area promotes vigorous vegetative growth, resulting in dense canopies that limit solar radiation penetration. This restriction of light interception suppresses anthocyanin synthesis, thereby reducing red colour development, which is a primary determinant of fruit quality and market acceptance.



The market increasingly demands medium-sized, uniformly coloured apples, which are rewarded with premium prices. Conversely, oversized, undersized, or pale fruits are heavily discounted, creating a sharp disparity between harvested yield and realized income. This mismatch highlights the limitations of ageing orchard systems under high-rainfall conditions and underscores the urgent need to evaluate the economic and biophysical implications of such systems for farmer livelihoods.

Farmer's Perspective: The Orchard Reality

From the farmer's standpoint, the measure of success in apple cultivation is not merely the total quantity harvested, but how much of that produce translates into meaningful income. In the case of Bari village, approximately 1.7 tonnes of apples were harvested from the orchard (Table 1). However, the economic analysis revealed a sharp disparity between physical yield and financial returns.

Table1. Apple Grading on Colour & Size basis & Sales of Analysis of Lower region of Kinnaur apples (Bari Village):

Sl. No.	Colour Intensity	Grading of Apple	Quantity (Kg)	Rate (₹/Kg)	Amount (₹)
1	0–100%	Extra Extra Large (EEL)	6.125	20	122.5
2	>80%	Extra Large (EL)	26.555	47	1248.09
3	>80%	Large (L)	198.88	92	18296.96
4	>80%	Medium (M)	324.27	92	29832.84
5	>80%	Small (S)	267.095	92	24572.74
6	>80%	Extra Small (ES)	163.925	77	12622.23
7	>80%	Extra Extra Small (EES)	66.955	64	4285.12
8	>80%	Picked Grade 2 (P2)	41.675	52	2167.1
9	60–80%	Extra Large (EL)	8.21	30	246.3
10	60–80%	Large (L)	61.275	71	4350.53
11	60–80%	Medium (M)	118.8	71	8434.8
12	60–80%	Small (S)	120.42	71	8549.82
13	60–80%	Extra Small (ES)	80.765	56	4522.84
14	60–80%	Extra Extra Small (EES)	37.855	42	1589.91
15	60–80%	Picked Grade 2 (P2)	26.67	30	800.1
16	0-60 %	Extra Large (EL)	0.68	13	17.68
17	0-60 %	Large (L)	5.19	26	134.94
18	0-60 %	Medium (M)	11.53	26	299.78
19	0-60 %	Small (S)	14.825	26	385.45
20	0-60 %	Extra Small (ES)	14.505	26	377.13
21	0-60 %	Extra Extra Small (EES)	8.255	26	214.63
22	0-60 %	Picked Grade 2 (P2)	6.105	26	158.73
23	0–100%	Unsorted (U/S)	12.94	20	258.8
24	0–100%	Reject/Low Grade (ROL)	108.3	26	2815.8
Total			1731.805		126304.81

Although every fruit was physically collected, only the well-coloured apples (>80% colour intensity) contributed significantly to farm income, generating nearly 58% of total revenue. These fruits were primarily medium- and large-sized apples that matched market-preferred standards of colour and uniformity, thereby securing premium prices. In contrast, pale fruits (≤60% colour intensity), despite being harvested and transported to the market, fetched negligible returns—often insufficient to cover labour and handling costs. Rejects and low-grade fruits, though present in volume, were almost economically insignificant.

This experience highlights a stark reality for farmers: the economic value of apple production is disproportionately dependent on quality attributes, particularly external colour. Crates filled with bright, uniformly red apples are in high demand, while those with poorly coloured fruits are either heavily discounted or remain unsold. Thus, for farmers, the challenge is not just producing apples, but producing apples of a grade that the market values. The chart is showing the precise comparison between harvest

share (kg) and income contribution (₹) by colour/grade categories. Values were computed from the original sales table.

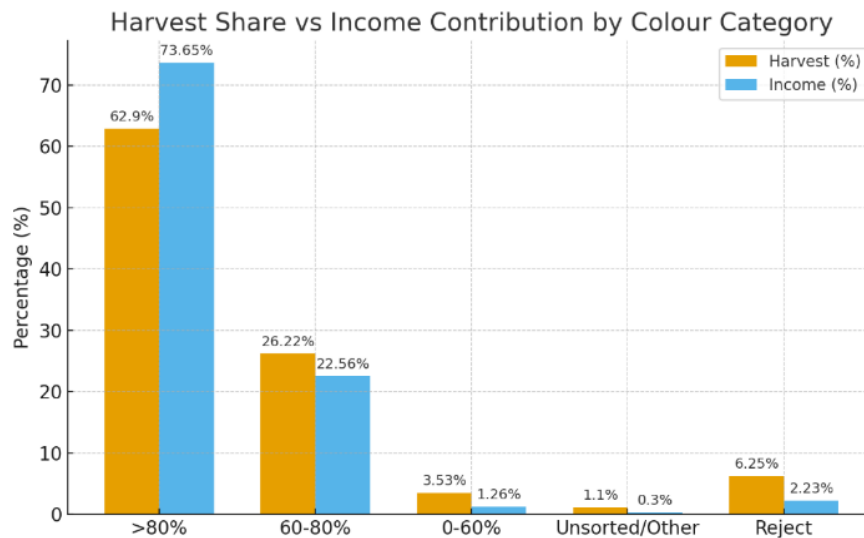


Figure 1. Harvest share (%) vs Income contribution (%) by colour category.

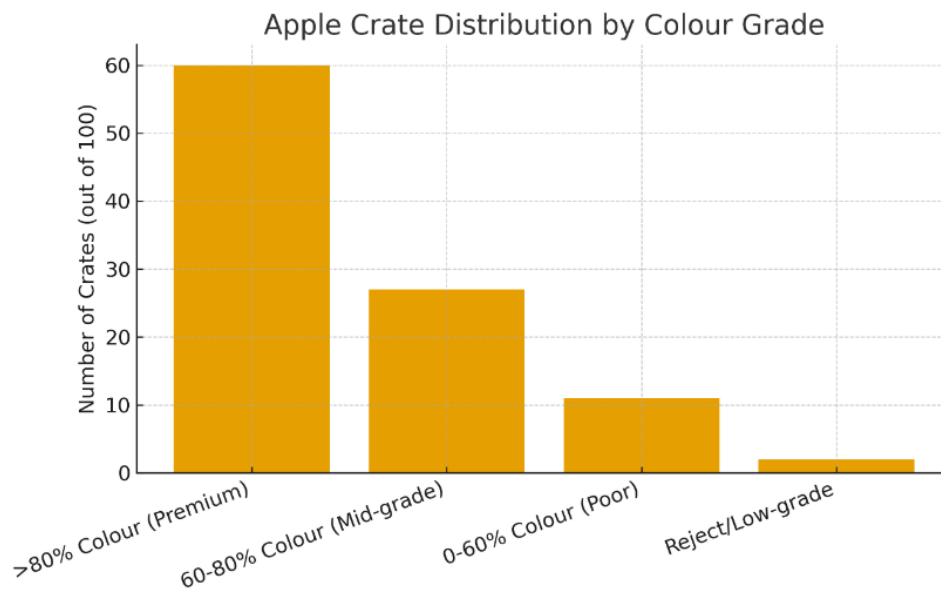
Table 2. Economic Value Gradient in Apple Harvest by Colour Intensity: Mass vs. Revenue Proportions, Bari Village Orchard (2025):

Category	Harvest (kg)	Harvest (%)	Income (%)
>80%	1089.355	62.9%	73.65%
60-80%	453.995	26.22%	22.56%
0-60%	61.09	3.53%	1.26%
Unsorted/Other	19.065	1.1%	0.3%
Reject	108.3	6.25%	2.23%

This table 2 aggregates grading data (total n = 1,731.8 kg; ₹126,305 revenue) from a mature apple orchard (*Malus domestica*), categorizing fruits by red blush intensity, a key anthocyanin-driven quality trait linked to light exposure and market pricing. Well-coloured fruits (>80% blush; 62.9% mass) dominate revenue (73.7%) via premium rates (₹85/kg avg.), reflecting optimal PAR interception (>50% transmission) that enhances PAL activity and pigmentation. Moderately coloured (60–80%; 26.2% mass) yield 22.6% income at discounts (₹63/kg), while poorly coloured (≤60%; 3.5% mass) contribute 1,000 mm) and management deficits, yielding a 3.4:1 value gradient and highlighting needs for pruning to boost premium shares by 20–30%.

Scientific Grading Analysis

The grading data from Bari village provides clear evidence of the disproportionate influence of fruit colour intensity on market value. When normalized to 100 crates of harvested produce, the distribution illustrates the dominance of well-coloured apples in determining economic returns. Approximately **60 crates** were classified as **well-coloured (>80% colour intensity)**, which consistently commanded premium prices in the market. These fruits, typically of medium to large size, represented the quality segment most favoured by consumers and traders. In contrast, only **25–28 crates** fell into the **moderately coloured (60–80%)** category. While these fruits were marketable, they were subject to discounts due to non-uniform appearance and weaker red blush development. A further **10–12 crates** belonged to the **poorly coloured (≤60%)** group. Despite being harvested and transported alongside other grades, these fruits fetched negligible prices and, in several cases, did not recover the cost of labour and handling. Finally, a small fraction of the harvest was categorized as **rejects or low-grade fruits**, equivalent to **2–3 crates per 100 harvested**. This segment was either unmarketable or sold at minimal returns, highlighting a substantial post-harvest economic inefficiency.



Effect of Management and Climate on Apple Quality

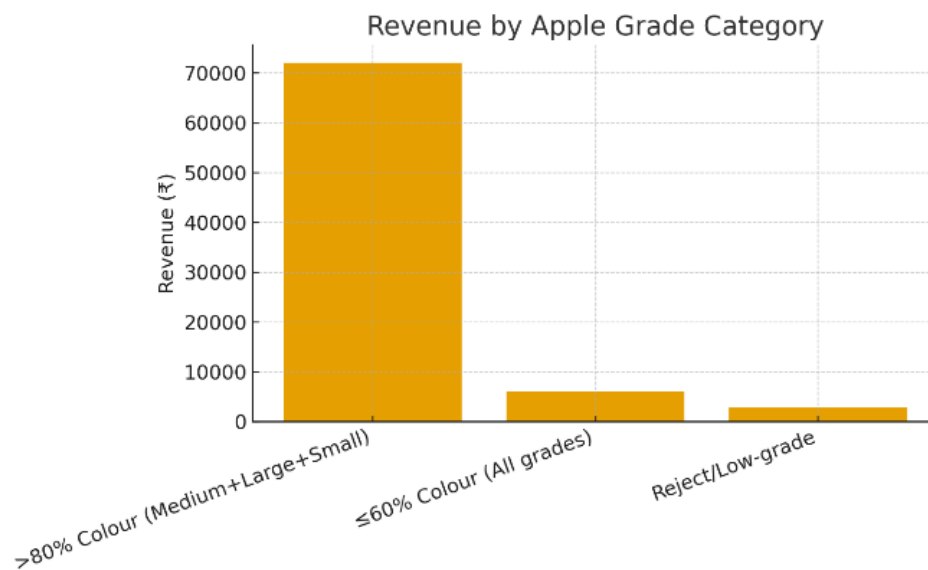
In Bari village, both orchard management practices and the local high-rainfall climate strongly influence apple quality and market returns. Heavy precipitation stimulates excessive vegetative growth, producing dense foliage that shades developing fruits and limits the sunlight needed for red colour development and uniform ripening. Most orchards are over 20 years old with large, untrained canopies; this weak canopy control results in irregular fruit size and poor distribution of nutrients and light. The traditional wide spacing of 4.5×4.5 m, originally adopted for soil conservation, also leads to poor light interception. In addition, the absence of systematic pruning, pollinizer planning and mulching further reduces fruit set, size and colour uniformity. Because farmers typically lack on-farm cold storage or mechanical graders, they are forced to sell mixed lots of premium and low-grade fruits at averaged, lower prices. Together, these factors explain why a farmer harvesting 100 crates may see only about 60 crates reach premium colour standards; improving canopy management, pollination planning and post-harvest handling can upgrade more crates to higher grades and directly increase farm income without expanding land area.



Economic Insight

An analysis of the Bari village case reveals a striking economic imbalance between quantity and value. Although the farmer harvested about 1,731 kg of apples, the bulk of the income came from a narrow slice of the crop: medium, large and small apples with more than 80 % colour intensity generated roughly ₹72,000 out of the total ₹1.26 lakh—nearly 58 % of revenue. In contrast, the poorer-coloured grades (≤ 60 % colour), despite contributing over 60 kg of fruit, accounted for less than 5 % of earnings. Even the reject

and low-grade category, which exceeded 100 kg, earned barely ₹2,800 in total. This skewed revenue pattern underscores how, in traditional high-rainfall orchards, it is not the harvested volume but the share of premium-quality fruit that determines profitability, highlighting the need for canopy management, better grading and post-harvest handling to lift more fruit into higher-value categories.



Farmer's Learnings & Scientific Recommendations

Experience from the Bari village orchard clearly shows that farmer profitability in high-rainfall Kinnaur depends more on fruit quality than on total harvest weight. Drawing on this case, several key learnings and recommendations emerge. Orchard renewal is critical: shifting from ageing 20–25-year-old trees to high-density plantings on dwarf or semi-dwarf rootstocks allows for uniform canopies, better light interception and a higher share of premium-grade fruit. Equally important is canopy management through annual pruning and training, which improves sunlight penetration and colour development. Systematic pollination planning, the use of compatible pollinizer cultivars and honeybee boxes ensures better fruit set, size uniformity and reduced drop. Post-harvest practices also need upgrading: on-farm sorting, grading and storage facilities can capture market premiums by keeping high-colour fruit separate from lower grades. Finally, farmers must adopt climate-adaptation measures such as mulching, organic manure application and rainwater management to balance vegetative growth, conserve soil moisture and reduce disease pressure. Together, these interventions can transform traditional orchards from high-volume but low-value systems into more resilient, high-return enterprises aligned with market demands.

Conclusion

In conclusion, the case of Bari village starkly illustrates that for Kinnaur's apple farmers, financial success is no longer a simple function of yield. The economic reality is dictated by colour. The profound disparity between harvest volume and income, where a mere 63% of the harvest by weight generates over 73% of the revenue, establishes fruit colour, driven by anthocyanin development, as the primary determinant of profitability. This "yield-income paradox" is a direct consequence of ageing orchards with dense canopies and high rainfall that stifle light penetration, coupled with market forces that premiumize uniformity and red blush. Therefore, the path to sustainable livelihoods lies not in expanding cultivation, but in a fundamental shift from traditional, volume-focused practices to quality-centric orchard management. Embracing scientific recommendations, including orchard renewal with high-density plantations, rigorous canopy management, systematic pollination planning, and upgraded post-harvest handling, is imperative. By transforming their approach to prioritize light and colour, farmers can ensure that a greater proportion of their harvest captures the market's premium, ultimately securing the future of apple cultivation in the high-rainfall regions of Kinnaur.

Nutrient Management in Coffee in Tamil Nadu: Sustaining Plantations for the Future

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Dr. M. Kabilan¹

¹Regional Coffee Research Station, Coffee Board, Thandigudi-624216, Tamil Nadu, India.

Introduction

Coffee is one of the most cherished plantation crops of Tamil Nadu, contributing not only to the livelihood of thousands of growers but also to the cultural and economic fabric of the state. While the Nilgiris and other parts of Tamil Nadu may not match the scale of Karnataka in terms of production, the region holds a distinct reputation for producing coffee with unique flavor notes shaped by altitude, soil and microclimate. Managing coffee is a complex art, where soil health, plant vigor and environmental factors blend to create the final cup quality. Among the many factors influencing productivity, nutrient management stands at the core. The balanced and scientific application of nutrients ensures not only high yields but also sustainability of plantations, resilience against climate change and better quality beans that fetch premium prices in the global market.

As we look toward the future, nutrient management in Tamil Nadu's coffee plantations is becoming more crucial than ever. Changing rainfall patterns, declining soil fertility and rising production costs challenge farmers to adopt precise and eco-friendly strategies. This article explores the present practices, emerging trends and future prospects of nutrient management in coffee cultivation across Tamil Nadu.

The Importance of Nutrients in Coffee Cultivation

Coffee is a perennial crop that remains in the same soil for decades, continuously drawing nutrients to support its growth, leaf flushes, flowering, fruit set and bean filling. Unlike seasonal crops, coffee requires a long-term vision of soil and plant health. Each stage of its growth demands specific nutrients in varying quantities. For example, nitrogen is vital for vegetative growth and leaf production, while phosphorus supports root development and flowering. Potassium plays a decisive role in bean filling, fruit development and enhancing resistance to pests and diseases.

Secondary nutrients such as calcium, magnesium and sulfur also play significant roles in maintaining the physiological functions of the coffee plant. Calcium supports cell wall strength, magnesium is at the heart of chlorophyll synthesis and sulfur aids in protein formation. Micronutrients like zinc, boron and iron, though required in minute quantities, can critically affect flowering, fruit setting and bean quality. A deficiency or imbalance of any of these nutrients often results in reduced yields, poor quality and increased susceptibility to stresses.

Coffee Soils of Tamil Nadu

The soils of Tamil Nadu's coffee-growing regions vary across altitude and terrain. In the Nilgiris, coffee is often grown in loamy soils rich in organic matter but subject to leaching due to heavy rainfall. In lower altitudes, red soils and lateritic soils dominate, which may be deficient in organic carbon and micronutrients. These soils demand careful nutrient replenishment because they are prone to erosion and nutrient runoff. The traditional shade-grown system of coffee in Tamil Nadu contributes to natural nutrient cycling through leaf litter, but this alone cannot sustain commercial levels of productivity. Understanding the soil profile, fertility status and limitations is the first step in planning nutrient management strategies tailored to each plantation.

Traditional Nutrient Management Practices

For decades, Tamil Nadu's coffee farmers have relied on organic sources to maintain soil fertility. Cattle manure, composted farmyard manure and green manures are applied during the monsoon months to enrich the soil. Fallen leaves from shade trees contribute significantly to organic matter recycling, slowly releasing

nutrients to the coffee roots. Wood ash, rich in potassium and trace elements, has also been a traditional input in some estates.

In mixed cropping systems, pepper vines, cardamom and fruit trees grown alongside coffee contribute to the diversity of organic residues in the soil. These traditional systems not only add nutrients but also improve soil texture and microbial activity. However, as yields and market demands increased over time, the need for chemical fertilizers arose and integrated approaches gradually developed.

Modern Fertilizer Practices

With the advancement of coffee research and recommendations by institutions like the Coffee Board of India, farmers in Tamil Nadu have increasingly adopted balanced fertilizer schedules. The use of urea, rock phosphate, muriate of potash and single super phosphate has become common. These fertilizers are applied in split doses, usually synchronized with rainfall and crop stages. For example, nitrogen is often applied in two to three doses during active growth, while potassium is emphasized during the berry development stage.

Fertilizer application in Tamil Nadu's plantations has become more precise over the years, with emphasis on avoiding blanket recommendations. Soil testing and leaf analysis are gaining importance to identify actual deficiencies and apply nutrients accordingly. This practice not only improves efficiency but also reduces wastage and environmental harm.

Organic and Biofertilizers in Coffee Plantations

In recent years, there has been a resurgence of interest in organic nutrient sources in Tamil Nadu's coffee sector. With consumers increasingly valuing sustainability and residue-free beans, many estates are moving toward organic certification. Vermicompost, poultry manure, neem cake and bone meal are becoming popular inputs. These sources not only supply nutrients but also improve soil microbial diversity and structure.

Biofertilizers such as Rhizobium, Azospirillum, phosphate-solubilizing bacteria and mycorrhizal fungi are being widely promoted for coffee plantations. These microbes help fix atmospheric nitrogen, solubilize phosphorus and enhance nutrient uptake. The adoption of biofertilizers reduces dependence on costly chemical fertilizers and improves long-term soil fertility.

Foliar Nutrition and Micronutrient Management

Foliar sprays are gaining importance in coffee plantations of Tamil Nadu as a quick method to correct nutrient deficiencies, especially of micronutrients. Zinc, boron and magnesium deficiencies are common in coffee, particularly in older plantations with depleted soils. Foliar sprays of zinc sulfate, borax and magnesium sulfate during critical growth stages improve flowering, fruit set and overall plant health.

Foliar nutrition is also useful during stress conditions, such as drought years when root absorption is limited. By directly supplying nutrients through leaves, foliar sprays help bridge temporary gaps and sustain productivity.

Role of Shade Trees and Intercrops

Shade trees in coffee plantations are not merely a cultural practice but a critical component of nutrient management. Species such as silver oak, dadap and native forest trees shed leaves that decompose into rich organic matter. This natural litterfall contributes nitrogen, phosphorus, potassium and trace elements back into the soil. Intercropping systems, common in Tamil Nadu, where pepper, banana and fruit trees coexist with coffee, add further layers of nutrient cycling. For instance, leguminous shade trees enrich nitrogen through biological fixation, while deep-rooted trees bring up nutrients from lower soil layers, depositing them on the surface through leaf litter. Thus, biodiversity within plantations directly supports nutrient sustainability.

Challenges in Nutrient Management

Despite progress, coffee plantations in Tamil Nadu face several challenges in nutrient management. Soil erosion, especially on sloping lands, leads to nutrient loss. Heavy rainfall during the monsoon often results in leaching of nitrogen and potassium beyond the root zone. In contrast, prolonged dry spells restrict

nutrient solubility and uptake. Rising input costs make fertilizers less affordable for smallholders, while organic sources may be insufficient to meet crop demands on a commercial scale. Labor shortages also affect timely application of manures and fertilizers. Moreover, unscientific use of fertilizers without soil testing can create imbalances, leading to nutrient antagonism or toxicities. Sustainability concerns, including carbon footprint and groundwater contamination, are prompting a rethinking of nutrient practices in the sector.

Innovations and Future Directions

The future of nutrient management in Tamil Nadu's coffee plantations lies in precision and sustainability. Digital soil health cards, drone-based nutrient monitoring and AI-driven recommendations are beginning to find space even in plantation agriculture. Site-specific nutrient management will become the norm, ensuring each plot receives exactly what it needs, no more and no less. Climate-smart agriculture practices will also shape nutrient strategies. For example, using controlled-release fertilizers that minimize leaching, adopting fertigation through drip irrigation and integrating organic mulches to conserve moisture and recycle nutrients will become standard. Research on nanofertilizers holds promise, as these formulations can deliver nutrients more efficiently at lower doses.

Conclusion

Nutrient management is the backbone of coffee cultivation in Tamil Nadu. From the lush slopes of the Nilgiris to smaller plantations spread across the state, the health and productivity of coffee plants depend on how effectively soils are enriched and balanced. While traditional practices of organic recycling continue to hold relevance, modern approaches involving chemical fertilizers, biofertilizers and precision tools are shaping the future.

Horse Gram: An Underutilized Superfood for Nutritional and Functional Food Security

Article ID: 72055

Shubham Thapa¹, Abha Rawat¹

¹Department of Seed Science and Technology, School of Agriculture and Allied Science, HNB Garhwal University (A Central University), Srinagar, Uttarakhand, India.

Abstract

Horse gram (*Macrotyloma uniflorum* (L.) Verdc.), an underutilized legume of the Fabaceae family, holds immense promise for addressing nutritional and functional food security. Traditionally consumed in rural and tribal areas, it is a cost-effective source of protein, dietary fiber, essential fatty acids, and minerals such as iron, calcium, and molybdenum. Its high lysine content complements cereal-based diets, while resistant starch, prebiotics, and bioactive phytochemicals contribute to antidiabetic, antioxidant, and digestive health benefits. In addition, horse gram has a long history in traditional medicine for managing ailments such as kidney stones, asthma, and obesity. Agronomically, horse gram is highly resilient, thriving in drought-prone and marginal environments, making it suitable for intercropping and sustainable farming practices. Despite these attributes, they remain neglected in mainstream food systems and research agendas. Promoting its wider utilization could support dietary diversification, functional food innovation, and climate-resilient agriculture. This review highlights horse gram's nutritional profile, therapeutic value, and agronomic potential, underscoring its role as a sustainable superfood to enhance human health and food security in developing regions.

Keywords: Horse gram, nutritional security, functional foods, therapeutic potential, sustainable agriculture.

Introduction

Food legumes have served as dietary staples for thousands of years and are regarded as the second most crucial crop group after cereals. They are also the second primary source of protein and nutrition for humans and animals worldwide (Bhartiya *et. al.*, 2015). In developing nations, a small number of commercialized legumes dominate cultivation and trade, thus significantly combating protein malnutrition. However, several underexploited indigenous legumes, such as horse gram (*Macrotyloma uniflorum* (L.) Verdc.), remain marginalized despite their exceptional potential for improving food and nutritional security among rural and tribal populations.



Horse gram, belonging to the *Fabaceae* family, is an essential but underutilized legume widely known for its rich nutrient content, medicinal uses, and resilience to harsh environmental conditions (Durst & Bayasgalanbat, 2014). It is well-suited for intercropping with cereals such as sorghum, maize, little millet, finger millet, and pearl millet. In India, horse gram is popularly called *kulaththa* and is recognized in Ayurveda and traditional medicine for its therapeutic value (Pati & Bhattacharjee, 2013).

Nutritional and Therapeutic Importance

Horse gram is unique because of its dual role as a nutrient-dense and therapeutic food crop. It is a rich source of protein, dietary fiber, essential fatty acids, and minerals such as iron, calcium, and molybdenum (Fig. 1), making it a low-cost, protein-rich pulse suitable for vulnerable communities. The amino acid composition of horse gram, particularly its high lysine content, makes it an excellent complement to methionine-rich cereals. In addition, it contains resistant starch, non-digestible carbohydrates, and prebiotics that support gut health and aid in diabetes management (Dutta *et. al.*, 2016).

Traditionally, horse gram has been prescribed for treating kidney stones, asthma, bronchitis, hypertension, and menstrual disorders. Several studies have validated its anti-hyperglycemic, anti-hyperlipidemic, antioxidant, and anti-inflammatory properties, highlighting its potential as a functional food.

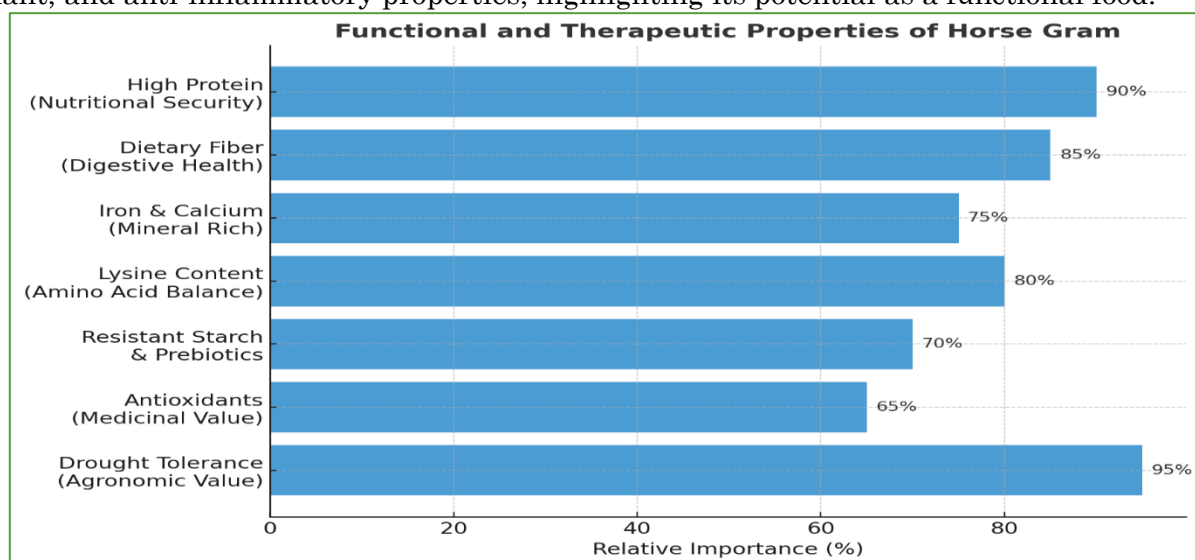


Fig. 1: Functional and Therapeutic Properties of Horse Gram

Nutritive Components of Horse Gram

Legumes are often called the “poor man’s meat” because of their affordability and high protein levels. Horse gram is particularly significant among legumes because of its dense nutritional composition.

Proximate Composition

Studies confirm that horse gram has high amounts of protein, crude fiber, and carbohydrates (Fig. 2). It is also rich in phytochemicals such as phenolic acids, flavonoids, and tannins that contribute to antioxidant activity (Sreerama *et. al.*, 2010; Kachave *et. al.*, 2020).

Table 1. Major nutrients in different milled fractions of horse gram (percent of dry matter)
(Adapted from Sreerama *et. al.*, 2010):

Constituent	Cotyledon	Embryonic Axe	Seed Coat
Moisture	5.8 ± 0.31b	8.4 ± 0.21a	3.9 ± 0.05c
Protein	22.6 ± 1.23a	18.6 ± 0.90b	9.1 ± 0.35c
Fat	1.8 ± 0.06b	2.6 ± 0.04a	0.6 ± 0.02c
Ash	2.9 ± 0.02b	2.2 ± 0.04b	3.8 ± 0.05a
Crude fiber	1.6 ± 0.02c	11.2 ± 0.26b	21.8 ± 1.6a
Total carbohydrate	66.9 ± 2.6b	68.2 ± 1.9b	82.6 ± 1.1a
Dietary fiber	16.7 ± 0.27c	22.6 ± 0.18b	36.4 ± 0.90a

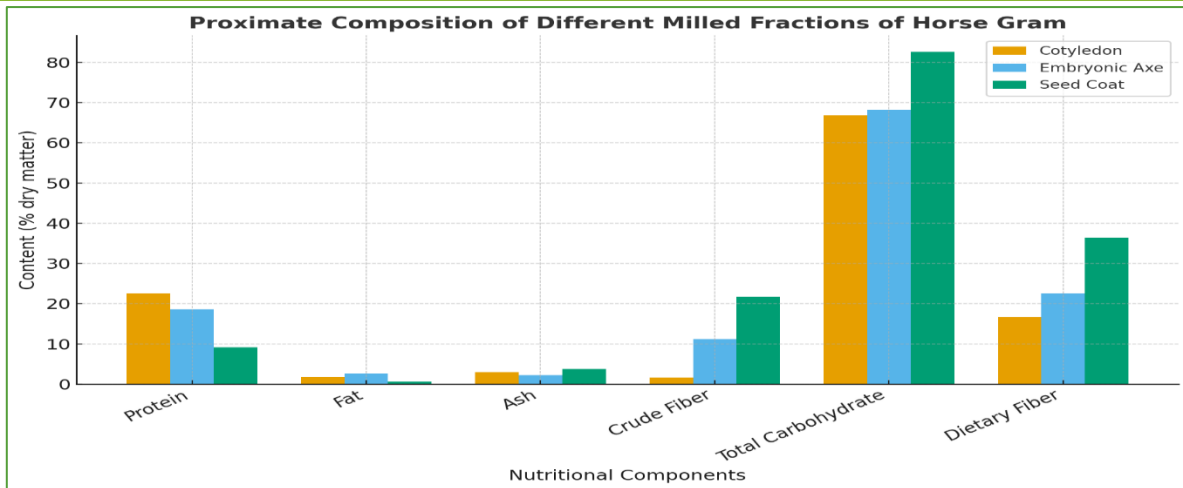


Fig. 2: Proximate Composition of Different Milled Fractions of Horse Gram

Protein Content in Horse Gram

Horse gram contains nearly double the protein of cereals, placing it on par with winged bean (*Psophocarpus tetragonolobus*), soybean (*Glycine max*), and chickpea (*Cicer arietinum*) (Petchiammal & Hopper, 2014). Wild horse gram species, such as *Macrotyloma sar-garhwalensis*, have reported 34–38% crude protein levels, nearly twice that of cultivated lines. Its higher lysine content compared to pigeon pea and chickpea makes it particularly valuable in cereal-based diets that are typically deficient in lysine.

Protein content increases after germination, with levels rising to around 24%, possibly due to biosynthesis during sprouting (Kachave *et. al.*, 2020). This makes horse gram suitable for developing value-added sprouts and fortified foods.

Carbohydrates, Fiber, and Minerals

Horse gram is an excellent source of complex carbohydrates and dietary fiber, contributing to its low glycemic index and benefitting diabetic diets (Sreerama *et. al.*, 2010). Its insoluble fiber improves digestion and prevents constipation, while soluble fiber supports cholesterol reduction. Horse gram is mineral-rich in calcium, iron, phosphorus, and molybdenum, contributing to bone health, hemoglobin synthesis, and enzyme activation.

Phytochemicals and Functional Properties

Horse gram contains several bioactive compounds such as flavonoids, phenolic acids, tannins, and saponins. These phytochemicals contribute to antioxidant, anti-inflammatory, and lipid-lowering effects. Extracts of horse gram seeds and sprouts have been studied for their potential anti-obesity, anti-hyperglycemic, and nephroprotective properties.

Agronomic and Socio-Economic Significance

Horse gram is highly drought-tolerant and requires minimal inputs, making it an ideal crop for resource-poor farmers in marginal environments (Arora *et. al.*, 2011). It improves soil fertility through nitrogen fixation and can be used as green manure. The crop also provides livestock fodder, making it a dual-purpose legume.

Horse gram remains underutilized despite its potential due to a lack of market demand, research investment, and consumer awareness. Promoting value addition, food product diversification, and nutraceutical applications could enhance its role in food and nutrition security.

Conclusion

Horse gram is a nutrient-dense, climate-resilient, and multifunctional legume with tremendous potential to address food and nutritional insecurity, particularly in developing countries. Its rich protein profile, high lysine content, dietary fiber, minerals, and bioactive compounds qualify it as a “superfood.” With proper

promotion, processing innovations, and policy support, horse gram can be repositioned from a neglected crop to a globally relevant functional food legume.

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An Overview on Importance of Human Capital for *Vikshit Bharat, 2047* Skilling-Future Ready Workforce

Article ID: 72056

Smti Porna Sarmah¹

¹SMS, Community Science, KVK, Kokrajhar, AAU, ICAR- ATARI Zone VI.

Introduction

“Viksit Bharat,” translates to “Developed India,” is a vision set forth by the Indian government to transform India into a developed nation by the year 2047, marking the 100th anniversary of its independence.

Vision as a Whole

The vision encompasses a wide range of development aspects, including economic growth, social progress, environmental sustainability, and good governance.

The vision also emphasizes the importance of sustainable development goals, improvements in the ease of living and doing business, enhanced infrastructure, and bolstered social welfare initiatives. It takes into account the emergence of a ‘phygital’ future which describes blending and reshapes digital experiences with physical world.

Viksit Bharat 2047 is not just a catchphrase but represents a complete blueprint for the country’s prosperity and will be a guiding principle for India during its Amrit Kaal as stated by honourable PM of India Narendra Modi g. The government has launched several initiatives to support this vision, focusing on programs such as ‘Made in India’, ‘Digital India’, and ‘Startup India’ to encourage investment, advance economic growth, and foster innovation across various industries.

The vision prioritizes inclusive development and social welfare to ensure everyone benefits from economic progress. Large-scale infrastructure projects are being launched to promote sustainable growth and improve the standard of living for all citizens.

Vision in Terms of Agriculture

Prosperous India in harmony with modern agriculture and giving opportunities to all citizen residing in every region to reach their potential.

Nutritive Components of Horse Gram

Legumes are often called the “poor man’s meat” because of their affordability and high protein levels. Horse gram is particularly significant among legumes because of its dense nutritional composition.

Aim of *Vikshit bharat abhijan*

It aims to elevate India to the rank of the world’s third-largest economy within the next five years, contingent upon the current government’s continued leadership.

Broad Objectives

The core objective of the Viksit Bharat initiative is: To foster inclusive economic participation among all citizens.

Objectives in Terms of Agriculture

1. Access to modern technologies and most lucrative market along with diversification of high value agriculture in line with emerging consumption pattern.
2. To help augment farmer substantially and sustainably for better livelihood.

Focused Target for *Vikshit Bharat* or Four Pillar of *Viksit bharat* -Developed India, 2047

The four pillars or focused target of *Viksit bharat* are:

1. Yuva (Youth)
2. Garib (Poor)
3. Mahila (Women)
4. Kisan (Farmers).

Human Capital for *Vikshit Bharat*, 2047

1. Policy Gaps and Challenges: Focus Area 1: Skilling for All.

a. Key challenges in Skilling and Implementation:

i. Mismatch between Skill and education: Skilled roles in agriculture and allied sector are occupied by underqualified worker informally.

ii. Drudgery Reduction: Women involvement in agriculture is more than man but lack of ergonomically designed tools especially for North-Eastern region is a matter of concern and needs to be address immediately to reduce drudgery in long run.

iii. Lack of Modern agricultural technologies: Agriculture and allied sector suffer from outdated curriculum that lacks modern technologies in agriculture like climate smart practice, use of AI in Agriculture in true sense, precision farming and agri- logistics.

b. Poor penetration in Vocational training: Mismatched between TVET and human needs:

Technical and vocational education and training (TVET) in agriculture and allied sectors are lacking alignment with customers demand and industrial needs. Moreover, the Master trainers/skill personnels are limited and are inaccessible/not known. Moreover ODL (Online Distance learning) does not efficiency works in skill development of workforce. Further, many rural areas especially in tribal districts faces digital inequality and are thus lagging behind.

c. Lack in Research and development: Research must be based on farmers problem which are equally address by many agriculture research institutes. Still innovative and upgraded technologies are limited and hence technologies must be address to unfelt need of the farmers and based on environment demands. Leveraging research in crop yield; development of climate resilient varieties; more innovation in development of Bio- fortified varieties of agriculture and horticulture commodities; development of ergonomically designed farm tools and equipment's for women and old aged; development of farmers friendly food processing equipment and technologies; development of farmers friendly AI tools; tools for non-bio-degradable waste management etc.

d. Less Emphasis on Tertiary agriculture: Least emphasis on Tertiary agriculture or service sector agriculture effects primary and secondary agriculture as it includes repairing of farm machinery; transportation of crop to market or processing facility; advertising and promotion of agriculture products including developed variety to farmers/consumers; implementation of insurance against crop failure in true sense; trade of agriculture goods; banking for farm loan; warehouse facility to store crops etc.

e. Limited policies in Value-added products/Food processing: Inadequate infrastructure, fragmented supply chain, low level of processing of perishable commodities compared to other countries, shortage of practically skilled manpower with technical knowledge and experience poses a challenge to the sector growth; multiple laws and regulation creates confusion and hinders the growth in food processing sectors.

2. Potential Solutions: Focus Area 1: Skilling for All. Key challenges in Skilling and Implementation:

a. Mismatch between Skill and education: Curriculum reform and hand on experience:

Skill gap in agriculture and allied sector demands a multi-pronged approach which mainly focus on aligning education with industrial need. It also fostering collaboration with educational institutes and employees: with industries and employees and with underqualified person with industries or agricultural educational institutes. Further, in KVK, many skills developments training is provided through hand holding by SMS but with very limited facilities/resources. So, in context of gaining practical experience, exposure visit, involvements in internship, apprenticeships and experiential

learning opportunities are a must for underqualified person/MR/school dropout children. Further, designing training programme based on consumer demand and industry needs is vital to uplift Indian economy in terms of agriculture. Moreover, ensuring align with job opportunities and are accessible to wider audience is also a matter of concern. Hence mobile unit facility for service delivery will not only generate employment opportunities but also mitigate the gap between farmers to retailers.

b. Drudgery reduction: Ergonomically designed farm tools/equipment's/ hazards must be addressed in accordance with average anthropometric measurement of North eastern people. As North-eastern people's anthropometric measurement is differing from NE region to NW region. As for example, an average Assamese women hand grip is different from women belongs to Haryana/Panjab. Hence, human workforce may be created to manufacture region wise/ custom wise ergonomically designed agriculture tools and equipments.

c. Lack of Modern agricultural technologies: Young scientific staff and active research scholars from diversified background must be updated and upgraded with scientific knowledge to the developed countries so as to acquire modern agriculture technologies. Further, system may be developed for dissemination of learned technologies immediately to other scientific staff. Emphasis must be given on documentation of learned upgraded technologies through systematic videography.

3. Poor penetration in Vocational training: Mismatched between TVET and human needs: Joint training initiatives with industries, collaborative curriculum development with industry's needs, regular curriculum review; integration of agriculture and allied technologies covering the concept of "farm to plate" must be given during TVET programme. Further, basic emphasis must be given on resource availability of the district/state/region.

4. Lack in Research and development:

a. Precision agriculture and digital platform: Research on implementation of precision agriculture techniques such as using sensor, drones and data analytics not only optimize resource use but also improve efficiency. Development of user-friendly digital platform that farmers access real time information, weather forecast, market prices.

b. Research on development of climate resilient and high yielding crop varieties through biotechnology and genetic enhancement is crucial. Moreover, development of Bio-fortified varieties of cereal crops, vegetables and fruit crop is vital to combat malnutrition and malnutrition.

5. Less Emphasis on Tertiary agriculture:

a. Youth must be provided with skill development training to do minor/major repairing of farm tools and machineries. Provision of mobile repairing service (Vehicle) will not only create employment opportunities but also give door step service delivery.

b. Providing subsidies and incentives for investments in tertiary agricultural activities can encourage private sector participation.

c. Marketing and advertisement of agriculture commodities/varieties etc, a team of youth may be empowered with vocational training through experts belongs to advertising or media agencies/companies.

d. Establishment of post-harvest management and handling training is important to limit food wastage. Hand holding and skill development trainings on post-harvest handling institutes will provide in hand training and build post handling workforce.

6. Limited policies in Value-added products/Food processing:

a. Investment in cold storage, transportation and processing are crucial to reduce wastage and improve efficiency. Skill development training on post-harvest handling and management must be introduced to check wastage.

b. Fostering collaboration and strengthening linkage between farmers, processor and retailers can improve supply chain efficiency and ensure better pricing. Educated youth must be trained skill fully so as to established linkage between diversified sector to a single window.

c. Streamlining regulation: Consolidating and clarifying regulations, potentially through single window clearance system can reduce compliance burden and encourage investment. Farmers/ entrepreneur sometimes discouraged/ demotivated with multiple regulations. Hence educated youth

may be trained so as to facilitate farmers/ entrepreneur and mitigate the gap between farmers to access different policies/regulations.

TURF

Article ID: 72057

Dr. A. Nirmala¹, Dr. K. Aruna²

¹Scientist (Crop production), TRVK, Sangupet

²Scientist (Crop production), TRVK, Sangupet

Professor Jayasankar Telangana Agricultural University, Rajendranagar, Hyderabad.

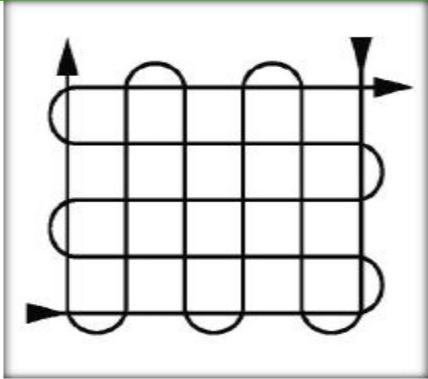
A garden without a lawn is not considered complete. The lawn is a natural green carpet that is an important aspect of a landscape. The soul of every garden is the lawn grass. In India, there are a variety of turf grass species that are grown. plugging, seedling, dibbling, and other procedures (names) can be used to establish turf. Turf has various advantages, like soil erosion management. Sowing, weeding, irrigation, fertilization, coring, drilling, mowing, vertical mowing, rolling, spiking, matting, water injection cultivation, slicing, and application of wetting agents, turf colorant, IPM, plant growth regulators, weed management and other practices should all be done in turf grass management.

Turf Grass Species

S.No.	Botanical name	Common name	Texture	Situation
1.	<i>Cynodon dactylon</i>	Hariyali or arugu or doob grass	Medium fine	Suitable for open sunny location, drought-resistant
2.	<i>Stenotaphrum secundatum</i>	St.augustine or buffalo grass	Coarse fine	Suitable for shady situation, require frequent watering
3.	<i>Sporobolus tremulus</i>	Chain grass or upparugu	Fine	Suitable for saline soil and open sunny locations
4.	<i>Poa annua</i>	Annual blue grass	Medium fine	Suitable for acid soils and suitable for higher elevation
5.	<i>Cynodon sp.</i>	Bermuda or Hyderabad grass	Fine	Suitable for an open sunny situation needs mowing
6.	<i>Agrostis stolonifera</i>	Bentgrass	Fine	Suitable for golf greens and other intensive cultivated areas
7.	<i>Zoysia matrella</i>	Manila grass	Medium	Suitable for open sunny situation

Other Grasses

		
Bent grass	Zoysia	Bandera grass

		
Red fescue	Centipede	Bermuda grass
		
Seedling method	Dibbling	Sprigging
		
Plugging	Hydroseeding	Sodding

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Aquaponics-Based Vegetable Farming: An Innovative Technology for Climate-Smart Urban Agriculture

Article ID: 72058

Aurobinda Behera¹

¹Department of Vegetable Science, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha-751003, India.

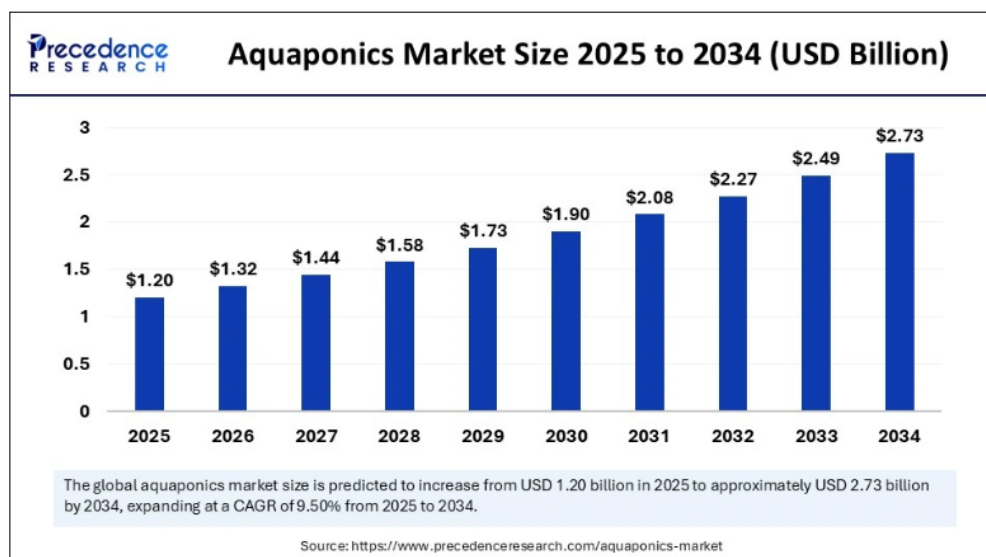
Abstract

Urban areas face growing challenges of food insecurity, limited land availability, water scarcity and high dependence on long supply chains. Aquaponics, an integration of aquaculture (fish rearing) and hydroponics (soil-less vegetable cultivation), offers an innovative and climate-smart approach to sustainable urban farming. The system recycles nutrient-rich wastewater from fish tanks to feed vegetables, while plants naturally filter the water, creating a closed-loop cycle. This minimizes water use by up to 90%, reduces fertilizer dependency and provides dual outputs fish and vegetables from a single system. With increasing interest in rooftop farming, kitchen gardens and peri-urban agriculture in India, aquaponics presents significant opportunities for food and nutritional security, especially in the context of climate change and rapid urbanization. This article explores the principles, advantages, global and Indian progress, challenges and future scope of aquaponics-based vegetable farming.

Keywords: Aquaponics, Urban farming, Vegetable production, Climate-smart agriculture, Resource recycling.

Introduction

Urbanization in India is progressing rapidly with more than 36% of the population already residing in cities (Census of India, 2021). Demand for fresh, safe and locally produced vegetables is rising in parallel with incomes and urban living. According to the Ministry of Agriculture's estimates, India's horticulture output reached about 362 million tonnes in the year 2024-25, marking an increase of ~2.8% over the previous year. Vegetables, being a core part of horticulture, are central to this expansion. Simultaneously, market trends indicate strong growth: the fresh vegetable market is projected to generate revenues of US\$1.36 billion by 2025 with annual growth projected at ~13.7% from 2025-2030. The total production value of vegetables is expected around US\$73.44 billion in 2025. Urban farming innovations are also gaining traction. The vertical farming market in India is estimated to have reached US\$62.21 million in 2024 and is forecast to grow rapidly (CAGR ~21.5%) through 2030. Moreover, projections suggest that by 2025 more than 30% of urban farms will use advanced techniques such as hydroponics, vertical farming or controlled environment agriculture.



In this scenario, aquaponics has emerged as an innovative climate-smart farming solution. It combines fish culture with hydroponic vegetable farming in a mutually beneficial cycle. By recycling fish waste into plant nutrients and purifying water through plant uptake, aquaponics creates a sustainable model for high-density urban vegetable production.

Principles of Aquaponics

Aquaponics operates on a **symbiotic relationship** between fish, plants and microorganisms:

1. **Fish Tanks:** Fish excrete waste rich in ammonia.
2. **Nitrifying Bacteria:** Convert ammonia into nitrates, which serve as plant nutrients.
3. **Hydroponic Beds:** Vegetables absorb nitrates, purifying the water.
4. **Recirculation:** Clean water returns to the fish tanks, completing the cycle.

This closed-loop system requires minimal external inputs and is highly resource-efficient compared to conventional farming.

Advantages of Aquaponics in Urban Vegetable Production

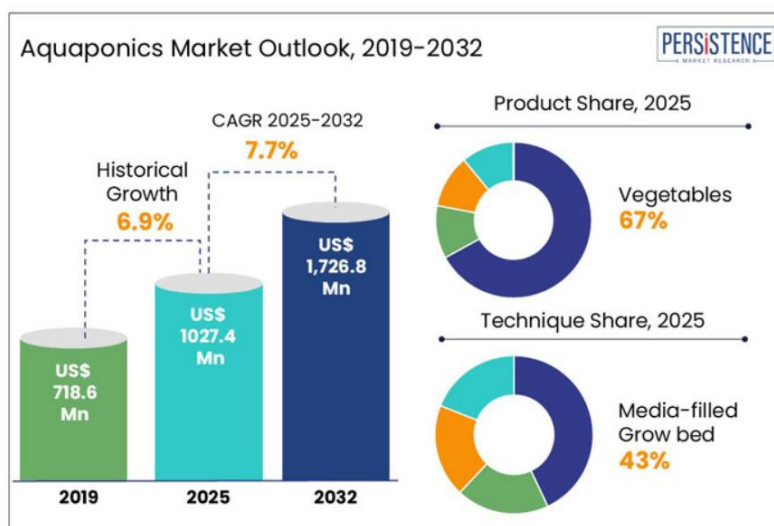
1. **Water Efficiency:** Uses up to **90% less water** than soil-based farming.
2. **Dual Production:** Provides both **vegetables and fish**, enhancing food security.
3. **Space Utilization:** Can be established on rooftops, balconies and urban backyards.
4. **No Soil Requirement:** Eliminates dependency on fertile land, ideal for cities.
5. **Reduced Chemical Use:** Minimal or no synthetic fertilizers and pesticides.
6. **Climate Resilience:** Independent of soil and less affected by erratic weather.
7. **Year-Round Production:** Controlled systems ensure continuous harvests.

Global and Indian Progress in Aquaponics

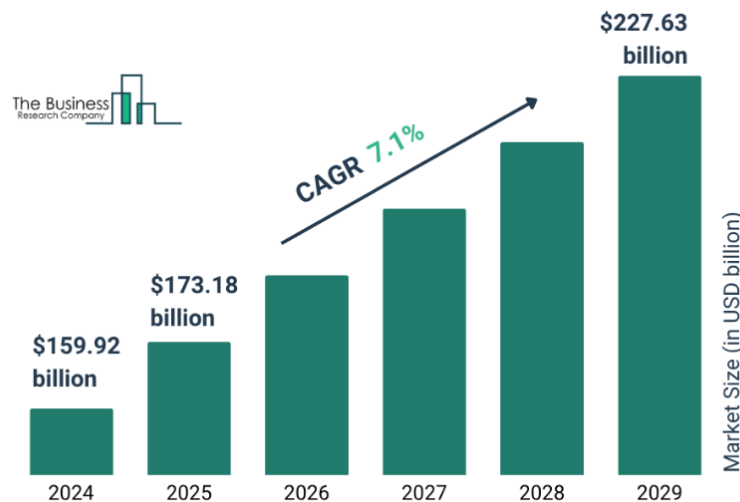
1. **Global Scenario:** Countries like USA, Singapore, Netherlands and Australia have commercial aquaponics farms supplying fresh vegetables to urban markets. Singapore, for example, has integrated aquaponics into high-rise buildings to reduce dependence on imports.

2. **Indian Scenario:** In India, aquaponics is still in a nascent stage but gaining popularity. Start-ups in states like Maharashtra, Kerala, Karnataka and Delhi are promoting rooftop aquaponics for urban households (Singh *et al.*, 2023).

3. **Research Institutions:** ICAR-Central Institute of Freshwater Aquaculture (CIFA), Bhubaneswar, has conducted successful experiments combining carp culture with leafy vegetable production. Private players are experimenting with exotic vegetables like lettuce, kale and herbs under aquaponics for niche markets (Sharma *et al.*, 2021).



Urban Farming Global Market Report 2025



Suitable Vegetables for Aquaponics

Not all vegetables are equally suitable for aquaponics. Best-performing crops include:

- 1. Leafy Vegetables:** Lettuce, spinach, amaranthus, kale, coriander.
- 2. Fruit Vegetables:** Tomato, cucumber, capsicum.
- 3. Herbs:** Mint, basil, parsley.
- 4. Short-Duration Crops:** Okra, chilli, beans in small-scale setups.

Leafy greens are especially suitable due to their fast nutrient uptake and short growth cycles.

Challenges in Adopting Aquaponics

- 1. High Initial Investment:** Setting up tanks, pumps and filtration systems is costly.
- 2. Technical Knowledge:** Requires understanding of both aquaculture and hydroponics.
- 3. Market Limitations:** Awareness among consumers about aquaponics-grown vegetables is still low in India.
- 4. Energy Requirement:** Continuous water circulation and aeration need electricity, though renewable options exist.
- 5. Standardization Issues:** Lack of clear government guidelines, subsidies or certification.
- 6. Risk of Imbalance:** Poor management can lead to fish mortality or plant nutrient deficiency.

Future Thrust for India

- 1. Policy Support:** Government should integrate aquaponics under urban agriculture and smart city programs.
- 2. Capacity Building:** Training through KVKs, ICAR institutes and universities to develop skilled manpower.
- 3. Start-up Ecosystem:** Promote entrepreneurship by providing financial incentives, incubation and credit access.
- 4. Renewable Integration:** Use of solar-powered pumps and low-cost sensors to reduce energy dependence.
- 5. Community Aquaponics Models:** Shared rooftop and peri-urban aquaponics farms can supply fresh vegetables to housing societies and urban markets.
- 6. Research Priorities:** Developing low-cost indigenous aquaponics models suitable for Indian vegetables like brinjal, okra and spinach.

Conclusion

Aquaponics offers a transformative pathway for climate-smart urban agriculture. By integrating fish and vegetable production in a closed-loop system, it provides sustainable, space-efficient and resource-conserving solutions for cities struggling with land and water scarcity. For India, where urban populations are projected to reach 50% by 2050, aquaponics can become a pillar of urban food security. With proper policy support, start-up promotion and public awareness, aquaponics-based vegetable farming can shift from being a niche innovation to a mainstream practice. It not only ensures fresh, chemical-free vegetables for urban consumers but also contributes to climate resilience and circular resource management making cities greener, healthier and self-reliant.

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Nutritional Composition and Health Benefits of Roasted Yellow Peas

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T. Thilagavathi¹, N. Prabhavathy Devi²

^{1&2}Department of Nutrition and Dietetics, Meenakshi College of Arts and Science Meenakshi Academy of Higher Education and Research, Chennai, India.

Abstract

In South India, roasted yellow peas, also known as pattani, are becoming more and more well-liked as a wholesome snack that is high in dietary fibre, vitamins, minerals, and plant-based protein. They belong to the legume family and offer a variety of health advantages, including blood sugar regulation, weight management support, cardiovascular protection, and digestive support. This article highlights their importance in both traditional and modern diets while also examining their nutritional makeup and health benefits.

Keywords: Roasted yellow peas, nutrition, health benefits.

Introduction

One of the earliest legumes to be grown, peas (*Pisum sativum*) are now a staple food in many countries. They belong to the Fabaceae family and are valued for their superior plant protein in addition to their flavour. Fresh, dried, or processed into products like split peas, pea flour, and pea protein isolates are some of the ways that people enjoy peas. They are important to sustainable agriculture because of their adaptability to different soil types and climates.

Peas are a great source of protein, dietary fibre, a variety of vitamins, including vitamin C and the B vitamins, and vital minerals, including potassium, magnesium, and iron. They are regarded as a healthy option because they are low in fat and cholesterol, which is especially beneficial for weight management and heart health.

Peas are a great source of dietary fibre, which helps improve gut microbial composition and provide a host of health benefits. They are also an excellent source of vitamins like folic acid and carotenoids, as well as minerals like calcium, iron, and zinc. In many parts of Asia and India, roasted yellow peas are a common snack.

They are very popular because of their crispy texture, reduced fat content, and great satiety. In addition to its cultural significance, pattani, which is traditionally used in recipes like sundal or eaten plain as a roasted snack, is becoming more well-known for its health advantages (Mudryj et al., 2014).

Packed with vitamins, dietary fibre, and vital minerals like potassium, magnesium, and iron, roasted yellow peas are a plant-based protein powerhouse. These wholesome peas are a favourite snack for people who are concerned about their health because they help maintain intestinal health and satisfy hunger. According to Singh et al. (2017), because of their low glycaemic index, legumes including peas are not only inexpensive protein sources but also useful for controlling blood sugar levels and reducing cardiovascular risks.

Roasted peas' high protein, fibre, vitamin, mineral, and phytochemical content offers a host of nutritional benefits. These components have anti-cancer and antioxidant qualities, improve digestion, lower blood sugar, and may also help lower cholesterol.

Roasted peas provide numerous health advantages, such as aiding in weight management, promoting digestive health, and regulating blood sugar levels, thanks to their substantial fiber and protein content.

Furthermore, they serve as a rich source of antioxidants that assist in safeguarding the body from harm. Consuming roasted peas can support cardiovascular health by reducing cholesterol and blood pressure levels. Moreover, they represent an important plant-based source of both protein and iron.

Pattani has retained its cultural significance in traditional Indian households, where it is regularly served at festivals or used in offerings. By fostering nutty undertones and reducing anti-nutritional components like phytic acid, toasting enhances flavour. In the business world, roasted pattani is increasingly widely available in supermarkets and is being marketed as a healthy alternative to fried snacks.

Nutritional Composition

Yellow peas are a nutrient-dense meal that outperforms many other legumes with a protein content of almost 25%. Additionally, they are abundant in vitamins A, C, and K, along with vital minerals such as iron, magnesium, phosphorus, and potassium (greg.app). Roasted yellow peas are a dense source of essential nutrients. Nutritional Composition of roasted yellow peas showed in Table 1.

Nutritional composition of roasted yellow peas (per 100 grams):

Nutrient	Amount
Calories	350–400 kcal
Protein	20–25 g
Carbohydrates	55–60 g
Dietary Fiber	15–20 g
Fat	1–2 g
Iron	4–6 mg
Magnesium	50–80 mg
Potassium	600–900 mg
Calcium	30–50 mg
Folate (Vitamin B9)	100–150 µg

Source: Mudryj *et al.*, 2014

Nutritional Benefits of Roasted Peas

As a high source of fibre, plant-based protein, and several vitamins and minerals, roasted peas offer a number of nutritional benefits. Additionally, they can help maintain heart health, control blood sugar, and support digestive wellness. Additionally, roasted peas may help with weight management because they contain antioxidants.

Fiber Composition: Dietary fibre, which is abundant in roasted peas, facilitates digestion by making sure that food passes easily through our digestive tract. Additionally, by providing sustenance for beneficial bacteria, the fibre content promotes a healthy gut flora.

Protein: Peas are a great plant-based protein source that is on par with some meat and fish alternatives, which makes them a great snack option for vegans and vegetarians alike. In addition to providing a sustained feeling of fullness, protein is essential for muscle growth and repair, which can help with weight management.

Vitamins and Minerals: A number of vitamins, including A, C, and B vitamins, as well as vital minerals like potassium, magnesium, and iron, are abundant in peas. Numerous body processes, including heart health promotion, immune response enhancement, and vision support, depend on these nutrients. Iron is required for the production of blood cells, vitamins C and A aid in cellular defence, and B vitamins are essential for energy metabolism.

Antioxidants: Flavonoids and carotenoids, especially polyphenolics, are among the many antioxidants found in peas that can help protect the body from damage caused by free radicals and may also have anti-inflammatory qualities.

Phytochemicals: Phytochemicals such polyphenolics, saponins, and galactose oligosaccharides, which are abundant in peas, have prebiotic, anti-cancer, and antioxidant properties.

Health Benefits of Roasted Yellow Peas

Regulation of Blood Sugar: Roasted peas' fibre and protein help control blood sugar, which makes them a great snack for diabetics or anybody looking to maintain steady energy levels. Peas' slow-digesting carbs and fibre content may improve blood sugar management. Furthermore, pea starch's moderate amylose content lowers its glycaemic index, which can help regulate blood sugar levels (Rankel, 2024).

Heart Health: Rich in fibre, potassium, and antioxidants, green peas promote cardiovascular health by lowering the risk of heart disease, regulating blood pressure, and lowering cholesterol. Peas' antioxidant, potassium, and magnesium properties aid in blood pressure regulation and cell damage prevention. Furthermore, minerals like potassium and magnesium may help lower blood pressure, and the omega-3 and omega-6 fatty acids in peas can reduce inflammation and plaque accumulation. According to Anderson et al. (2009), incorporating legumes like peas into your diet on a regular basis may help lower LDL (bad) cholesterol.

Cancer Protection: Studies suggest that the antioxidants included in peas may provide a preventive effect against certain forms of cancer.

Digestive Health

The high fiber content in peas supports a healthy digestive system by facilitating digestion, preventing constipation, and encouraging regular bowel movements (Ferreira et al., 2021).

Weight Management: Peas can improve feelings of fullness and help with weight management because they are high in fibre and low in calories. Roasted peas' dietary fibre and protein content encourage fullness, which may lessen overindulgence and help with weight management (Mollard et al., 2011).

Bone and Muscle Support: Roasted peas contain minerals like calcium, phosphorus, and magnesium that are essential for sustaining muscular function and bone density, especially for active people and older ones (Rankel, 2024).

Immune Support: Vitamins and minerals, such as zinc and vitamin C, which are vital for strengthening the immune system and preventing infections, are abundant in peas.

Brain Health: Choline, a vitamin that is important for brain health and cognitive function, is abundant in peas.

Eye Health: Peas include antioxidants called lutein and zeaxanthin, which are good for the eyes and may help prevent age-related macular degeneration.

Details Regarding Roasted Peas: The nutritional composition of peas may be slightly altered by roasting, however the beneficial chemicals present are not greatly reduced. Roasted peas are a great and easy snack option, especially for people who prefer a crunchier texture.

Considerations: Although roasted peas can make a healthy snack, it's important to watch how much salt and oil are used throughout the roasting process. Choose healthier oils and try to limit your intake of sodium.

Conclusion

In summary, roasted peas are a versatile and wholesome snack that offers a host of health benefits. They are an excellent complement to a well-rounded diet because of their high fibre and protein content as well as essential vitamins and minerals. Roasted peas can improve general health and wellness whether they are eaten by themselves or combined with other foods.

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Metarhizium anisopliae: A Technical Review - Biology, Mode of Action, Production and Use as a Biocontrol Agent

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S. S. Band¹, A. D. Matte²

¹Assistant Professor of Agricultural Entomology, College of Agriculture, Muktainagar, Dist. Jalgaon, Maharashtra, India, 425 306.

²Assistant Professor of Agricultural Entomology, DUPCA, Jalgaon, Dist. Jalgaon, Maharashtra, India, 425 306.

Introduction

Metarhizium spp. (Hypocreales: Clavicipitaceae) are soil-borne fungi that parasitize arthropods. *M. anisopliae* has been developed into commercial mycoinsecticide formulations because it can infect many insect orders and offers an environmentally friendlier alternative to many chemical insecticides. Its roles extend beyond insect pathogenesis - some strains are rhizosphere-competent and can act as plant endophytes, contributing to integrated pest management strategies. *Metarhizium anisopliae* is a widely studied entomopathogenic ascomycete used as a mycoinsecticide for control of a broad range of arthropod pests. This review summarizes taxonomy and morphology, infection cycle and virulence determinants (enzymes, Destruxin, immune-evasion proteins), genomic insights, production and formulation approaches, field application considerations, safety/non-target issues, and current challenges and opportunities for improved deployment (Mesquita et al., 2023).

Taxonomy and Morphology

1. Taxonomy: *Metarhizium anisopliae* (Metschnikoff) Sorokin — a species complex with closely related species (e.g., *M. robertsii*, *M. acridum*). Molecular phylogenetics has refined species delimitations within the genus; historically many isolates labelled *M. anisopliae* have been reclassified (Pattemore et al., 2014).

2. Morphology: Conidiophores bearing phialides that produce elongated, single-celled conidia (oval to cylindrical). Colonies often show characteristic olive-green to dark green conidial mats on agar; infected insect cadavers typically appear “green muscardine” due to conidial sporulation.

Infection Cycle and Pathogenic Mechanisms

The infection of an insect host by *M. anisopliae* is a multistep process:

1. Attachment & germination: Conidia adhere to cuticle surfaces; under favorable humidity/temperature they germinate and form an appressorium or penetration peg.

2. Cuticle penetration: A mixture of mechanical pressure and an array of cuticle-degrading enzymes (proteases, chitinases, lipases) allow penetration through the integument (Schrack & Vainstein, 2010a).

3. In vivo proliferation: Once in the hemocoel, hyphal bodies proliferate in the hemolymph. The fungus produces secondary metabolites (notably destruxins) that disrupt host physiology and suppress immune responses. Mcl1 (a collagen-like surface protein) and other surface factors help mask the fungus from immune recognition (Aw & Hue, 2017).

4. Host death and sporulation: After killing the host (hours to days, depending on dose, strain and host species), the fungus often emerges from the cadaver and forms abundant conidia to continue transmission.

Key experimental and review studies describe these steps in detail and identify destruxins and secreted enzymes as important virulence determinants (Aw & Hue, 2017).

Virulence Determinants — Destruxins and Proteins

1. Destruxins: Cyclic hexadepsipeptides produced by many *Metarhizium* isolates; they have insecticidal activity, perturb ion channels and cellular signaling, and suppress humoral and cellular immune responses

in insects. Biosynthetic gene clusters for destruxins have been characterized in *Metarhizium* species (work on destruxin biosynthesis elucidates key PKS/NRPS pathways) (Wang et al., 2012).

2. Enzymes and surface proteins: Secreted proteases and chitinases are central to cuticular degradation; Mcl1 and similar proteins contribute to immune evasion. The combination of enzymatic degradation and toxin-mediated immune suppression allows successful systemic infection (Schrank & Vainstein, 2010b).

Genomics and Molecular Tools

Genome sequencing and comparative transcriptomics of *M. anisopliae* (and comparison to host-specialist species such as *M. acridum*) have revealed gene families associated with host range, cuticle-degrading enzymes, secondary metabolite clusters, and factors related to environmental persistence. These genomic resources underpin strain improvement, molecular diagnostics, and identification of genetic determinants of virulence and environmental fitness (Gao et al., 2011).

Mass Production, Formulation and Shelf Life

1. Production: Solid (rice/grain) and liquid fermentation methods are used to mass-produce conidia. Process optimization (substrate, aeration, temperature) aims to maximize sporulation, conidial yield and viability.

2. Formulation: Formulations include wettable powders, oil-based suspensions, granules, and microencapsulation. Oils, stickers and adjuvants improve adhesion to insect cuticle and reduce UV/desiccation damage. Field performance depends on formulation stability, conidial viability under storage and environmental stressors. Comparative reviews summarize commercial *Metarhizium* products and field-testing results (Sullivan et al., 2022).

Field Application and Efficacy

Efficacy in the field is influenced by environmental variables (temperature, humidity, UV exposure), application method (foliar spray, soil drench, baiting), target pest biology and timing. *Metarhizium* is particularly effective for soil-dwelling stages (larvae, grubs, wireworms) and for certain hemipteran and coleopteran pests. Integration with other IPM measures (reduced pesticide residues, habitat management) improves establishment and control. Recent field reviews and meta-analyses report promising but variable efficacy depending on context (Mesquita et al., 2023).

Non-Target Effects and Safety

Historically, EF-based entomopathogens like *M. anisopliae* are considered low risk to vertebrates, many beneficial arthropods, and humans — but risk assessments are strain-specific. Reported safety evaluations conclude minimal risk under proper use, although caution is warranted regarding immunocompromised individuals and occupational exposure during manufacturing and application. Regulatory dossiers for marketed strains include detailed toxicology and non-target testing (Schrank & Vainstein, 2010a).

Challenges, Resistance and Environmental Interactions

1. Environmental persistence: Soil microbial communities, fungistasis and abiotic stresses may reduce establishment and resporulation of applied conidia. Encapsulation and nutrient amendments have been explored to improve persistence.

2. Resistance: Insect populations can show varying susceptibility; rotation and IPM reduce selection pressure.

3. Regulatory & commercialization hurdles: Strain identification, consistent production quality, and field efficacy under diverse agroecosystems remain practical barriers. Comprehensive lists and comparative performance of commercial *Metarhizium* products have been published (Sullivan et al., 2022).

Future Directions

1. Strain improvement and precision deployment: Genome-informed selection and molecular markers for high-performing, ecologically safe strains (Gao et al., 2011).

2. Formulation science: Improved UV-protective, moisture-retentive formulations and delivery systems (granules, alginate beads, seed coatings).

3. Integration with microbial consortia / endophytism: Exploiting rhizosphere/endophyte traits for plant health and systemic pest suppression (Mesquita et al., 2023).

4. Regulatory harmonization and farmer adoption research: To scale use while ensuring environmental safety and consistent efficacy (Sullivan et al., 2022).

Conclusion

Metarhizium anisopliae represents one of the most versatile and extensively studied entomopathogenic fungi, offering a sustainable and ecologically safe alternative to conventional chemical insecticides. Its broad host range, well-characterized infection mechanisms, and ability to function both as an insect pathogen and as a rhizosphere/endophytic associate underline its importance in integrated pest management. Advances in genomics have deepened understanding of virulence determinants, host adaptation, and environmental persistence, paving the way for targeted strain selection and improvement. Despite challenges related to field variability, environmental constraints, and regulatory hurdles, progress in formulation technologies and mass production continues to enhance efficacy and stability. Future research focusing on precision deployment, microbial consortia, and farmer-centric adoption strategies will be critical to fully harnessing the potential of *M. anisopliae*. Overall, this fungus stands as a promising tool for sustainable crop protection, aligning agricultural productivity with environmental safety.

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Heat-Proof Crops: Building Resilience for a Warming World

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G. S. Madhu Bindu¹, M. Madhavi¹, V. Ramya¹, I. Shakuntala Devi¹, K. Charanteja¹

¹Professor Jayashankar Telangana Agricultural University.

Summary

Facing the critical threat of climate change to global food security, the development of heat-proof crops is imperative. This effort employs a dual strategy of genetic innovation, such as genomics-assisted breeding and CRISPR gene editing to enhance thermal tolerance and photosynthesis coupled with adaptive agronomic practices like priming techniques, optimized irrigation, and crop diversification. These approaches are exemplified by the successful development of resilient varieties of staple crops like wheat and inherently hardy cereals such as sorghum. Overcoming barriers to adoption requires integrated efforts in research, policy, and farming support to deploy these vital crops, ensuring a sustainable and secure food supply for a warming world.

Introduction

Climate change, driven by rising global temperatures and extreme weather, severely threatens agricultural productivity and global food security. The development and deployment of heat-proof crops/varieties engineered or bred to withstand high-temperature stress are critical for adaptation. These crops represent a proactive approach to ensuring a stable food supply for a growing global population (Kole *et al.*, 2015; Cavanagh and Matthews, 2025).

The Need for Heat Resilience

Heat waves disrupt essential physiological processes like photosynthesis and reproduction, drastically reducing the yield and quality of staple crops such as wheat and maize. This challenge is most acute in regions where agriculture is the primary livelihood and food security is already precarious. Developing climate-resilient crops is therefore a fundamental strategy to prevent food insecurity caused by climate-related yield losses (Bamniya *et al.*, 2024).

Key Strategies for Development

A multi-faceted approach is essential for creating effective heat-tolerant crops.

1. Genetic and Molecular Innovations:

- a. Genomics-Assisted Breeding (GAB):** This approach uses genetic markers to rapidly identify and select heat-tolerance traits from wild relatives and cultivated crops, significantly accelerating traditional breeding programs (Kole *et al.*, 2015).
- b. Gene Editing:** Technologies like CRISPR allow for precise modifications to introduce heat tolerance, such as enhancing the production of protective heat shock proteins (HSPs) that stabilize cellular structures.
- c. Enhancing Photosynthesis:** Scientists are working to improve the heat tolerance of photosynthesis by optimizing key components like the Rubisco enzyme, which is crucial for carbon fixation but becomes inefficient at high temperatures (Cavanagh and Matthews, 2025).

2. Agronomic and Systems Approaches:

- a. Thermotolerance Priming:** Pre-exposing plants to mild stress "primes" them for a more robust response to future heat events. This can be achieved through chemical treatments, beneficial microbes, or controlled heat exposure.
- b. Agronomic Adaptations:** Modifying farming practices is crucial. This includes adjusting planting dates to avoid peak heat, using efficient irrigation (e.g., drip) and mulching to conserve water, and improving soil health to enhance resilience (Vala *et al.*, 2024).

c. Crop Diversification: Shifting towards naturally resilient crops like pearl millet and sorghum reduces risk and enhances overall system stability compared to relying on a few heat-sensitive staples.

Promising Examples

- 1. Wheat:** Heat-tolerant varieties have been developed that can increase yields by 8-12% under stress conditions.
- 2. Pearl Millet & Sorghum:** These cereals are inherently resilient to heat and drought, making them vital for food security in vulnerable regions.
- 3. Soybean & Horticultural Crops:** Research is focused on identifying heat-tolerant genotypes to protect key sources of protein, oil, and nutrition.

Challenges and Future Directions

Significant barriers remain, including high costs, knowledge gaps, and policy limitations that slow adoption, especially in resource-poor settings. The complexity of heat tolerance, governed by many genes and environmental interactions, requires interdisciplinary collaboration. Strengthening extension services, farmer education, and global research partnerships is critical.

Future Research Should Focus on

- 1. Exploring wild relatives:** Mining their valuable stress-tolerance genes for introgression into cultivated varieties.
- 2. Understanding circadian biology:** Investigating how the plant's internal clock regulates responses to temperature fluctuations (de Leone *and Yanovsky*, 2024).
- 3. Harnessing metabolomics:** Identifying metabolic biomarkers and regulatory hubs linked to stress tolerance for breeding (Guchowska *et al.*, 2025).
- 4. Promoting Climate-Smart Agriculture (CSA):** Implementing CSA frameworks and policies to support sustainable adoption (Vala *et al.*, 2024).

Public-private partnerships are essential to mobilize resources and scale up these innovations.

Conclusion

The development of heat-proof crops is a vital step toward building agricultural systems resilient to climate change. Through a combination of innovative science, supportive policies, and farmer-centric approaches, these crops can help sustain and increase productivity, ensuring global food security in a warming world. Continued investment in research and adoption is crucial for a sustainable future.

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Five Modern Garden Pathway Designs to Try

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T. Navya Swetha¹

¹Assistant Professor, SKLTGHU, College of Horticulture, Mojerla, Floriculture and Landscaping.

A well-designed garden pathway does more than provide a functional route through your yard—it sets the tone for your garden, guiding visitors while enhancing the overall aesthetic. Modern garden pathways combine style, creativity, and functionality, transforming ordinary gardens into visually striking spaces. Whether your outdoor area is small or expansive, pathways can be designed to reflect contemporary trends while complementing plants, lighting, and outdoor décor. This guide explores **five modern garden pathway designs** you can try, offering inspiration, design tips, and practical advice for creating a stunning garden walkway.

Why a Modern Garden Pathway Matters?



Before diving into specific designs, it's important to understand the benefits of a modern garden pathway:

- a. Enhances Visual Appeal:** Pathways create a structured, polished look in your garden.
- b. Guides Movement:** Directs visitors naturally and safely through different garden areas.
- c. Protects Plants:** Prevents foot traffic from damaging flower beds or lawns.
- d. Adds Dimension:** Different shapes, textures, and materials can add depth and interest.
- e. Boosts Property Value:** Well-designed pathways elevate the overall curb appeal of your home.
- f. Integrates Functionality and Style:** Pathways can double as seating areas, decorative features, or outdoor lighting displays.

With careful planning, modern pathways can merge functionality and artistry, making your garden an inviting retreat.

1. Stepping Stone Pathways: Stepping stones are a classic choice that can be modernized with creative layouts, materials, and spacing.



How to Create a Stepping Stone Pathway:

- a. Materials:** Concrete, natural stone, slate, or large tiles can be used.
- b. Layout:** Place stones in straight lines for a minimalistic look, or stagger them for a natural, flowing design.
- c. Spacing:** Leave enough space between stones for grass or low ground cover to grow.
- d. Ground Cover Options:** Moss, thyme, or creeping sedum creates a soft, green contrast around the stones.

Benefits: Steppingstone pathways are versatile, easy to install, and ideal for gardens with small spaces or irregular shapes.

2. Gravel and Pebble Pathways: Gravel pathways are durable, low-maintenance, and offer a contemporary, textured look. They are perfect for minimalist or Japanese-inspired gardens.



How to Build a Gravel Pathway:

- a. Base Layer:** Lay a weed barrier or landscape fabric to prevent weed growth.
- b. Gravel Layer:** Add a 2–3 inch layer of crushed stone or gravel.
- c. Borders:** Use metal, wood, or stone edging to define the pathway and prevent gravel migration.
- d. Decorative Touch:** Mix different colored pebbles or stones for a visually appealing pattern.

Benefits: Gravel paths are cost-effective, drain well, and can be installed in curved or linear designs.

Design Tip: Combine gravel with large stepping stones for added dimension and a contemporary feel.

3. Wooden Boardwalk or Decking Pathways:



Steps to Create a Wooden Pathway:

- a. Material Choice:** Use weather-resistant woods like teak, cedar, or composite decking.
- b. Support:** Install a stable base with gravel or concrete piers for durability.
- c. Spacing:** Leave small gaps between boards for water drainage and expansion.
- d. Finishing Touches:** Apply sealant or wood stain to enhance longevity and aesthetics.

Benefits: Wooden pathways create a natural, warm feel while providing a smooth, modern surface.

Design Tip: Mix horizontal and vertical plank orientations for a contemporary, patterned look.

4. Geometric or Mosaic Pathways: Geometric and mosaic pathways make a bold statement and are perfect for modern or artistic garden designs.



How to Design a Geometric Pathway:

- a. Materials:** Use tiles, pavers, concrete slabs, or stones in varied shapes like hexagons, triangles, or squares.
- b. Pattern Options:** Try herringbone, chevron, or interlocking geometric patterns.
- c. Colors:** Incorporate contrasting colors for a striking visual effect, or neutral tones for a sleek minimalist look.
- d. Installation:** Lay tiles or pavers on a compacted sand base, and fill gaps with sand or mortar.

Benefits: Geometric pathways are eye-catching, customizable, and complement contemporary garden décor.

Design Tip: Combine small mosaic tiles with larger pavers to create texture and depth.

5. Green or Grass Pathways: Grass pathways are a simple yet modern approach, blending functionality with a lush, natural aesthetic.



How to Create a Grass Pathway:

- a. Design:** Outline the path with edging to define the space and prevent grass from spreading.
- b. Hardscape Integration:** Combine grass with stone, gravel, or wood to create a hybrid modern look.
- c. Plant Choice:** Use hardy turfgrass or low-growing ground cover for a soft walking surface.
- d. Maintenance:** Mow regularly and trim edges to keep the path neat.

Benefits: Grass pathways provide a soft, eco-friendly surface and blend seamlessly with the surrounding landscape.

Design Tip: Curved grass pathways with irregular steppingstones create a natural, flowing design.

Tips for Designing a Modern Garden Pathway

- 1. Plan Your Route:** Consider the natural flow of your yard and traffic patterns.
- 2. Choose Complementary Materials:** Match pathway materials with garden style, plants, and furniture.
- 3. Incorporate Lighting:** Add solar lights, lanterns, or LED strips for nighttime visibility and ambiance.
- 4. Add Borders:** Edging with stones, metal, or plants keeps pathways defined and neat.

- 5. Mix Textures:** Combine wood, stone, gravel, or greenery to create depth and interest.
- 6. Consider Drainage:** Ensure pathways are slightly raised or sloped for water runoff.
- 7. Include Rest Spots:** Integrate benches or small seating areas along longer pathways.
- 8. Seasonal Appeal:** Use perennial plants or ground covers that look attractive year-round.
- 9. Keep It Safe:** Smooth surfaces for walking and non-slip finishes for wet areas.
- 10. Personalize:** Add sculptures, planters, or decorative stones to make the pathway unique.



These design tips ensure that your modern garden pathway is both functional and visually appealing.

Benefits of Modern Garden Pathways

- 1. Enhances Curb Appeal:** Pathways make gardens look more organized, stylish, and inviting.
- 2. Defines Space:** Creates clear divisions between flower beds, lawns, and functional areas.
- 3. Increases Property Value:** Well-designed pathways are attractive to potential buyers.
- 4. Encourages Exploration:** Guides visitors and family members through different garden features.
- 5. Supports Sustainable Gardening:** Gravel, permeable pavers, and green pathways help manage water runoff.

Modern garden pathways balance aesthetics and practicality, elevating the overall design of your outdoor space.

Conclusion

Creating a modern garden pathway is a rewarding way to transform your outdoor space. From steppingstones and gravel pathways to wooden boardwalks, geometric designs, and lush grass paths, each option provides a unique combination of style, functionality, and charm.

When planning your pathway, consider your garden layout, the materials you prefer, and the type of plants you want to integrate. Combining texture, color, and creativity ensures that your pathway becomes a striking feature that enhances both movement and aesthetics.

Whether you want a minimalist steppingstone trail, a geometric mosaic walkway, or a soft green path through your yard, modern garden pathways allow you to make a lasting impression while optimizing your outdoor space. With careful planning and design, your garden pathway can become a central element of your landscape, guide visitors and creating a serene, visually stunning environment for all seasons.

Drip Irrigation and Fertigation Effects on Fruit Yield and Quality

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K. Venkata Ramudu¹

¹Horticulture Assistant, Department of Horticulture, Andhra Pradesh-518222.

Abstract

Drip irrigation offers one of the most efficient methods for utilizing both water and fertilizers. By wetting only a limited portion of the soil, trickle irrigation restricts the active root zone and reduces the plant's ability to forage extensively for nutrients and water. To address this limitation while also reducing irrigation and fertilizer costs, the integration of fertigation with drip systems is considered highly effective. Fertigation provides several benefits: nutrients are supplied directly in available forms to the root zone, water and fertilizer use efficiency are improved, nitrogen leaching losses are minimized, and the nutrient concentration in the soil solution can be better managed. In addition, the overall cost of nutrient application is reduced. These combined advantages make fertigation an important practice under drip irrigation, contributing significantly to yield improvement in many fruit and field crops.

Introduction

Drip irrigation, also referred to as trickle or micro irrigation, is a highly efficient method that applies water slowly and directly to the crop root zone. Compared with overhead or furrow irrigation, drip systems typically use less than half the amount of water and can achieve over 90% efficiency. In contrast, sprinkler systems generally operate at only 50–70% efficiency. This high efficiency is attributed to several factors: water is absorbed into the soil before it can evaporate or run off, water is applied precisely where needed near the plants rather than across the entire field, weed growth is minimized, and reduced water contact with stems, leaves, and fruits helps create less favorable conditions for diseases.

Drip irrigation is widely used for perennial crops like vines and trees where individual emitters are placed at the base of each plant. However, because of the high capital investment required for installation, the system is most often adopted in high-value crops. Suitability varies with soil type: clay soils need slow water application to prevent ponding and runoff, while sandy soils require higher emitter discharge rates to ensure adequate lateral spreading of water.

When combined with fertigation, drip irrigation enhances nutrient delivery directly to the root zone. This integration not only improves water and fertilizer use efficiency but also promotes better crop growth, higher yields, and improved quality in a wide range of fruit crops.

Fertigation refers to delivering fertilizers through irrigation water. Although it can be practiced with different irrigation methods, drip irrigation is the most widely used in fruit cultivation. This system, however, demands greater technical knowledge to manage effectively.

Water scarcity and the high cost of fertilizers are two of the biggest challenges faced by fruit growers today. Fortunately, modern farming practices like drip irrigation and fertigation are helping farmers save resources, increase yields, and improve fruit quality. Research across different fruit crops shows that these technologies not only conserve water and reduce fertilizer losses but also deliver higher profits to farmers.

Advantages of Drip Irrigation

1. Ensures maximum utilization of available water resources.
2. Limits water supply to weeds, thereby suppressing their growth.
3. Helps achieve higher crop yields.
4. Enhances the efficiency of fertilizer usage.
5. Minimizes weed growth and reduces the population of potential pest hosts.
6. Requires less labor and has relatively lower operating costs.
7. Prevents soil erosion.

8. Improves water infiltration in soils with low intake capacity.
9. Easily adaptable to advanced automatic control systems.
10. Prevents fertilizer runoff into groundwater.
11. Reduces evaporation losses compared to surface irrigation methods.
12. Aids in better seed germination.
13. Decreases the need for frequent tillage operations.

Disadvantages of Drip Irrigation

1. Prone to clogging of emitters and pipes.
2. May cause uneven moisture distribution in the soil.
3. Can lead to salinity problems over time.
4. Installation costs are higher compared to furrow irrigation.
5. Requires skilled design, installation, and management for efficient operation.

Smarter Water Use in Fruits

Drip irrigation delivers water directly to the root zone of plants, minimizing evaporation losses and ensuring that every drop counts. Studies on sapota, mango, guava, and banana have shown that crops grown under drip systems require much less water compared to traditional irrigation, while yields remain consistently higher. For instance, banana under drip fertigation at 75% of the recommended fertilizer dose recorded the highest yield and water-use efficiency, proving that “less can sometimes be more.” Similarly, in sapota, drip irrigation with plastic mulch increased yields by over 21% compared to ring-basin irrigation.

Fertigation: Feeding Crops the Smart Way

Fertigation, which means delivering water-soluble fertilizers through drip irrigation, ensures that nutrients are supplied exactly where plants need them. Research has repeatedly shown its benefits:

In pomegranate, replacing conventional fertilizer application with fertigation increased yields to 11.88 t/ha, while saving up to 30% fertilizer. In guava, 75% fertigation combined with 75% irrigation improved flowering, fruit set, and boosted yields to nearly 30 t/ha. In apples, fertigation increased yield by 13%, fruit hardness by over 10%, and sugar content by 7%. What makes fertigation even more attractive is its cost-effectiveness. One study reported a benefit-cost ratio of 3.21 in pomegranate at 80% fertigation with water-soluble fertilizers—meaning every rupee invested returned more than triple in profit.

Quality and Quantity Together

A major concern for farmers is not only how much fruit they produce, but also the quality of that fruit. Fertigation has proven to enhance both. In papaya, fertigation with nitrogen and potassium encouraged early flowering, increased fruit numbers, improved sweetness (TSS), and even reduced fruit cavity index. In litchi and guava, fertigation boosted fruit size, weight, vitamin C levels, and sugar content. Grape studies also showed significantly higher yields when 125% fertigation was applied using water-soluble fertilizers.

Saving Fertilizer, Labor, and the Environment

By precisely dropping nutrients into the soil near roots, fertigation cuts down wastage, reduces leaching of nitrogen into groundwater, and saves on labor costs. In pomegranate, fertigation at 50% nitrogen not only maintained good yield but also saved half the nitrogen requirement and labor cost. In guava, drip fertigation at 75% ETc saved nearly 34% water compared to traditional irrigation.

A Winning Choice for Farmers

Across crops like banana, mango, guava, grapes, papaya, apple, litchi, pomegranate, and sapota, one message stands clear: drip irrigation combined with fertigation consistently delivers more yield, better-quality fruits, significant water savings, and higher profit margins.

Farmers adopting 75–100% drip fertigation with balanced nutrient supply have reported yield increases of 15–35%, better fruit quality, and savings on costly inputs. As agriculture faces increasing challenges of resource scarcity, climate variability, and rising input costs, drip irrigation with fertigation is proving to be the sustainable path forward.

Summary

Drip irrigation supplies water directly to the root zone, reducing evaporation and ensuring efficient usage, leading to higher yields with less water in crops like sapota, mango, guava, and banana. Fertigation delivers fertilizers through this system, providing nutrients exactly where needed, enhancing yields—such as a 30% increase in pomegranate and improved fruit quality in crops like apple and papaya—while saving up to 30% on fertilizer use. This method also reduces nutrient wastage, lowers labor costs, and conserves water, with guava irrigation saving nearly 34% water compared to traditional methods. Overall, drip irrigation combined with fertigation consistently improves fruit yield and quality by 15–35%, saves vital resources, and boosts farmer profitability, making it a sustainable and effective approach in the face of growing agricultural challenges.

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Raja Gopala Reddy, A., Santosh, D.T., and Tiwari, K.N., (2017). A review on Effect of Drip Irrigation and Fertigation on Growth, Development and Yield of Vegetables and Fruits. *International Journal of Current Microbiology and Applied Sciences*. 6 (2):1471-1483

Advances in Seed Nano priming for Enhancing Abiotic-Stress Tolerance

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Kumari Punam Sinha¹

¹PhD Research Scholar, Department of Seed Science and Technology, UBKV, Pundibari, Coochbehar, West Bengal.

Abstract

A precise, low-input technique called seed Nano priming—imbibition of seeds with ultra-low doses of engineered or bio-derived nanomaterial's (NMs)—has become popular for accelerating and synchronizing germination, enhancing early vigour, and protecting seedlings from oxidative stress, salinity, drought, and temperature extremes.

Nano priming uses the high surface area, redox activity, and tunable surface chemistry of nanoparticles (NPs) to (i) promote controlled reactive oxygen species (ROS) signaling and antioxidant preparedness; (ii) modulate ion homeostasis (e.g., higher K^+/Na^+ under salt); (iv) improve water relations and membrane stability; (v) deliver micronutrients or signal molecules with seed-coat-resident “nano-depots” in contrast to conventional priming (hydro-, osmo-, halo-, or hormone-priming). In cereals, legumes, oilseeds, and fiber crops, strong evidence has been gathered over the past ten years for metal/metal-oxide (ZnO , FeO_4 , TiO_2 , SiO_2), rare-earth (CeO_2), carbon-based (graphene oxide, carbon dots, fullerenols), and polymeric (chitosan-based) nanomaterials. Nowadays, field and semi-field research shows yield-relevant effects and, in certain situations, multi-year scalability.

A useful choice framework for researchers and seed technologists is outlined in this paper, which synthesizes mechanistic insights, material classes, dose/time windows, crop-specific results, and biosafety/regulatory considerations.

Introduction

The initial life stages—germination and stand establishment—are disproportionately harmed by the growing abiotic restrictions that affect agriculture worldwide, including unpredictable rainfall, salinization, heat waves, and cold snaps. At this point, slight physiological improvements add up to major yield variations. The benefits of traditional seed priming can vary depending on the climate and may diminish over time. A supplementary approach is provided by nanoprimering, which creates biochemical “preconditioning” that lasts into the early stages of seedling development by exposing nanoscale compounds to the seed coat and embryonic tissues during brief imbibition windows. According to recent reviews and experiments, nanoprimering is a more effective kind of priming that may be applied frequently at parts per million (ppm) levels. It provides multi-mechanistic stress resilience without requiring repeated soil or foliar treatments. Higher α -amylase and protease activity, better osmotic adjustment, faster and more uniform germination, and greater antioxidant enzyme baselines (SOD, CAT, and APX) are among the reported benefits. K^+/Na^+ ratios frequently increase in salinity, and relative water content improves in drought.

What Makes Nano priming Different?

Leverage in physicochemistry. In addition to their high specific surface area, which allows for quick interaction with seed mucilage and cell walls, nanoparticles also offer catalytic redox properties (such as CeO_2 “nanozyme” ROS buffering), tunable size/charge for better seed-coat residency and controlled release, and bioavailable forms of micronutrient delivery that prevent soil fixation (such as Fe, Zn). aiming in space and time. The seed's normal “metabolic switch-on” occurs during short soak times (1–8 hours on average), which makes minor disruptions disproportionately effective: aquaporins upregulate, mitochondrial biogenesis speeds up, and starch hydrolases activate earlier. Nanoscale therapies activate ion transporters and hormone pathways (ABA, GA, and SA) in a number of systems, which subsequently buffer stress. nano-depots for seed coats. NP is retained in the seed coat and close to the embryo, according to imaging

studies. This allows for gradual leaching to the radicle or plumule during early growth, reducing environmental release in comparison to bulk soil application.

Mechanistic Basis of Stress Tolerance

1. Reserve mobilization and enzyme activation: α -amylase is continuously raised by nanopriming, which increases soluble sugars and accelerates radicle protrusion. In rapeseed, CeO_2 nanopriming enhanced α -amylase activity and enhanced germination under salt stress; in cereals and legumes, metal-oxide and carbon-based NPs have elevated amylase/protease.

2. Regulated ROS signaling and readiness for antioxidants: Early imbibition triggers germination with mild bursts of ROS; nanopriming takes advantage of this by increasing antioxidant set-points (SOD, CAT, APX) and by using nanozymes (like CeO_2) that buffer excessive ROS, protecting membranes (lower MDA) under later stress.

3. Under salinity, ion homeostasis: According to several research, nanoprimed seedlings exhibit better K^+/Na^+ ratios—a key factor in salt tolerance—due to increased K^+ retention and decreased Na^+ buildup.

4. Membranes, photosynthesis, and water interactions: Under salt/drought conditions, ZnO , SiO_2 , FeO_4 , graphene oxide (GO), and carbon dots (CDs) exhibit enhanced relative water content, chlorophyll stability, and PSII efficiency. While SiO_2 and ZnO enhanced osmolytes and chlorophyll under stress in legumes and cereals, GO priming in peanuts boosted Fv/Fm and grain production in field plots.

5. Transcriptional remodeling and signaling: Nanopriming alters carbon-nitrogen metabolism, antioxidant networks, and phytohormone biosynthesis/response (e.g., SA in CeO_2 environments), according to omics data (RNA-seq, metabolomics). These alterations are linked to higher stress acclimation and quicker germination.

Materials and Formulations Used in Nanopriming

1. Nanoparticles of metal or metal oxide: For resistance to salt and drought, ZnO NPs are the most frequently reported. Under drought conditions, wheat seeds primed with 120–250 ppm ZnO exhibited enhanced germination, increased antioxidant activity, and upregulated stress-responsive genes.

- Iron oxides, or $\text{FeO}_4/\text{FeO}_3$, increase chlorophyll and decrease $\text{H}_2\text{O}_2/\text{MDA}$ under drought; primed flax in field experiments demonstrated increased biomass and output.
- TiO_2 : Supports drought tolerance by increasing photosynthetic pigments and phenolics (mechanistic and empirical research).
- SiO_2 : Enhances membrane stability and K^+ homeostasis; primed seeds are more resistant to salt, resulting in enhanced germination and seedling development.

2. Nanozymes of rare earth: CeO_2 (nanoceria): In rapeseed, PAA-coated nanoceria (PNC) priming decreased ROS, boosted salt tolerance, and improved the balance of Na and K. Related research indicates that the SA pathway is activated.

3. Nanomaterials based on carbon: Peanut seeds primed with graphene oxide (GO) (400 mg L^{-1}) showed improved germination, more robust photosystems under 200 mM NaCl, and yield increases of approximately 12–14% over two seasons.

- Carbon Dots (CDs):** Se-doped CDs (PAA@Se-CDs) enhanced rapeseed salt tolerance; CDs generated from plastic waste and bio-CDs as priming agents enhanced germination rate, seedling vigor, and drought/salt performance across pea, rice, and oilseeds.
- Fullerenols:** Polyhydroxylated fullerene derivatives have been associated with enhanced germination and seedling robustness in cereals and legumes. They also function as ROS scavengers. (Crop and mechanical data are increasing.)

4. Biogenic and polymeric nanomaterials: Because of their safety and regulated release, chitosan-based nanoformulations—often metal-loaded, like Cu-chitosan—are appealing. Wheat nanoprimed with Cu-chitosan demonstrated improved pigment status and membrane integrity under PEG and salt stress. Green-synthesized Au/Ag NPs from plant extracts enhanced germination and seedling vigor at incredibly low doses as demonstrated by phytochemical-capped NPs, suggesting biocompatible coverings as a new design area.

Crop-Specific Evidence and Outcomes

1. ZnO nanopriming (~120–250 ppm; 3–8 h) in wheat (*Triticum aestivum*) enhances drought tolerance, chlorophyll, antioxidant capacity, and germination index; stage-based ZnO treatments also promote seedling vigor and, in certain experiments, yield components.
2. Through ROS homeostasis and K/Na balance, CeO₂ nanopriming improves salt tolerance in rapeseed (*Brassica napus*); further research demonstrates SA upregulation.
3. Under salinized circumstances, GO priming increases germination, photosynthesis, and pod yield in peanuts (*Arachis hypogaea*) (field-level validation).
4. Flax (*Linum usitatissimum*): In a split-plot field configuration, Fe oxide nanopriming improved biomass and the agronomic profile under water stress.
5. Rice and Lathyrus/sweet pea: SiO₂ or CD nanopriming enhanced root development, osmotic balance, and germination; transcriptomics links nitrogen metabolism and photosynthesis.

Practical Protocols: Dose, Time, and Rinsing

Timing and focus. Low-ppm (10–250 ppm) working doses with brief soaking (1–8 h) at room temperature and surface drying are reported in the majority of investigations. Depending on surface chemistry, GO works best at 400 mg L⁻¹ for peanuts, ZnO is typically 100–250 ppm for cereals, CeO₂ is at tens of ppm, and CDs are often 50–2,000 ppm. Avoid aggregation (using light sonication or dispersion aids) and always titrate a dose-response curve.

1. **Seed cleanliness and health:** To prevent pre-germination, use sterile or deionized water and keep an eye on the seed's moisture content after priming. Although there are a number of advantages to seed-coat preservation, loose particles can be removed with a quick rinse if ecotoxicity is an issue.
2. **Compatibility:** Check for antagonism when layering nanopriming with beneficial bacteria (PGPR) or biostimulants. Carbon-based NMs are often more microbe-friendly, although some NPs can be antimicrobial at greater levels.

Safety, Biosafety, and Regulatory Considerations

1. **Exposure minimization:** Compared with soil/foliar nanofertilizers, seed nanopriming uses tiny quantities and concentrates NPs on/in the seed coat—reducing environmental release. Field and semi-field reports have not flagged acute toxicity at agronomic doses; nonetheless, chronic exposure and trophic transfer assessments are needed case-by-case.
2. **Material choice matters:** Prefer food-grade or biocompatible carriers (e.g., chitosan), green-synthesized coatings, and micronutrients already essential to plants (Zn, Fe, Si). For nanozymes (CeO₂) and carbon nanomaterials, document dose limits and particle size distributions.
3. **Standards & reporting:** Follow minimum information standards for engineered nanomaterials (size, ζ-potential, crystallinity, coatings), and include germination/seedling endpoints, residuals on seed coats, and leachates. Regulatory pathways for seed treatments are often more tractable than for foliar nanoproducts, but local compliance is essential.

Knowledge Gaps and Research Priorities

1. **Field durability:** More season-long and multi-location experiments are required (some now exist for GO, Fe-oxides); many research stop at the seedling stage.
2. **Trait-specific design:** Primers that are targeted to a particular crop or stress may be produced by surface-functionalization to target aquaporins, ion channels, or hormone crosstalk.
3. **Microbiome interactions:** Dose-safe materials and colonization dynamics monitoring are necessary for co-priming with PGPR/mycorrhiza.
4. **Residue analytics:** Standardize the measurement of early seedling translocation and seed-coat retention.
5. **Risk frameworks:** evaluations of the food chain, soil biota, and chronic conditions for recurrent applications, particularly for non-nutritive NMs.

A Decision Framework for Researchers and Seed Technologists

1. Describe the stress: When comparing salinity (ionic/osmotic) and drought (rapid desiccation at the seedling stage), ZnO/SiO₂/Fe-oxide or CeO₂/GO/CDs are frequently suggested. For metal oxides, start with safe baselines of 25–100 ppm, CeO₂ 10–50 ppm, CDs 100–500 ppm, and GO 200–500 mg L⁻¹. Then, titrate.

2. Make the most of the time: soaking for 2–6 hours usually balances uptake and seed health; before storing or planting, dry to original moisture (~10–12% for cereals). Assess early indicators such as α-amylase, soluble sugars, MDA, SOD/CAT/APX, and K⁺/Na⁺; correlate with measures for emergence and homogeneity.

3. Carefully scale: Verify in germination trays, pots, and field micro-plots; monitor yield components and stand establishment.

Conclusion

A significant amount of "stress preparedness" is condensed into a brief, low-dose pre-sowing step by seed nanoprimer. There is increasing mechanistic clarity: persistent gains under drought and salinity are supported by antioxidant priming, hormone and ion-homeostasis tuning, membrane/PSII protection, and earlier reserve mobilization. Nanoprimer is positioned to supplement traditional priming and on-farm seed technologies as procedures advance, particularly in the areas of material selection, dose/time, and safety reporting. This will provide climate-vulnerable crops with dependable emergence and resilience.

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Innovations in Gene Stacking for Sustainable Agriculture and Food Security

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Bandela Chandana¹, Thalari Vasanth²

¹Bidan Chandra Krishi Vishwavidhyalaya, West Bengal, India.

²Professor Jayshankar Telangana Agricultural University, Hyderabad, India.

Abstract

Gene stacking or gene pyramiding, is an advanced strategy in crop improvement that integrates multiple beneficial genes into a single genotype to enhance complex traits simultaneously. While traditional breeding enabled stacking through hybridization and marker-assisted selection, modern molecular tools such as transgenic approaches, recombinase-mediated integration, modular cloning systems, and genome editing have greatly improved precision and efficiency. Gene stacking offers significant advantages, including durable pest and disease resistance, reduced chemical dependence, multi-trait enhancement, and accelerated breeding timelines. However, challenges remain in achieving stable multigene expression, managing unintended effects, preventing pest adaptation, and navigating complex regulatory and economic barriers. Emerging innovations such as CRISPR-based multiplex editing, plant artificial chromosomes, nanotechnology-enabled delivery, and AI-driven predictive modeling are expected to overcome these limitations. Collectively, gene stacking represents a cornerstone of next-generation crop improvement, with strong potential to address food security and sustainability challenges.

Keywords: Gene stacking, Crop improvement, Marker-assisted selection, Genome editing, Plant artificial chromosomes.

Introduction

“Gene stacking,” also called gene pyramiding or multigene stacking, is a cutting-edge breeding strategy that integrates multiple genes, each conferring valuable traits, into a single crop variety (Dormatey *et al.*, 2020). Unlike traditional single-gene approaches, stacking enables the simultaneous improvement of several traits such as pest and disease resistance, herbicide tolerance, nutritional enhancement, and stress resilience within the same genotype.

Historically, stacking was achieved through conventional breeding, where parental lines carrying different desirable traits were crossed and combined in their offspring (Que *et al.*, 2010). While effective, this process was slow and often limited by recombination and linkage drag. The introduction of molecular breeding tools such as marker-assisted selection (MAS), genomic selection, and direct genetic engineering has transformed gene stacking into a more precise and efficient practice (Kumar *et al.*, 2024).

In biotechnology, stacking often involves the integration of multiple transgenes into plants, either simultaneously or sequentially. This can be accomplished using multigene cassettes, recombinase-mediated systems, or artificial chromosome platforms (Rajput *et al.*, 2023). The impact of this approach is evident in commercially successful crops.

For example, maize varieties combining Bt insect resistance with herbicide tolerance dominate global markets, while Golden Rice, enriched with provitamin A, represents a nutritional biofortification success (Bajaj and Mohanty, 2005). By 2011, transgenic stacks already covered about 26% of global biotech crop area, with countries like Australia widely adopting stacked cotton varieties carrying both insect and herbicide resistance traits (Stiller and Wilson, 2014).

Looking ahead, innovations such as plant artificial chromosomes (PACs) and synthetic biology approaches promise to further expand stacking capacities by allowing insertion of multiple large genes without disrupting the host genome. In this context, gene stacking has emerged as a cornerstone of modern crop improvement, leveraging both conventional and molecular strategies to build resilient, high-performing varieties (Chaudhary *et al.*, 2024).

Gene Stacking Methods in Crop Improvement

- 1. Crossing and Re-transformation Strategy:** Existing transgenic lines can be crossed or re-transformed to merge traits into a single genotype (Yau and Stewart, 2013).
- 2. Cre/FLP-Mediated Site-Specific Integration with Marker Removal:** Recombinase systems such as Cre-lox enable targeted integration, followed by marker excision using nucleases like I-SceI or ZFNs.
- 3. Sequential and Simultaneous Multi-Gene Transformations:** Used widely in crops like potato, this includes sequential re-transformation, insertion of linked cassettes, or simultaneous transfer of multiple resistance (R) genes.
- 4. Multi-Site Gateway Cloning Strategy:** A modular cloning approach that assembles multi-gene cassettes through multiplexed recombination events.

Methods of Gene Stacking

1. Hybrid Stacking (Conventional Breeding)

- a. Involves crossing lines carrying distinct beneficial genes.
- b. Serial hybrid stacking can create triple or quadruple trait stacks.
- c. MAS accelerates this process by tracking target loci with precision.

2. Molecular (Transgenic) Stacking

- a. Insertion of multiple genes via Agrobacterium-mediated transformation or biolistic.
- b. Examples include stacking resistance genes in potato or combining Bt with herbicide tolerance in rice.

3. Site-Specific Recombinase-Mediated Integration

- a. Employs enzymes like Cre or FLP for targeted gene cassette insertion at defined loci.
- b. Modified recombination systems reduce reversibility and allow repeated integrations.

4. Designer Nucleases & Marker-Free Stacking

- a. Integration with nucleases such as I-SceI, ZFNs, TALENs, or CRISPR enables clean, marker-free stacking.
- b. Split selectable marker systems simplify co-transformation.

5. Modular Cloning Platforms

- a. Systems like PSM (Pyramiding Stacking of Multigenes) combine Gibson assembly and Gateway cloning.
- b. MoClo (Modular Cloning) enables efficient assembly of standardized multigene constructs.

- 6. Intra-Genomic Homologous Recombination:** Uses natural recombination pathways for precise stacking within plant genomes.

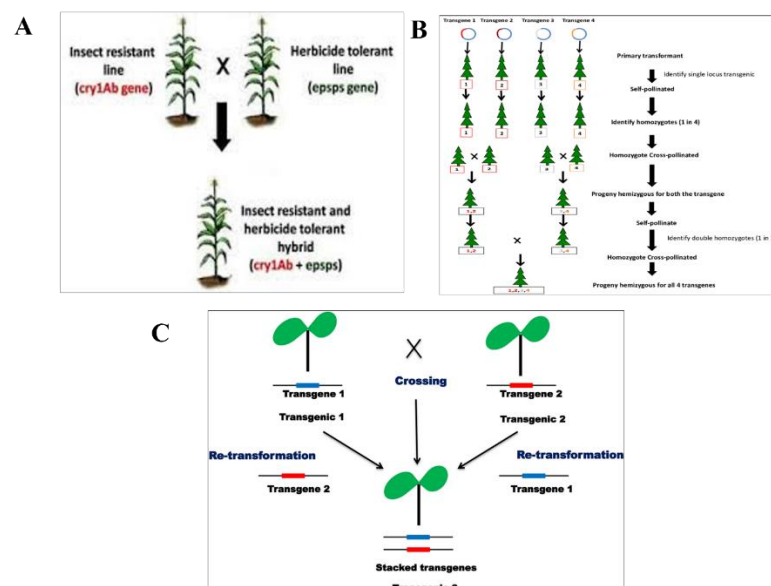


Figure: A. Traits stacking in biotechnological crops B. Hybrid gene stacking process C. Crossing and re-transformation-based strategy for gene stacking in crop plants.

Comparative Overview of Stacking

Method	Key Advantage
Hybrid Stacking + MAS	Simple, reliable, widely tested in the field
Molecular Stacking	Direct, multigene integration possible
Recombinase-Mediated	Precision and repeatability at specific loci
Nuclease + Marker Removal	Clean, marker-free stacking
Split Marker System	Streamlined co-transformation
Modular Cloning (PSM, MoClo)	Flexible, scalable, construct design efficiency
Homologous Recombination	Potentially precise and endogenous integration

Advantages of Gene Stacking

1. Enhanced and Durable Resistance:

- Multiple Bt toxin genes reduce the risk of pest resistance.
- Delays adaptation compared to single-gene methods.

2. Reduced Reliance on Chemicals:

- Lowers pesticide and herbicide use, cutting costs and environmental burden.
- Supports sustainable farming and IPM practices.

3. Broad Trait Improvement:

- Enables simultaneous enhancement of yield, stress tolerance, and nutrition.
- Facilitates complex metabolic engineering, such as biosynthetic pathway construction.

4. Accelerated Breeding: MAS reduces generational time, pyramiding multiple traits in 2–3 generations instead of six or more.

Disadvantages of Gene Stacking

1. Technical Complexity:

- Large multigene constructs are difficult to integrate.
- Risk of gene silencing and inconsistent expression.

2. Unintended Effects: May trigger unexpected phenotypic or ecological changes.

3. Evolution of Resistance: Over time, pests may develop cross-resistance, reducing stack durability.

4. Regulatory and Ethical Concerns:

- Approval processes are lengthy and costly.
- Raises issues of equity, accessibility, and corporate control.

5. Economic Barriers:

- High seed costs may hinder adoption in smallholder systems.
- Consumer skepticism in some regions limits market penetration.

Future Prospects

1. CRISPR-Based Precision Multiplex Editing:

- Multiplexed CRISPR systems allow simultaneous editing of several loci.
- Large-scale trials in wheat are exploring CRISPR-driven yield gains.

2. Plant Artificial Chromosomes (PACs):

- Function as independent, customizable super-vectors.
- Successfully tested in maize, rice, and barley.

3. Integration with Genomics and Phenomics:

- Genomic selection accelerates pyramiding across breeding populations.
- High-throughput phenomics supports stress and yield trait validation.

4. Nanotechnology in Gene Delivery:

- DNA/RNA-loaded nanoparticles enable non-transgenic stacking.
- Reduces tissue damage and regulatory hurdles.

5. Harnessing Underutilized Crops: Stacking in crops like millets, fonio, and pigeon pea enhances nutrition and resilience.

6. AI and Predictive Modeling:

- a. AI platforms (e.g., **Deep PlantCARE**, **Agri-GNN**) predict trait outcomes.
- b. Guides intelligent design of stacked constructs.

Conclusion

Gene stacking, whether achieved by traditional pyramiding or modern transgenic/genome-editing techniques, has become a transformative strategy for crop improvement. Stacked traits, as seen in Golden Rice or Bt-herbicide tolerant maize, highlight its potential for building resilient, sustainable, and nutritionally enhanced crops. Yet, challenges remain ranging from the technical complexity of maintaining stable multi-gene expression, to ecological concerns, pest adaptation, and stringent regulatory frameworks. Looking forward, emerging innovations such as CRISPR-based multiplex editing, plant artificial chromosomes, nanotechnology-driven delivery, and AI-guided predictive modeling offer promising solutions. Together, these advances will likely reshape the landscape of gene stacking, enabling more precise, scalable, and equitable applications in global agriculture.

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Dry Flowers – A Blooming Market in India

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Miss. R. Aarthi¹, Dr. M. Manikandan¹, Dr. A. Shanthi¹, Dr. C. Jayalakshmi¹

¹Department of Horticulture, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal – 03 (A Government of Puducherry Institution affiliated to Pondicherry University).

Flowers remain an essential part of human existence. Flowers are used for every occasion, including greetings, funerals, births and deaths. Although they are the most beautiful, fresh flowers are also the costliest and ephemeral. Conversely, dried flowers are accessible all year round, last a long time and enhance appearance. Customers have become "eco-conscious" and prefer dry flowers to fresh ones, which has led to an exponential growth in the market for dry flowers. Dry flowers are frequently used to create cards, wall quilts, candles, lampshades, jute bags, photo frames, boxes, books, cards and a variety of presents. The appearance and beauty of these items are improved by the use of dried flowers in their creation. Dry flower is an excellent gift item for anyone who has an eye for beauty.

India is among the top nations in the dry flower market. India exports more than Rs. 150 crores worth of dried flowers and plants annually. The dried flower potpourri variant has dedicated processing facilities and is solely focused on exports. India has a clear advantage in the dried flower and plant industry for the abundant resources, diverse range of products and experience. The industrial leader for dry flowers is Tamil Nadu.

Dry flowers are in high demand in both the Indian and global markets. The United States, Japan and Europe are the nations that import dry flowers from India. Due to the abundance of different types of plants, India is the leading exporter of dry flowers. Dry flowers don't mean only flower parts, but also includes dried shoots, seeds, barks etc.

Preservation Techniques

1. Air Drying
2. Glycerin
3. Silica Gel
4. Pressing
5. Sand
6. Others.

Methods of Drying

Flowers and leaves are dried using a variety of techniques. The drying technique used is primarily determined by the characteristics of the plant, such as whether it is glabrous, succulent or not, hardy or delicate.

1. Air Drying: One of the simplest ways to preserve flowers is air drying; this gives plants a fresh appearance that lasts for many years. Flowers that are dried using air make wonderful decorations on their own, but when they dry, they create more exquisite and unique flower arrangements. This is often known as the "hang and dry" technique. It is the simplest and most traditional method of drying. No specialized equipment is required. Flowers and their leaves are tied to stems and hung inverted.

The following characteristics make a location perfect for hanging flowers:

- i. Darkness
- ii. Excellent airflow
- iii. Ideal humidity levels
- iv. To keep their shape, flowers are then coated with clear varnish or hairspray. Products that are air dried often lose their natural colour more quickly.

2. Water drying: This preservation technique involves removing the leaves from the flower stems and submerging them in five centimeters of water. After that, this is kept out of direct sunlight and in a warm location. As the flower dries, the water is absorbed and then evaporates. This method works well for drying

hydrangeas, heathers, hybrid delphiniums, gypsophila, acacia, bells of Ireland, proteas and yarrow. Water drying is the most effective method for drying hydrangea flowers.

3. Press Drying: Applying pressure is one of the most often used techniques for drying flowers since it extracts moisture while preserving the blooms colour and structure. Flowers can be compressed in a variety of ways. The simplest way is to put them in heavy books and let them dry. Flower presses are also used. Pressing works best on unglazed paper, like newsprint or an old phone book. Pressed flowers work particularly well for flower photos and as decorations for note cards, place cards and a variety of other products.

4. Embedding in desiccants to dry: Simply put, a desiccant is a material that has a strong affinity for water and can be employed as a drying agent. The most popular approach and one that many people believe to be the greatest all-around method is to embed the blossoms in a granular, desiccating substance. Throughout the drying process, the container needs to remain closed. The blossom will be dried after 4–14 days, depending on its thickness.

5. Glycerin drying: This technique substitutes glycerin and water for the moisture in a flower or foliage. Instead of drying, the flower is kept. Whole bunches or individual leaves that have been dried maintain their inherent suppleness and form. The leathery structure of the leaves allows them to be dusted or even wiped with a damp cloth without harm and they last indefinitely. The procedure of drying glycerin is as follows. A hammer is used to shatter the cut end of the stem after the bark has been removed. This section of the stem is submerged in the mixture of glycerin and water. After a month, the leaf turns brown and shiny. Softness and elasticity can be successfully maintained in a variety of leaf varieties. Stems or leaves are submerged in a 33% glycerol solution to accomplish this.

6. Microwave oven Drying: Microwave drying is a rapid and easy process. Only a few minutes are needed and the dried flowers that are produced appear more vibrant and fresh. This method works great with flowers like dahlias, zinnias, violets, roses and lilies.

7. Freeze drying: Also referred to as "lyophilization," freeze drying is the process of reducing an objects temperature and then vacuum is used to remove all the moisture. It is now the most efficient and cutting-edge way for preserving flowers. It is a novel hoover method that, depending on the blossom, takes about four weeks. Flowers that have been freeze-dried undergo a process that extracts water as vapour straight from the ice, bypassing the liquid phase. This process, known as sublimation, needs less pressure to take place. Evaporation is the basis for all other drying techniques. Stated differently, hot air is used to extract water vapour from liquid water. Over the course of four weeks, the freeze-drying equipment gradually brings the freeze-dried flowers back to room temperature after lowering the temperature to -20 degrees Fahrenheit. While the colours are enhanced, the freeze-dried flowers maintain their natural shape thanks to this gradual preservation method.

Dyeing and Bleaching

Dried bouquets and other dry flower products have the main disadvantage of being lifeless and lacking the vibrancy of fresh flowers. Flowers are washed and dyed to solve this issue. This improves the product's aesthetic attractiveness. In essence, bleaching is decolorizing or whitening. It is a crucial stage in the drying plant processing process. The discolouration that happens during the dehydration stage of plant preservation is eliminated by this chemical activity. It makes it possible to utilise colouring pigments effectively. The most popular bleaches for plant leaves are a variety of substances, including sodium hypochlorite, hydrogen peroxide and sodium chlorite. It is possible to employ both natural and chemical dyes. For this, enamel paints, tube paints, interior paints and poster paints could be used.

Skeleton Leaves

Skeleton leaves, also known as fossil leaves, are semi-transparent leaves. Fresh leaves are soaked in bleaching water to prepare them and the tender green flesh from the vein network is then rubbed by hand. The leaves can then be stained a variety of colours to make them seem lovely and appealing. Despite their inherent fragility, they are strong and simple to adhere to a range of surfaces. They are ideal for adorning wedding favours, candles, the reception table and bridal bouquets.

Products from Dry Flower

1. Handcrafted paper
2. Wall quilt
3. Shades of lamps
4. Books
5. Boxes
6. Cards
7. Picture Frames
8. Bags made of jute
9. Candlesticks.

Potpourri

A mixture of dried, sweet-smelling plant components, such as flowers, leaves, seeds, stems and roots, is called potpourri. The plant's aromatic oils serve as the foundation for the potpourri. These oils are most abundant during flowering, but they are not limited to the flowers. Therefore, they ought to be picked as soon as the plant starts to bloom. A well-prepared potpourri will last for several months. It has countless applications. With their enduring scents, potpourri is used to scent closets and drawers, create enticing stationery, finish off room décor with eye-catching baskets, or make unique presents to give to friends. In addition to their widespread use for aroma and aesthetic purposes, potpourris are also used to keep moths away from wool clothing while it is being stored.

According to Cognitive Market Research, air drying held a prominent market share due to its natural preservation method. With increasing demand for sustainable and eco-friendly products, air-dried flowers offer an environmentally friendly alternative to artificial or chemically preserved blooms. Consumers appreciate the charm and authenticity of air-dried flowers, making them a significant trendsetter in the dried flower market.

The silica gel is the fastest-growing category over the forecast period as it preserves the quality and longevity of dried flowers. By effectively absorbing moisture, silica gel helps prevent decay, discoloration and microbial growth in dried flower arrangements. Its moisture-absorbing properties make it an indispensable component for floral preservation, ensuring that dried flowers maintain their aesthetic appeal and shelf life.

Plant materials can be dried for a variety of reasons, one of which being the abundance of materials. Approximately 80% of flower species are thought to be effectively dried and stored. To create a range of designs, one does not require costly equipment or sophisticated skills. If conserved, packaged and managed properly, dried ornamentals can last longer on the market than fresh flowers, which quickly lose their marketable value and quality. The adaptability of dried ornamentals is another distinctive feature. Depending on the style, design and purpose that one prefers, they can be organized into several crafts. The dry flower industry is waiting to be explored and needs to be popularized.





Advancements of Tillage Equipment in Agricultural Engineering

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Shivesh Chandra Pandey¹, Preeti²

¹Dept. of Farm Machinery and Power Engineering, College of Agricultural Engineering and Technology, AAU, Godhra, Gujarat.

²Dept. of Processing and Food Engineering, College of Agricultural Engineering and Technology, AAU, Godhra, Gujarat.

Introduction

Tillage is one of the oldest and most essential operations in agriculture, carried out to prepare the soil for planting, manage crop residues, incorporate nutrients, and suppress weeds. In the past, this process was largely dependent on animal-drawn wooden plows, which required high labour input and provided limited efficiency. Over the years, agricultural engineering has transformed tillage practices by introducing mechanized and scientifically designed implements that enhance both productivity and sustainability.

Modern tillage equipment is not only faster and more efficient but also engineered to maintain soil health and reduce environmental degradation. Tools such as chisel plows, subsoilers, rotary tillers, and zero-till drills represent significant improvements over traditional methods, allowing farmers to achieve better soil structure while conserving moisture and energy. Furthermore, the integration of precision technologies, including GPS and variable-depth controls, has enabled smarter tillage operations tailored to specific soil conditions.

The continuous advancement of tillage machinery reflects a broader shift toward sustainable agriculture. By balancing productivity with resource conservation, these innovations support farmers in addressing challenges like soil erosion, climate change, and rising global food demand. Hence, studying the evolution and advancement of tillage equipment provides critical insights into the role of engineering in modern farming systems.

It has been a cornerstone of agricultural production for centuries, serving as a crucial operation to prepare seedbeds, manage crop residues, incorporate fertilizers, and control weeds. Traditional tillage relied heavily on animal-drawn wooden plows, which were labor-intensive and limited in efficiency. With the rise of agricultural engineering, significant advancements have been made in the design, efficiency, and sustainability of tillage equipment, aiming to reduce drudgery, enhance soil health, and improve overall farm productivity.

Evolution of Tillage Practices

Initially, primary tillage was performed using simple plows that fragmented soil clods to create a workable seedbed. However, repeated soil inversion often led to compaction, organic matter loss, and erosion. This drove the need for engineered solutions that balanced soil loosening with conservation. Over time, traditional plows were replaced with mechanized implements such as moldboard plows, disc plows, and chisel plows. These mechanized tools, powered by tractors, improved working efficiency while reducing dependence on manual labor.

Modern Tillage Equipment

Contemporary tillage equipment is designed with precision engineering to address both productivity and sustainability. Chisel plows and subsoilers are now preferred for breaking hardpan layers without excessive soil inversion, thereby maintaining soil structure. Rotary tillers, power harrows, and cultivators offer better soil pulverization and uniform seedbed preparation. Zero-till drills and strip-till machines represent revolutionary approaches that minimize soil disturbance, conserve moisture, and promote carbon sequestration. The integration of hydraulic systems, adjustable depth controls, and wear-resistant materials has further enhanced equipment performance and durability.

Conservation and Smart Tillage Technologies

A major advancement in recent decades has been the adoption of conservation tillage systems, which reduce soil erosion, maintain organic matter, and improve water infiltration. Implements like no-till planters allow direct seeding into residue-covered soils, lowering energy and labor inputs. Precision agriculture tools have also been integrated into tillage equipment, enabling variable-depth tillage guided by GPS and soil mapping technologies. These smart systems allow farmers to optimize tillage intensity according to soil conditions, thus reducing fuel consumption and greenhouse gas emissions.

Impact on Sustainability and Productivity

Modern tillage innovations not only improve operational efficiency but also address the global challenge of sustainable agriculture. By reducing the need for repeated passes, farmers save fuel and time while preserving soil fertility. Conservation tillage and minimum tillage practices have been shown to increase microbial activity, enhance soil carbon storage, and improve long-term yields. Moreover, the mechanization of tillage equipment has allowed scaling up of production to meet growing food demand without proportionally increasing resource use.

Conclusion

Advancements in tillage equipment within agricultural engineering have transformed farming practices from labor-intensive operations to sustainable, high-efficiency systems. The development of conservation tillage technologies, integration of precision agriculture, and the use of durable engineering materials are key milestones in this journey. As agriculture faces climate change and food security challenges, the role of advanced tillage equipment in supporting sustainable intensification will remain central.

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Digital and AI Tools in Plant Pathology: Advancing Diagnostics and Disease Management

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AD Matte¹, S S Band²

¹Assistant Professor of Agricultural Entomology, DUPCA, Jalgaon, Dist. Jalgaon, Maharashtra, India, 425 306.

²Assistant Professor of Agricultural Entomology, College of Agriculture, Muktainagar, Dist. Jalgaon, Maharashtra, India, 425 306.

Introduction

Plant diseases pose one of the most significant threats to food security, causing yield losses of up to 40% in major crops worldwide (Savary et al., 2019). Traditional disease management relies heavily on chemical pesticides and conventional diagnostic methods such as visual inspections or laboratory assays, which are time-consuming, expensive, and often inaccessible to smallholder farmers (Picon et al., 2019). The rapid development of digital technologies—including artificial intelligence (AI), machine learning (ML), Internet of Things (IoT), remote sensing, and big data analytics—has opened new horizons for plant pathology. These tools enable early detection, accurate diagnostics, predictive modeling, and smart disease management, helping to reduce crop losses, minimize pesticide overuse, and promote sustainable agriculture (Xie et al., 2020).

Artificial Intelligence and Machine Learning in Disease Diagnostics

Image-Based Diagnosis: AI models, particularly convolutional neural networks (CNNs), have revolutionized plant disease detection by classifying diseased leaves from digital images (Mohanty et al., 2016). Smartphone-based systems now allow real-time identification of diseases such as rice blast, maize leaf blight, and tomato leaf curl with accuracy exceeding 90% (Ferentinos, 2018). Barbedo (2019) demonstrated that deep learning can recognize even early-stage lesions, outperforming human experts in consistency. These models are increasingly integrated into mobile apps like Plantix and Nuru, making advanced diagnostic tools accessible to farmers worldwide.

Predictive Modeling: Beyond classification, AI enables predictive epidemiology by integrating weather, crop, and soil data. ML algorithms such as Random Forest and Support Vector Machines (SVMs) have been applied to predict late blight outbreaks in potato and rust epidemics in wheat (Sharma-Purushothaman et al., 2021). Such predictive systems allow for timely interventions, reducing reliance on calendar-based pesticide spraying.

Digital Imaging and Spectroscopy

Hyperspectral and Multispectral Imaging: While traditional RGB cameras detect visible symptoms, hyperspectral imaging (HSI) and multispectral imaging (MSI) capture spectral signatures across multiple wavelengths. These technologies detect physiological changes before visible lesions appear, enabling early disease detection (Mahlein, 2016). For example, Sankaran et al. (2010) showed that HSI could differentiate between healthy and diseased citrus trees infected with citrus canker. Similarly, Mahlein (2016) demonstrated that HSI can classify fungal diseases in sugar beet with high precision.

Thermal and Chlorophyll Fluorescence Imaging: Thermal imaging detects variations in canopy temperature, often linked to pathogen-induced stomatal closure. Chlorophyll fluorescence imaging provides insights into photosynthetic efficiency, which decreases in infected plants (Sankaran et al., 2010). These tools are now central to high-throughput phenotyping platforms used in disease resistance breeding.

Remote Sensing and GIS Applications: Remote sensing through unmanned aerial vehicles (UAVs), satellites, and drones provides large-scale monitoring of disease epidemics. Garcia-Ruiz et al. (2013) demonstrated UAV-based remote sensing to detect citrus greening in orchards. Integration with Geographic Information Systems (GIS) allows spatial mapping of disease hotspots. AI-driven models

trained on such data have successfully forecasted wheat rust spread across East Africa and South Asia (Sharma-Purushothaman et al., 2021). These tools are crucial for regional early warning systems and global surveillance.

IoT and Smart Agriculture in Disease Monitoring: The Internet of Things (IoT) integrates sensors that monitor microclimatic variables—temperature, humidity, soil moisture—that influence pathogen development. Real-time data streams are transmitted to cloud platforms, where AI models generate risk alerts (Sharma et al., 2020). For instance, IoT-based smart traps equipped with cameras can automatically identify and count insect vectors like aphids, supporting integrated pest and disease management (Balducci et al., 2018). Coupled with decision-support systems, IoT enables site-specific fungicide applications, lowering costs and minimizing environmental impact.

Big Data Analytics and Cloud Platforms: The vast amount of data generated from digital imaging, genomics, IoT sensors, and environmental monitoring demands advanced big data analytics. Cloud-based AI systems facilitate global sharing of datasets, promoting collaborative plant disease surveillance (Xu et al., 2020). Integrating genomic data with field-based digital tools also allows researchers to model host–pathogen interactions and predict pathogen evolution (Nelson et al., 2018). Such insights are vital for breeding disease-resistant varieties and designing durable management strategies.

Case Studies of Digital and AI Applications

1. PlantVillage Nuru App – An AI-powered mobile app that diagnoses multiple cassava and maize diseases in sub-Saharan Africa, providing offline functionality for smallholder farmers (Mohanty et al., 2016).

2. Wheat Rust Early Warning System – Combines climate, satellite, and ground survey data to predict rust outbreaks across Ethiopia, Kenya, and India, significantly reducing losses (Sharma-Purushothaman et al., 2021).

3. HSI for Sugar Beet Diseases – Mahlein (2016) used hyperspectral imaging to distinguish between *Cercospora* leaf spot, powdery mildew, and rust before visible symptoms appeared.

Challenges and Limitations

Despite remarkable progress, several barriers remain:

1. Data Scarcity and Bias: Many ML models require large, annotated datasets, which are scarce for underutilized crops (Barbedo, 2019).

2. Generalization Issues: Models trained under controlled conditions may fail under diverse field environments.

3. Adoption Barriers: Limited internet connectivity, affordability, and digital literacy restrict farmer adoption in developing countries.

4. Ethical and Policy Concerns: Data sharing, privacy, and biosecurity regulations remain underdeveloped (Nelson et al., 2018).

Future Prospects

The future of digital plant pathology lies in integrated, multi-modal platforms that combine imaging, IoT, climate, and genomic data. Emerging trends include:

1. Explainable AI - Models that provide interpretable results to build trust among users.

2. RNA-based biosensors - Coupling molecular diagnostics with digital platforms for portable, field-ready disease detection.

3. Edge AI - On-device computation to enable real-time analysis without internet dependency.

4. Global digital surveillance networks - Linking cloud-based systems for transboundary disease management (Xie et al., 2020).

Conclusion

Digital and AI technologies are revolutionizing plant pathology by shifting from reactive to predictive disease management. Tools such as CNN-based mobile diagnostics, hyperspectral imaging, IoT sensors, and big data analytics provide farmers and researchers with unprecedented capabilities to detect, monitor, and forecast plant diseases. By addressing challenges related to data availability, field applicability, and farmer adoption, these innovations can play a critical role in achieving sustainable, climate-resilient agriculture. Strategic collaborations between researchers, governments, and tech developers will be essential to fully unlock the potential of digital plant pathology.

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Trichoderma: A Multifunctional Fungal Genus for Sustainable Agriculture

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AD Matte¹, S S Band²

¹Assistant Professor of Agricultural Entomology, DUPCA, Jalgaon, Dist. Jalgaon, Maharashtra, India, 425 306.

²Assistant Professor of Agricultural Entomology, College of Agriculture, Muktainagar, Dist. Jalgaon, Maharashtra, India, 425 306.

Introduction

The genus *Trichoderma* (family: Hypocreaceae, order: Hypocreales) is one of the most studied fungal groups in agricultural microbiology due to its versatile ecological role. These filamentous fungi are naturally occurring in soils, plant rhizospheres, and decaying organic matter. Since their discovery, *Trichoderma* species have been recognized for their antagonistic behavior against plant pathogens, rapid colonization ability, and strong enzymatic activity.

Over the last three decades, *Trichoderma* spp. has emerged as **biocontrol agents (BCAs)**, **biofertilizers**, and **biostimulants**, making them integral to **sustainable agriculture**. Their efficacy in reducing dependence on chemical pesticides, enhancing nutrient cycling, and stimulating plant defenses aligns with global demands for eco-friendly and climate-resilient farming systems (Harman, 2011; Vinale et al., 2008).

Taxonomy and Distribution

1. Kingdom: Fungi
2. Phylum: Ascomycota
3. Class: Sordariomycetes
4. Order: Hypocreales
5. Family: Hypocreaceae
6. Genus: *Trichoderma* Pers.

The genus was first described in 1794 by Persoon, and later revised with modern phylogenetic tools. Today, **more than 400 species** have been described, though only a few are of significant agricultural importance (Bissett et al., 2015).

Key Agricultural Species

1. *Trichoderma harzianum*
2. *Trichoderma viride*
3. *Trichoderma asperellum*
4. *Trichoderma atroviride*
5. *Trichoderma koningiopsis*

These species are cosmopolitan, thriving in tropical, subtropical, and temperate agroecosystems. Their adaptability to diverse soils, including degraded or saline soils, enhances their utility in different cropping systems.

Mechanisms of Action

1. Mycoparasitism: One of the most studied mechanisms is **direct parasitism of plant pathogens**. *Trichoderma* detects pathogenic fungi through chemical signaling, attaches to their hyphae, and initiates penetration. It secretes **cell-wall-degrading enzymes (CWDEs)** such as:

- a. **Chitinases** – break down chitin in fungal cell walls.
- b. **β -1,3-glucanases** – degrade glucans in fungal walls.
- c. **Proteases and lipases** – dismantle structural proteins and lipids.

This results in the collapse of the pathogenic hyphae (Benitez et al., 2004).

2. Antibiosis: *Trichoderma* produces **low-molecular-weight antibiotics** and **secondary metabolites**, inhibiting pathogens at a distance. Examples include:

- a. **Peptaibols** – linear peptides with strong antifungal properties.
- b. **Gliotoxin** – effective against *Rhizoctonia* and *Fusarium*.
- c. **Trichodermin, viridin, harzianolide** – inhibit spore germination and hyphal elongation (Vinale et al., 2008).

These metabolites also act as signaling molecules, modifying host–pathogen–fungus interactions.

3. Competition for Nutrients and Space: Due to their **fast growth rate** and ability to utilize diverse carbon sources, *Trichoderma* spp. rapidly colonizes the rhizosphere. They compete with pathogens for root exudates and infection sites, thus limiting pathogen establishment.

4. Induced Systemic Resistance (ISR): *Trichoderma* colonization stimulates **defense-related genes** in host plants. This leads to activation of **jasmonic acid (JA)** and **ethylene (ET)** pathways, which provide resistance against necrotrophic pathogens. In some cases, **salicylic acid (SA)** pathways are also activated, enhancing resistance against biotrophic pathogens (Shoresh et al., 2010).

5. Plant Growth Promotion: Beyond pathogen control, *Trichoderma* enhances plant vigor by:

- a. Producing phytohormones such as **IAA, gibberellins, cytokinins etc.**
- b. Solubilizing phosphorus, zinc, and other micronutrients.
- c. Producing **siderophores** that chelate iron and make it available to plants.
- d. Enhancing root architecture and nutrient uptake efficiency (Harman, 2011).

Applications in Agriculture

1. Biocontrol Agent (BCA): *Trichoderma* is extensively used to manage soilborne pathogens such as:

- a. *Fusarium oxysporum* (wilt diseases)
- b. *Rhizoctonia solani* (root rot, damping-off)
- c. *Sclerotium rolfsii* (collar rot)
- d. *Pythium* spp. (seedling blight)
- e. *Phytophthora* spp. (blight and root rot).

2. Seed Treatment: Seed coating with *Trichoderma* formulations:

- a. Increases germination percentage.
- b. Protects seedlings against seedborne pathogens.
- c. Induces early vigor, reducing seedling mortality.

3. Soil Amendment: When applied with organic manures or compost, *Trichoderma*:

- a. Decomposes organic residues via its strong cellulolytic activity.
- b. Enhances soil microbial diversity.
- c. Improves soil structure and nutrient cycling (Kredics et al., 2018).

4. Biofertilizer Role: *Trichoderma*-based biofertilizers are now included in sustainable soil fertility management programs. They reduce dependency on synthetic fertilizers and increase nutrient use efficiency.

5. Bioremediation: Some *Trichoderma* strains degrade xenobiotics such as pesticides, hydrocarbons, and heavy metals. This makes them useful for soil detoxification in contaminated sites.

6. Abiotic Stress Tolerance: Recent studies indicate *Trichoderma* helps plants tolerate:

- a. **Drought** (by improving water-use efficiency).
- b. **Salinity** (by regulating osmolytes).
- c. **Temperature fluctuations** (via antioxidant enzyme activation).

Commercial Formulations

Trichoderma is commercially available in:

1. **Wettable powder (WP)** formulations.
2. **Granules (G)**.
3. **Liquid suspension** formulations.

In India, formulations like **Trichoderma harzianum 1% WP** and **Trichoderma viride 1% WP** are registered under the **Insecticides Act, 1968**.

Advantages Over Chemical Pesticides

1. Environmentally safe, biodegradable, and non-toxic.
2. Pathogens rarely develop resistance.
3. Improves soil fertility while managing diseases.
4. Compatible with **Integrated Pest Management (IPM)** programs.

Limitations

1. Field efficacy may vary with **soil type, moisture, and temperature**.
2. Limited shelf life under poor storage conditions.
3. Incompatibility with certain fungicides.
4. Requires careful formulation for large-scale adoption.

Future Prospects

1. **Genomics and Proteomics:** Whole-genome sequencing of *Trichoderma* spp. has revealed novel genes for mycoparasitism and stress tolerance.
2. **Molecular Breeding:** Development of genetically improved strains with higher stress tolerance and biocontrol efficiency.
3. **Nanoformulations:** Nanocarrier-based delivery of *Trichoderma* spores to enhance shelf life and field performance.
4. **Climate Resilient Agriculture:** Use of *Trichoderma* in mitigating climate-induced biotic and abiotic stresses.

Conclusion

Trichoderma represents a cornerstone in sustainable crop production systems due to its **biocontrol, biofertilization, and biostimulation properties**. Its integration into eco-friendly farming practices reduces chemical pesticide use, improves soil health, and ensures crop productivity. However, further advancements in formulation technology and molecular research are necessary to overcome field-level limitations and fully exploit its potential.

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Biopesticides: Harnessing Microbes for Sustainable Agriculture

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Varala Krishnaveni¹

¹Research Scholar, Department of Plant Pathology, Vasantrao Naik Marathwada Krishi Vidyapeeth University, Parbhani, Maharashtra, 431402.

Abstract

Agriculture today faces the challenge of feeding a growing population while reducing environmental harm. Conventional chemical pesticides, though effective, often pollute soil and water, endanger human and animal health, and contribute to pest and pathogen resistance. Biopesticides derived from bacteria, fungi, viruses, and nematodes offer an eco-friendly alternative. Microbial biofungicides, in particular, play a key role in managing fungal diseases, major contributors to crop losses globally. These biopesticides act by directly infecting pests, producing inhibitory compounds, outcompeting harmful organisms, and stimulating plant defenses. Widely integrated into Integrated Pest Management (IPM) programs, they help maintain soil health, protect beneficial organisms, and reduce chemical residues in food. In India, biopesticides account for approximately 9% of the total pesticide market, with strong projected growth. Advances such as microbial consortia, nano encapsulation, genetically optimized strains, and precision agriculture applications are enhancing efficacy, making microbial biopesticides a sustainable, targeted, and environmentally responsible solution for modern crop protection.

Introduction

Modern agriculture faces a critical challenge: producing enough food for a growing global population while minimizing environmental damage. Conventional chemical pesticides, though effective, have long-term drawbacks they pollute soil and water, threaten human and animal health, and often lead to pesticide-resistant pests and pathogens. This has created a pressing need for sustainable and eco-friendly alternatives.

Biopesticides, derived from living organisms, are emerging as a vital solution in sustainable agriculture. These natural agents include bacteria, fungi, viruses, and nematodes, and act against insects, nematodes, and plant pathogens with minimal environmental impact (Gogos et al., 2012; Chhipa, 2017). Particularly, biofungicides play a crucial role in controlling fungal diseases, which are among the major contributors to crop losses worldwide.

By precisely targeting harmful organisms, biopesticides preserve beneficial insects, maintain soil health, and reduce chemical residues in food, contributing to both agricultural productivity and ecological balance (Kah et al., 2019; Rai et al., 2015).

In addition, microbial biopesticides are central to Integrated Pest Management (IPM) programs, reducing reliance on synthetic chemicals and supporting resilient, sustainable farming systems.

Microbial Biopesticides

Microbial biopesticides are formulations derived from microorganisms that suppress or eliminate crop pests and pathogens. They work in diverse ways:

1. Infecting or killing insects directly (bioinsecticides)
2. Producing toxins that inhibit pests and pathogens
3. Outcompeting harmful organisms for resources
4. Stimulating plant defense responses against diseases (biofungicides)

Unlike conventional pesticides, microbial biopesticides target only harmful organisms, reducing off-target effects and environmental contamination (Raliya et al., 2016).

Types of Microbial Biopesticides

Bacterial Biopesticides:

a. *Bacillus thuringiensis* (Bt): Produces toxins lethal to specific insect larvae, widely used in cotton, maize, and vegetables.

b. *Pseudomonas spp.* and *Bacillus subtilis*: Act as biofungicides, suppressing soil-borne fungal pathogens.

Fungal Biopesticides (Biofungicides & Bioinsecticides):

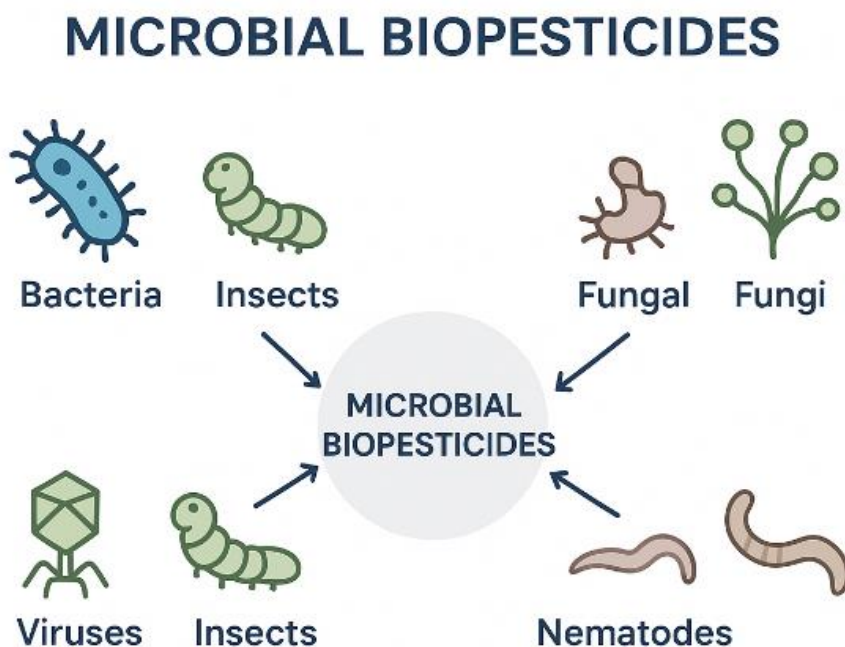
a. *Trichoderma spp.*: Controls fungal diseases like root rot, damping-off, and sheath blight.

b. *Beauveria bassiana*: Targets insect pests such as aphids and whiteflies.

c. *Metarhizium anisopliae*: Attacks soil-dwelling insect larvae.

Viral Biopesticides: *Nucleopolyhedroviruses* (NPVs): Target caterpillar pests without affecting other organisms.

Nematode-based Biopesticides (Bionematicides): Entomopathogenic nematodes attack soil pests like grubs and larvae, reducing damage in crops such as sugarcane, vegetables, and horticultural plants.



Advantages Over Chemical Pesticides

- 1. Eco-friendly & Biodegradable:** Do not leave toxic residues.
- 2. Target-specific:** Beneficial insects and pollinators remain unharmed.
- 3. Food Safety:** Crops are free from harmful chemical residues.
- 4. Reduced Pest Resistance:** Microbes evolve naturally, making it difficult for pests to develop resistance.
- 5. Disease Management:** Biofungicides suppress fungal pathogens, reducing crop losses (Parisi et al., 2015).

Applications Across Crops

Biopesticides are increasingly used in a variety of crops:

- 1. Rice:** Bt reduces stem borer infestations; *Trichoderma spp.* controls sheath blight.
- 2. Cotton:** Fungal and bacterial biopesticides manage bollworms and soil pathogens.
- 3. Vegetables & Fruits:** Biofungicides and nematodes protect tomatoes, cucumbers, cabbage, and citrus from pests and diseases.

Companies like Biozyme, Biobest, and JS Biotech provide trusted commercial formulations for Integrated Pest Management (IPM) programs (Kumar et al., 2019; Malhotra et al., 2020).

Recent Advances in Microbial Biopesticides

- 1. Microbial Consortia:** Multi-strain formulations combine bacteria, fungi, and nematodes for synergistic pest and disease suppression (Frontiers).
- 2. Innovative Formulations:** Microencapsulation and nano-encapsulation protect microbes from environmental stress and enable controlled release, improving shelf-life and field performance.
- 3. Genetically Optimized Strains:** Engineered microbes produce higher levels of natural toxins or antifungal compounds, increasing efficiency.
- 4. Integration with Precision Agriculture:** Drones, sensors, and AI-driven monitoring allow targeted application, reducing waste and improving efficacy.
- 5. Global Regulatory Support:** FAO and WHO recently published guidelines (2024) to standardize microbial pesticide development, promoting wider adoption in IPM programs.

Market Potential and Indian Context

In India, biopesticides currently account for approximately 9% of the total pesticide market, reflecting a growing awareness of eco-friendly alternatives and supportive government policies. The Indian market is projected to grow from USD 260 million in 2024 to USD 702.3 million by 2033, at a CAGR of 10.3%, driven by increasing demand for microbial-based crop protection, including biofungicides, bioinsecticides, and bionematicides. Although still smaller than chemical pesticides, microbial biopesticides are gaining prominence in IPM programs, promoting sustainable and environmentally responsible farming.

Challenges and Limitations

- 1. Shelf-life & Storage:** Microbial formulations are sensitive to temperature, UV light, and moisture.
- 2. Slower Action:** Effects may take several days compared to chemical pesticides.
- 3. Application Knowledge:** Correct methods and farmer training are essential for efficacy.
- 4. Environmental Variability:** Field performance may vary under different conditions.

Future Prospects

The future of microbial biopesticides is bright, with several trends shaping the next generation of sustainable crop protection:

- 1. Next-Generation Microbial Consortia:** Combining multiple microbial species with complementary functions enhances pest and disease suppression while improving plant resilience.
- 2. Advanced Formulations and Delivery Systems:** Microencapsulation, nano-encapsulation, and seed coatings increase microbial survival, controlled release, and field performance.
- 3. Genetically Optimized Strains:** Engineering microbes to produce higher levels of natural toxins or antifungal metabolites strengthens pest and disease control.
- 4. Integration with Precision Agriculture:** AI, drones, and sensor-based monitoring enable site-specific application, reducing waste and maximizing efficiency.
- 5. Expansion of Regulatory Frameworks:** Updated FAO and WHO guidelines facilitate faster approval, wider adoption, and farmer confidence.
- 6. Market Growth and Awareness:** Rising demand for organic and sustainable food, coupled with government support, will increase adoption in IPM programs.
- 7. Research in Novel Microbes:** Exploring underutilized species and microbial-plant interactions promises discovery of new biopesticides with enhanced efficacy.

Conclusion

Biopesticides including bioinsecticides, biofungicides, and bionematicides represent a sustainable, eco-friendly alternative to chemical pesticides. By harnessing the power of microbes, farmers can achieve

effective pest and disease control, enhance crop yields, and reduce environmental impact. With advances in microbial consortia, nano-formulations, genetic optimization, and precision agriculture integration, these tiny warriors are poised to play a transformative role in modern agriculture.

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Modern Fish Preservation Techniques and their Importance

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Sania Naznin¹, Anurag Bhuyan²

¹M. F. Sc, Fish Processing Technology, West Bengal university of Animal and Fisheries Sciences, Pancha Sayar, Chakgoria, Kolkata.

²PhD, Fish Processing Technology, College of fisheries, Assam Agricultural University, Raha, Assam.

Abstract

Fish and seafood are crucial sources of nutrition globally but are highly perishable due to their high moisture content and enzymatic activity. Traditional preservation methods such as sun drying, smoking, and salting are inadequate to meet modern demands for safe, high-quality, and long-lasting seafood. This article reviews advanced fish preservation techniques, including refrigeration, freezing, Modified Atmosphere Packaging (MAP), irradiation, High-Pressure Processing (HPP), vacuum packaging, and the use of natural preservatives. Each method plays a critical role in extending shelf life, maintaining nutritional and sensory quality, and ensuring food safety by inhibiting microbial growth and oxidation. Modern preservation techniques significantly reduce post-harvest losses, promote global seafood trade, enhance food security, and contribute to environmental sustainability by preventing overfishing. As consumer preferences shift toward convenient and “clean label” seafood products, continuous innovation in preservation technology is essential. These advancements help meet the growing global demand for seafood while supporting sustainable and safe consumption practices.

Keywords: Preservation, Seafood, Shelf-life, Techniques.

Introduction

Fish and seafood are indispensable components of human nutrition across the globe, especially in coastal regions where they form a primary source of protein, omega-3 fatty acids, vitamins, and essential minerals. As per the Food and Agriculture Organization (FAO), the global fish production reached over 179 million tonnes in 2018, highlighting the vital role fish plays in the world's food supply chain. However, fish are highly perishable due to their high-water content, enzymatic activity, and susceptibility to microbial spoilage. Traditionally, methods like sun drying, smoking, and salting were used by local communities to preserve fish, but these methods often compromised product quality and were unsuitable for long-term storage or large-scale trade.

With rapid technological advancement, urbanization, and the globalized seafood market, modern preservation techniques have become essential for maintaining the quality, safety, and shelf life of fish products. These methods not only ensure that consumers receive fresh and nutritious seafood but also play a critical role in reducing post-harvest losses, improving food security, and supporting sustainable fisheries management. As consumers increasingly demand high-quality, convenient, and safe seafood products, fish preservation technologies have evolved to meet these challenges.

Modern Fish Preservation Techniques

1. Refrigeration and Freezing: Refrigeration is one of the most commonly employed preservation methods in the seafood industry. It involves storing fish at temperatures between 0°C and 4°C, which slows down the activity of spoilage bacteria and enzymatic processes, thereby extending the freshness for a limited period, usually up to a few days. Refrigerated fish are widely used in local markets and for short transportation.

Freezing takes preservation further by storing fish at temperatures of -18°C or lower. This method halts microbial growth and enzymatic activities almost completely, allowing fish to be stored for several months without significant loss of quality. Quick freezing techniques like blast freezing and cryogenic freezing are especially effective. They rapidly reduce the temperature of the fish, minimizing the formation of large ice

crystals that can damage cell structure. This preserves the fish's texture, flavor, and nutritional content better than traditional slow freezing (FAO, 2020).

2. Modified Atmosphere Packaging (MAP): Modified Atmosphere Packaging (MAP) is a modern method where fish is sealed in packaging with a controlled atmosphere—typically consisting of a mix of carbon dioxide (CO₂), nitrogen (N₂), and oxygen (O₂). This gas mixture slows down the growth of aerobic bacteria and oxidative processes, maintaining the quality of the fish during refrigerated storage. MAP is particularly effective in preserving the color, odor, and texture of chilled fish, making it a preferred choice for fresh fish products sold in supermarkets. It also helps extend the shelf life from a few days to several weeks under proper storage conditions (Rahman, 2018).

3. Irradiation: Irradiation involves exposing fish to controlled doses of ionizing radiation (such as gamma rays, electron beams, or X-rays). This process effectively destroys pathogenic microorganisms, parasites, and spoilage bacteria without significantly raising the temperature of the fish or using chemical preservatives. As a result, it is considered a non-thermal and chemical-free method of preservation. Irradiation ensures food safety, reduces the incidence of foodborne diseases, and prolongs shelf life. It is especially beneficial for fish products destined for export, where maintaining high safety and quality standards is crucial (WHO, 2016).

4. High-Pressure Processing (HPP): High-Pressure Processing (HPP) is an innovative non-thermal technique that exposes fish to ultra-high pressures (up to 600 MPa) to inactivate spoilage and pathogenic microorganisms. Unlike thermal treatments, HPP preserves the original texture, taste, color, and nutritional value of the fish. The process is performed at low or ambient temperatures, making it ideal for ready-to-eat seafood products. Furthermore, HPP does not require chemical preservatives, appealing to consumers seeking “clean label” foods (Campus, 2010). This technique is gaining popularity in the seafood industry for producing high-quality packaged products with extended shelf life.

5. Vacuum Packaging: Vacuum packaging is a simple but effective preservation technique where air is removed from the packaging before sealing. The absence of oxygen inhibits the growth of aerobic bacteria and oxidation reactions, significantly extending the shelf life of fish. It is commonly combined with refrigeration or freezing to maintain freshness. Vacuum packaging is cost-effective and widely used for retail and industrial purposes.

6. Use of Natural Preservatives: In response to consumer demand for natural food products, natural preservatives such as plant extracts (e.g., rosemary, clove oil), organic acids (e.g., citric acid), and chitosan have been incorporated into fish preservation methods. These natural compounds exhibit antimicrobial and antioxidant properties that help reduce spoilage and maintain fish quality without synthetic chemicals. They are gaining popularity for eco-friendly and consumer-safe preservation (Rahman, 2018).

Importance of Modern Fish Preservation Techniques

The significance of modern preservation methods cannot be overstated, especially considering that approximately 20-30% of fish catch is lost globally due to spoilage, particularly in developing regions lacking cold chain infrastructure (FAO, 2020). These losses represent not only economic waste but also a missed opportunity to address global food security challenges.

1. Food Security and Waste Reduction: Modern preservation techniques help reduce post-harvest losses, ensuring more fish reaches consumers in good condition. This is vital in regions where fish constitutes a primary source of protein and nutrition. Reducing spoilage minimizes waste, helping to alleviate hunger and contribute to sustainable food systems.

2. Improved Food Safety: Preservation technologies like irradiation, HPP, and MAP contribute significantly to reducing the risk of foodborne diseases caused by bacteria such as *Listeria monocytogenes* and *Salmonella*. These techniques ensure that consumers receive safe and high-quality seafood products, reducing public health risks.

3. Global Seafood Trade Facilitation: With the growth of international seafood trade, modern preservation methods enable longer transportation distances while maintaining product quality. Techniques such as freezing, MAP, and HPP are essential in ensuring that fish arrives at distant markets with minimal deterioration.

4. Environmental Sustainability: By extending the shelf life of fish products, preservation methods reduce the pressure to overfish, as products can be stored and consumed over longer periods. This helps promote sustainable fisheries management and conservation of marine biodiversity.

Conclusion

Modern fish preservation techniques, including refrigeration, freezing, MAP, irradiation, HPP, vacuum packaging, and the use of natural preservatives, are critical in ensuring the availability, quality, and safety of fish products. These methods address the major challenges of spoilage, food safety, waste reduction, and environmental sustainability. As the global demand for high-quality seafood continues to rise, innovations in preservation technologies will play a pivotal role in supporting the industry and meeting consumer expectations. Future developments will likely focus on energy-efficient, cost-effective, and environmentally friendly methods, aligning the seafood industry with sustainable and health-conscious practices.

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Direct Seeding Rice: The Future of Sustainable Rice Cultivation

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Roshani Singh¹, Parshant Kumar Sharma²

¹Department of Genetics and Plant Breeding, Chandra Sekhar Azad University, Kanpur, Uttar Pradesh, India.

²Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India.

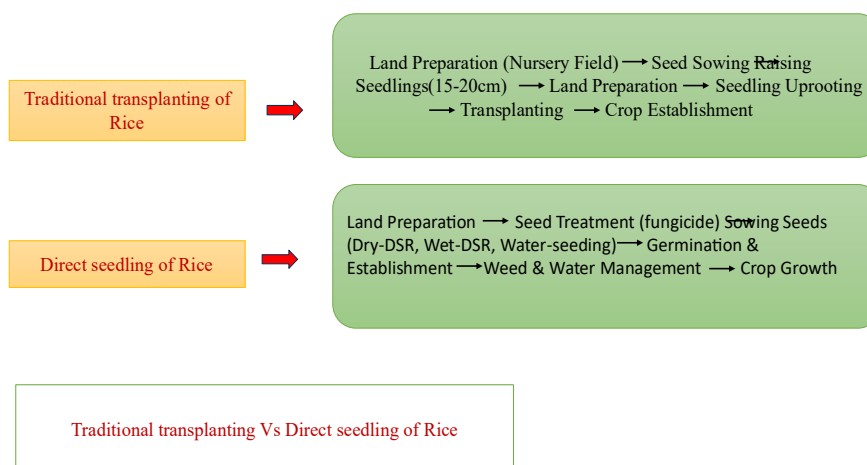
Abstract

Direct Seeding of Rice (DSR) is emerging as a sustainable and resource-efficient alternative to traditional transplanting methods. By sowing seeds directly into the main field, DSR reduces the need for nurseries, labor, and continuous water usage, while also allowing earlier crop maturity and lower production costs. It offers significant economic advantages to farmers and contributes to environmental sustainability by conserving water, reducing methane emissions, and maintaining soil health. Adoption of suitable rice varieties with desirable morphological and physiological traits enhances crop establishment, weed competitiveness, and yield stability under direct seeding conditions. With increasing labor shortages, water scarcity, and climate change challenges, DSR represents a climate-smart approach that can ensure food security and sustainable rice production in the future.

Keywords: Climate-Smart Agriculture, Crop Productivity, Direct Seeding of Rice (DSR), Weed Management, Rice Varieties.

Introduction

Rice is a staple food for more than half of the world's population, and its cultivation is critical for global food security (Kumar & Ladha, 2011). Traditional methods of rice cultivation, particularly transplanting, require large amounts of water, labor, and time, making them increasingly unsustainable in the face of water scarcity and labor shortages (Pathak et al., 2011). **Direct Seeding of Rice (DSR)** offers an innovative alternative, where seeds are sown directly into the main field, eliminating the need for nurseries and transplanting (Chaudhary et al., 2023). This method not only saves water and reduces labor costs but also shortens crop duration, supports mechanization, and lowers overall production expenses (Singh et al., 2022). With its potential to improve efficiency, conserve resources, and reduce environmental impact, DSR is emerging as a climate-smart and sustainable approach that could transform rice farming for the future (Shankaria, 2023).



Direct Seeding of Rice (DSR)

Direct seeding of rice is a method of rice cultivation in which seeds are sown directly into the main field, instead of first raising seedlings in a nursery and then transplanting them. This technique eliminates the nursery stage and the labor-intensive process of uprooting and transplanting seedlings.

There are three main types of direct seeding:

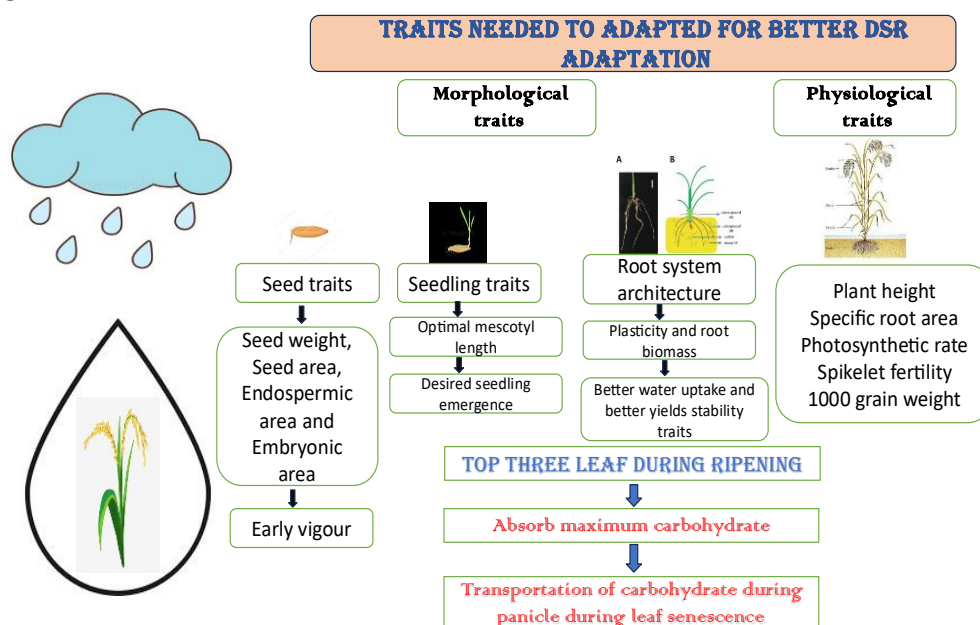
- Dry-DSR** – Dry seeds are drilled or broadcast on prepared but non-puddled soil.
- Wet-DSR** – Pre-germinated seeds are broadcast on puddled and wet soil.
- Water-seeding** – Seeds are broadcast into standing water in the field.

Advantages: Direct Seeding of Rice (DSR) offers several advantages over traditional transplanting. It saves water by eliminating the need for continuous flooding and reduces labor requirements since there is no nursery raising or manual transplanting. DSR also shortens crop duration, allowing rice to mature 7–10 days earlier, which enables timely sowing of subsequent crops and lowers the overall cost of cultivation. Additionally, it promotes better soil health by avoiding puddling, reduces methane emissions, and is well-suited for mechanization using seed drills or broadcasting equipment, making it a more efficient and environmentally friendly method of rice cultivation.

Disadvantages: Direct Seeding of Rice (DSR) also has some disadvantages. It is more prone to weed infestation because there is no standing water to suppress weeds, often requiring the use of herbicides and careful weed management. Uneven crop establishment can occur if seeds fail to germinate properly or if soil conditions are not ideal. DSR requires well-leveled fields and precise irrigation, and not all rice varieties perform well under this system, as some may be prone to lodging or poor tillering. Additionally, certain pests and diseases may be more problematic compared to traditional transplanting, making careful monitoring and management essential.

Traits Needed to Adapt for Better DSR Adaptation

For better adaptation to Direct Seeding of Rice (DSR), rice varieties should possess specific morphological and physiological traits. Morphologically, they should exhibit early vigour, a strong and well-branched root system, high tillering ability, lodging resistance, and favorable leaf architecture to ensure rapid growth, efficient light capture, and a strong crop stand. Physiologically, varieties should have uniform and quick germination, weed-competitiveness through early canopy closure or allelopathic potential, efficient water and nutrient use, tolerance to abiotic stresses such as drought or intermittent flooding, and high photosynthetic efficiency to support biomass accumulation and overall competitiveness. Together, these traits help DSR crops establish well, suppress weeds, and achieve higher yield under the challenges of direct seeding cultivation.



Suitable Varieties for DSR

For Direct Seeding of Rice (DSR), suitable varieties are those that combine early vigour, strong root systems, high tillering ability, lodging resistance, and stress tolerance. These varieties should also be short-to medium-duration, ensuring timely harvesting and compatibility with crop rotations. Some commonly recommended DSR-suitable varieties include:

1. Indica varieties: *PR 126*, *IR 64*, *Swarna*, *MTU 1010* – known for high yield and adaptability.
2. Hybrid varieties: *KRH 2*, *DRRH 1* – show early vigour and good weed competitiveness.
3. Short-duration varieties: *IR 20*, *Samba Mahsuri* – suitable for regions with limited water or short cropping windows.

These varieties are preferred because they establish well under direct seeding conditions, compete effectively with weeds, and maintain good grain yield.

Economic and Environmental aspects of DSR:

Aspects	Benefits
Economic	Saves labor and water, lowers cultivation costs, enables early crop maturity, supports mechanization.
Environmental	Conserves water, reduces methane emissions, improves soil health, promotes climate-smart farming.

Conclusion

Direct Seeding of Rice (DSR) represents a modern, resource-efficient, and sustainable method of rice cultivation. By eliminating the need for nurseries and manual transplanting, DSR reduces labor and water requirements, shortens crop duration, and lowers overall production costs, making it economically beneficial for farmers. Environmentally, it conserves water, reduces methane emissions, and maintains soil health, contributing to climate-smart agriculture. While challenges such as higher weed pressure and careful crop management exist, adopting suitable varieties with the right morphological and physiological traits ensures successful establishment and higher yields. Overall, DSR offers a practical and forward-looking alternative to traditional rice cultivation, supporting sustainable food production in the face of labor shortages, water scarcity, and climate change.

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Application and Mechanism of Virus Induced Gene Silencing (VIGS) in plants

Article ID: 72073

Roshani Singh¹

¹Department of Genetics and Plant Breeding, Chandra Sekhar Azad University, Kanpur, Uttar Pradesh, India.

Abstract

Virus-Induced Gene Silencing (VIGS) is a rapid and powerful reverse genetics tool widely employed in functional genomics to study gene function in plants. The technique exploits the plant's natural RNA-mediated antiviral defense mechanism, where viral vectors carrying fragments of the target gene trigger post-transcriptional gene silencing. VIGS offers several advantages over traditional transgenic approaches, including simplicity, cost-effectiveness, and the ability to analyze multiple genes in a relatively short time. It has been successfully applied to various crops for studying genes involved in development, metabolism, and stress responses, as well as in identifying candidate genes for disease resistance. Despite its advantages, VIGS has limitations such as host range dependency, variable silencing efficiency, and transient expression. Continuous improvements in vector design and delivery methods are enhancing the versatility and reliability of this approach, making VIGS an indispensable tool in plant molecular biology and crop improvement programs.

Keywords: Functional genomics, gene function, plant defense, reverse genetics, Virus-Induced Gene Silencing (VIGS).

Introduction

Virus-induced gene silencing (VIGS) is a powerful approach that exploits a plant's natural antiviral defense system to inhibit the expression of targeted viral transcripts (Dommes et al., 2019). The term VIGS was first introduced by van Kammen, who described it as a process of 'recovery from viral infection' (Kammen 1997). Virus-Induced Gene Silencing (VIGS) has become a powerful tool in plant biology, primarily for functional genomics, as it enables rapid and transient silencing of target genes without the need for stable transformation. It has been widely used to study gene function by observing phenotypic changes after silencing, with the *phytoene desaturase* (PDS) gene commonly employed as a marker due to its visible photobleaching phenotype. The earliest VIGS vector was developed from tobacco mosaic virus (TMV) by Kumagai et al. (1995), who successfully silenced the NbPDS gene in *Nicotiana benthamiana* through inoculation with in vitro-synthesized RNA transcripts.

Procedure of Virus Induced Gene Silencing

Virus-Induced Gene Silencing (VIGS) is a reverse genetics technique that exploits the natural RNA interference (RNAi) pathway in plants to suppress the expression of specific genes. In this process, a fragment of the target gene is inserted into a viral vector, which is then introduced into the host plant through methods such as agroinfiltration or mechanical inoculation. During viral replication, the engineered viral RNA is recognized as foreign, and the plant's defense system responds by producing double-stranded RNA (dsRNA), which is subsequently cleaved into small interfering RNAs (siRNAs) by Dicer-like (DCL) enzymes. These siRNAs are incorporated into the RNA-induced silencing complex (RISC), where they guide the complex to complementary RNA sequences. As a result, both the viral RNA and the endogenous plant mRNA containing the homologous sequence are degraded, leading to silencing of the target gene (Baulcombe, 1999; Burch-Smith et al., 2004). Once initiated, the silencing signal spreads systemically throughout the plant, allowing efficient and transient knockdown of gene expression, often associated with visible phenotypic changes (Senthil-Kumar & Mysore, 2014).

Figure: Application of virus induced gene silencing in plant

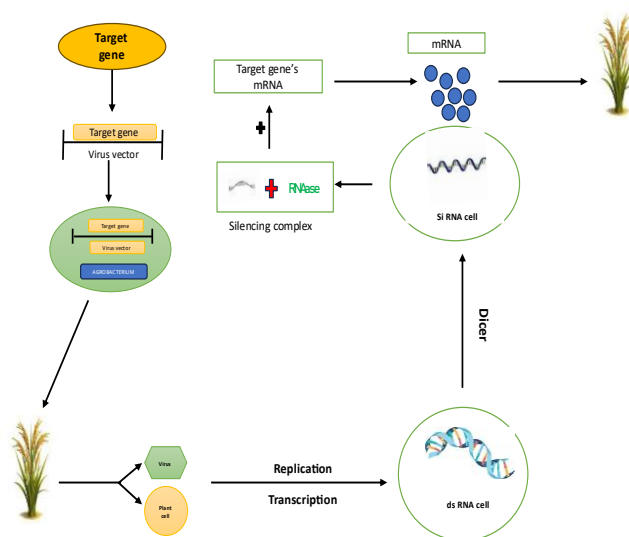


Figure: Application of virus induced gene silencing in plant

Application of Virus Induced Gene Silencing in Plants

1. Virus-Induced Gene Silencing (VIGS) has emerged as a versatile tool in plant research, particularly for functional genomics, as it enables rapid and efficient analysis of gene function without requiring stable transformation. By silencing target genes and observing resulting phenotypic changes, VIGS has been widely applied to study diverse biological processes. For example, the silencing of *phytoene desaturase* (PDS) produces a characteristic photobleaching phenotype, which serves as a visual marker of silencing efficiency.
2. VIGS is also extensively used to investigate plant–pathogen interactions by identifying host genes involved in resistance or susceptibility to various pathogens, including fungi, bacteria, and viruses.
3. Beyond disease studies, it has proven valuable in dissecting metabolic pathways such as those regulating flavonoid, alkaloid, and terpenoid biosynthesis, thereby enhancing our understanding of traits like flower pigmentation, fragrance, and nutritional quality. Additionally, VIGS facilitates the study of genes conferring tolerance to abiotic stresses such as drought, salinity, and temperature fluctuations, providing insights into plant adaptation mechanisms.
4. In crop improvement research, it accelerates the identification of genes related to yield, quality, and resistance traits, offering a rapid alternative to traditional transgenic approaches. Moreover, its adaptability for high-throughput functional screening makes VIGS a powerful strategy for large-scale gene characterization in a relatively short period of time.

Limitations of Virus Induced Gene Silencing in Plants

Although Virus-Induced Gene Silencing (VIGS) is a rapid and powerful tool for functional genomics, it has several limitations that restrict its application. One major drawback is its **transient nature**, as silencing typically lasts only a few weeks, which limits its use in studying long-term developmental processes. Additionally, the **efficiency and stability of silencing** vary depending on the viral vector, plant species, and target gene, often resulting in incomplete or inconsistent knockdown (Burch-Smith *et al.*, 2004). VIGS may also cause **off-target effects**, where genes with high sequence similarity to the target gene are unintentionally silenced, complicating data interpretation (Senthil-Kumar & Mysore, 2011). Furthermore, the **host range of viral vectors** is limited, meaning that suitable vectors are not available for all plant species (Baulcombe, 1999). In some cases, viral infection itself can induce **disease-like symptoms**, which may interfere with the analysis of gene function. Finally, VIGS is less effective in silencing genes expressed

in tissues with low viral movement, such as roots or meristems, restricting its applicability in certain studies (Lu *et al.*, 2003).

Conclusions of Virus Induced Gene Silencing in Plants

Virus-Induced Gene Silencing (VIGS) is a valuable reverse genetics tool that exploits the plant's natural RNA silencing machinery to transiently suppress target gene expression. It has proven highly effective in functional genomics, enabling rapid analysis of gene roles in development, metabolism, and responses to biotic and abiotic stresses. VIGS also facilitates large-scale gene characterization and accelerates crop improvement research by providing insights into traits related to yield, quality, and stress tolerance. Nevertheless, its versatility and adaptability continue to make it a widely used and powerful approach in plant molecular biology.

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Rapid Plant Tissue Analysis: A Ready Reckoner for Fertilizer Recommendation to Crops

Article ID: 72074

Dr. Pragyan Paramita Rout¹, Dr. Ipsita Das¹, Dr. Dhaneshwar Padhan², Dr. Srujani Behera

¹Department of Soil Science & Agricultural Chemistry, College of Agriculture, OUAT, Chiplima, Odisha.

²Central Sericultural Research & Training Institute, Central Silk Board, Mysore, Karnataka

³Department of Plant Pathology, College of Agriculture, OUAT, Bhawanipatna, Odisha.

Rapid Plant Tissue Analysis

Soil fertility evaluation is the process of assessing a soil's ability to supply nutrients for plant growth, using techniques like soil testing, plant tissue analysis, and visual plant symptom diagnosis. A rapid plant tissue test is a quick analytical method to determine the nutrient status of plant, providing timely intervention to address nutrient deficiencies or toxicities in crops and generate proper fertilization schedule. This method involves testing of sap collected from ruptured cells of growing plant parts mainly leaves for unassimilated N, P, K and other nutrients. The concentration of these nutrients in the cell sap gives a rapid and qualitative index of nutrient content in plants hence serves as a good indicator of supply of nutrients from soil. These tests offer an advantage over traditional laboratory analysis by enabling *in-situ* testing of nutrients in the field, helping farmers to optimize fertilizer use and manage crop nutrition efficiently.

Collection of Plant Tissues and Sample Preparation

The selection of crop growth stage for sampling, plant parts to be tested and interpretation are very important. The most critical stage of growth for tissue testing is at the time of bloom or from bloom to early fruiting stage. The nutrient concentration that is considered adequate usually changes as the plant grows and matures. Young actively growing leaves usually contain higher concentrations of nutrients than older leaves. In general, the conductive tissue of recently matured leaves (RMLs) is to be sampled. For rapid tissue test, index tissue to be sampled for different crops are furnished below (Source: TNAU Agri Tech Portal).

Crops	Nutrients					
	N	P	K	Ca	Mg	S
Cereals	Stem/Midrib	Leaf blade	Leaf blade	Leaf lamina	Leaf lamina	Leaf blade
Pulses	Petiole	Leaf blade	Leaf blade	Leaf lamina	Leaf lamina	Leaf blade
Oil seeds	Petiole	Leaf blade	Leaf blade	Leaf lamina	Leaf lamina	Leaf blade
Cotton	Petiole	Petiole	Petiole	Petiole	Petiole	Petiole
Banana	Leaf lamina	Leaf lamina	Leaf lamina	Leaf lamina	Leaf lamina	Leaf lamina
Papaya	Petiole	Petiole	Petiole	Petiole	Petiole	Petiole
Vegetables	Petiole, Leaf blade	Petiole Leaf blade	Petiole, Leaf blade	Petiole, Leaf blade	Petiole, Leaf blade	Petiole, Leaf blade

General precautions to be followed during sample collection and analysis are:

1. During collection plant samples should be wiped clean to avoid contamination.
2. Washing of samples with water prior to analysis should be avoided as certain water-soluble nutrients may be lost.
3. Samples should be kept cool, prevented from desiccation, and should be processed within 24 hours to avoid degradation and inaccuracy in result.
4. Sampled tissue should be sliced into 0.5 cm thin pieces, dipped into ether (98% v/v) solution, and put into a freezer for at least 2 hours.

5. For sap extraction, crusher should be made of PVC, stainless steel, or even nylon to avoid cross-contamination with metallic elements.

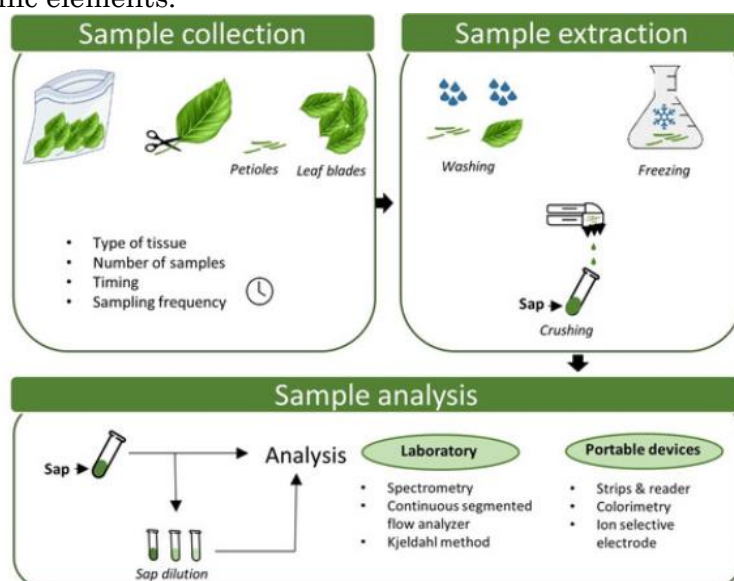


Fig 1. Flow diagram depicting sequential steps followed for plant tissue testing (Esteves *et al.*, 2021)

Common Techniques in Rapid Tissue Tests

Colorimetric Tests: It involves the use of suitable extracting reagents to develop a colour and the intensity of colour indicates the presence and relative quantity of a specific nutrient.

Portable meters: Devices like SPAD (Soil Plant Analysis Development) meters are used to estimate nitrogen content by measuring the chlorophyll in a leaf, as chlorophyll concentration often correlates with nitrogen levels.

Ion-selective electrodes: It involves use of sensing electrodes to measure specific ions directly in plant sap.

Standard Procedure for Tissue Test

Nutrient	Reagents	Procedure	Inference
Nitrogen (N)	1 % diphenylamine in conc. H ₂ SO ₄	Small bits of leaf or petiole are taken in a petridish and a drop of 1% diphenylamine is added.	Dark blue : Sufficient N Light blue : Slightly deficient N No colour : Highly deficient N
Phosphorus (P)	Ammonium molybdate solution & Stannous chloride powder	Freshly chopped leaf bits are taken in a test tube and 10 ml of ammonium molybdate reagent is added and kept for few minutes. After shaking, a pinch of stannous chloride is added.	Dark blue : Sufficient P Bluish green : Slightly deficient P No colour : Highly deficient P
Potassium (K)	Sodium cobalt nitrate reagent & Ethyl alcohol (95%)	Cut leaf bits are taken in a test tube and 10 ml sodium cobalt nitrate is added and shaken vigorously for few a minutes and kept for 5 minutes. Then add 5 ml of ethyl alcohol reagent, allowed to stand for 3 minutes.	No turbidity : Severe K Deficiency Slightly turbidity : Moderate K deficiency High turbidity : Sufficient K

Calcium (Ca)	Morgan Reagent (glacial acetic acid + sodium acetate)	0.5 g of cut leaves are taken into a glass vial (both of healthy plant and deficient plant in different vials) and 5 ml of Morgan's reagent is added. After allowing it to stand for 15 minutes, 2 ml of glycerin and 5 ml of 10 % ammonium oxalate is added and the solution is shaken for 2 minutes.	Turbidity resembling after 15 minutes indicate the amounts of calcium in normal plant tissue.
Magnesium (Mg)	5% sucrose solution 2% Hydroxylamine hydrochloride Titan yellow 10% Sodium hydroxide	To a tea spoonful of finely cut plant tissues, 1 ml of 5 % sucrose solution, 1 ml of 2 % Hydroxylamine hydrochloride, 1 ml of Titan yellow is added in in sequence. Then solution is made alkaline with 2 ml of 10% NaOH.	Red colour indicates presence of Mg & yellow colour indicates absence or traces of Mg.
Iron (Fe)	con. HCl con HNO ₃ 20% ammonium thiocyanate 2 ml of amyl alcohol	Finely cut leaf materials (0.5g) are taken into a glass vial and 1ml of conc. HCl is added in it. After 15 minutes, 10ml of distilled water and 2-3 drops of conc HNO ₃ are added. 10 ml of this solution is pipetted out into a specimen tube after 2 minutes and 5 ml of 20% ammonium thiocyanate is added and stirred. Further, 2 ml of amyl alcohol is added, shaken well and allowed to stand for few minutes.	The intensity of red colour in amyl alcohol layer indicates the quantity of iron.

Advantages

Quick diagnosis: Rapid tissue tests provide immediate results, allowing farmers to quickly identify nutrient imbalances in plants, especially when visible symptoms appear.

Timely intervention: Rapid testing allows for timely fertilizer applications or other nutrient management strategies, preventing further crop losses and supporting quick recovery.

Optimized nutrient use: By providing real-time insights into a plant's nutritional needs, these tests help to apply the fertilizers based on 4 R concept (right amount, right time, right method and right source).

Early stress detection: Rapid tissue tests can detect nutrient stress before it becomes severe, helping to prevent plants from becoming more vulnerable to pests, diseases, and other environmental stresses.

Beyond basic nutrients: Tissue testing can also detect potentially harmful levels of elements like cadmium, lead, arsenic, and selenium that may not be a focus of typical soil tests.

Conclusion

Rapid tissue test is a quick, on-site method for identifying nutrient deficiencies / toxicities in plants, to optimize crop nutrition for better crop yield and quality. Key steps include proper sampling (selecting index tissues at right crop growth stage), careful handling to prevent contamination, and comparison of results with established sufficiency ranges for accurate interpretation. Though this method is effective for early diagnosis of "hidden hunger" and efficient nutrient management, its accuracy is limited as it provides only qualitative information on nutrient status. Hence the result of tissue testing must be supplemented with soil test values and whole plant analysis for comprehensive evaluation of soil fertility.

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Role of CRISPR/Cas9 in Developing Stress-Tolerant Wheat

Article ID: 72075

Roshani Singh¹

¹Department of Genetics and Plant Breeding, Chandra Sekhar Azad University, Kanpur, Uttar Pradesh, India.

Abstract

Wheat, a major staple crop, is increasingly threatened by climate change, including drought, heat, salinity, and disease pressures. Traditional breeding methods are often slow and less precise in addressing these stresses. CRISPR/Cas9, a revolutionary genome-editing tool, enables precise, efficient, and cost-effective modification of stress-related genes, facilitating the development of resilient, high-yielding wheat varieties. Its ability for multiplex gene editing allows simultaneous improvement of complex traits, surpassing conventional methods. Integration with genomics and bioinformatics further enhances its potential for climate-smart wheat breeding. CRISPR/Cas9 offers a promising approach to ensure sustainable wheat production and global food security under changing environmental conditions.

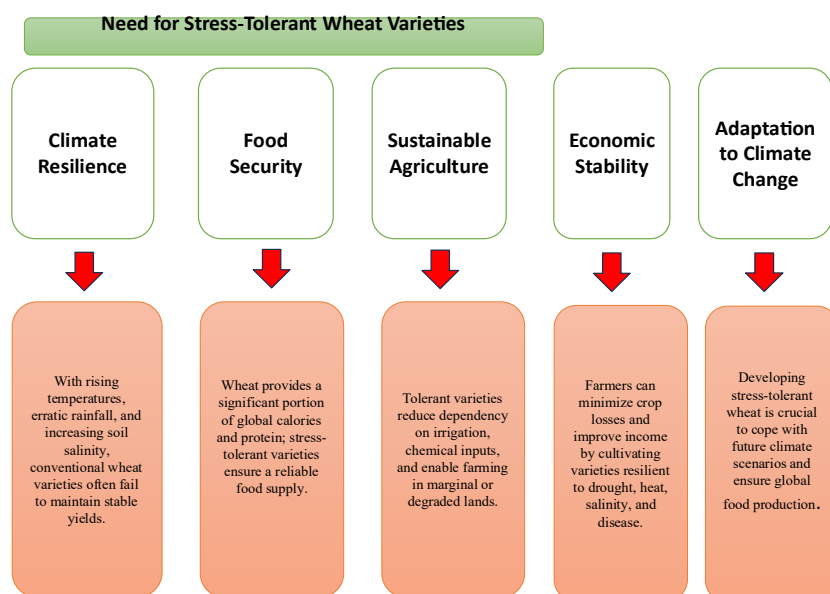
Keywords: Climate-resilient crops, CRISPR/Cas9, disease resistance, drought, heat, genome editing, salinity, stress tolerance.

Introduction

Wheat is one of the most important staple food crops worldwide, providing about 20% of the total dietary calories and protein consumed globally. It is cultivated on more land area than any other food crop, making it a cornerstone of global food security (Food and Agriculture Organization [FAO], 2021; International Plant Protection Convention [IPPC], 2023).

Climate Change Challenges in Wheat:

Factor	Impact
Drought	Low soil moisture, poor germination, reduced yield
Heat	Sterility, smaller grains, shortened growth cycle
Salinity	Reduced water uptake, stunted growth, chlorosis
Pest and diseases	Increased rusts, blights, new pest strains
Extreme weather	Floods, frosts, storms damaging crops



Introduction of CRISPR/Cas9 as a Revolutionary Tool in Crop Improvement

CRISPR/Cas9 is a precise and efficient genome-editing tool that allows targeted modification of plant genes. It enables the development of crops with improved traits such as stress tolerance, disease resistance, and higher yields, faster and more accurately than traditional breeding methods (Kafle, 2023; Mishra, 2024).

Figure: A flow chart of target plant generation by CRISPR/Cas9 method.

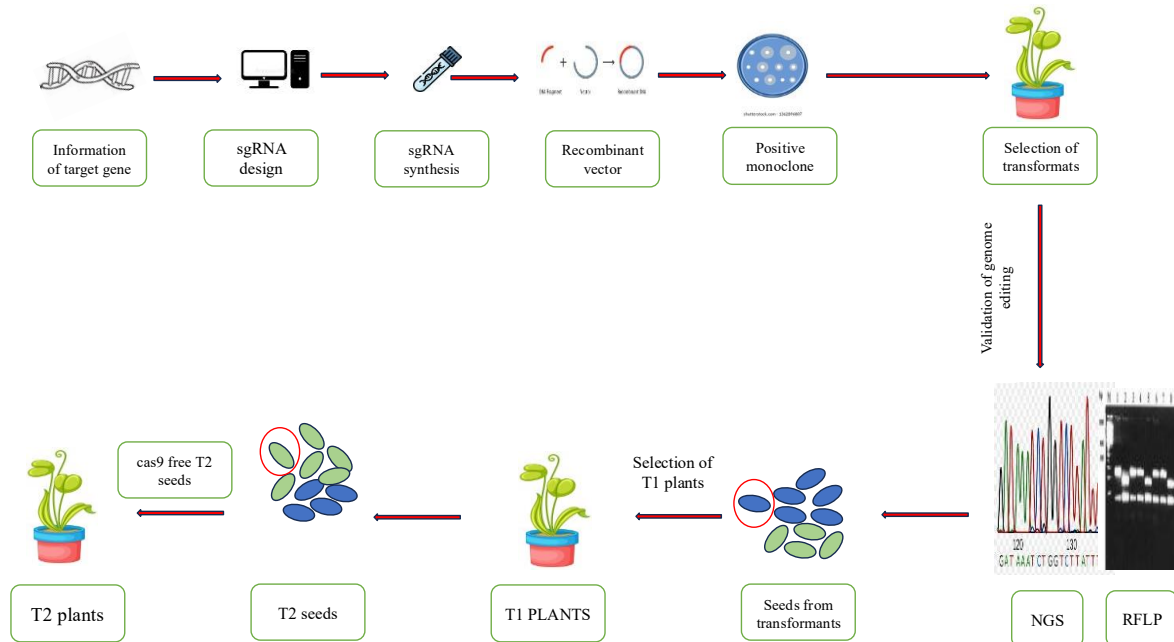


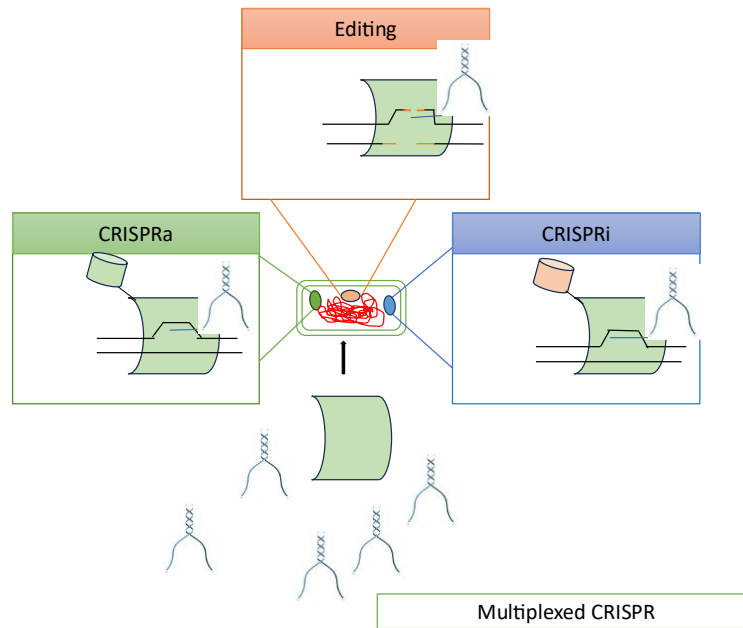
Figure: A flow chart of target plant generation by CRISPR/Cas9 method.

Advantages Over Traditional Breeding and Transgenic Methods in CRISPR/cas9

- 1. High Precision:** Targets specific genes without affecting other parts of the genome.
- 2. Faster Development:** Produces improved varieties in months to a few years, unlike traditional breeding that may take decades.
- 3. Multiplex Editing:** Can modify multiple genes at once for complex trait improvement.
- 4. No Foreign DNA Required:** Unlike transgenic methods, CRISPR can edit existing genes, reducing GMO-related regulatory hurdles.
- 5. Cost-Effective:** Requires fewer resources and field trials compared to conventional breeding.
- 6. Versatility:** Applicable to crops with complex genomes, such as wheat.
- 7. Sustainable Agriculture:** Enables development of stress-tolerant, high-yielding, and disease-resistant varieties efficiently.

Multiplex Genome Editing with CRISPR/Cas9

CRISPR/Cas9 allows simultaneous editing of multiple genes in a single plant, enabling the improvement of complex traits such as drought tolerance, heat resistance, and disease immunity. This capability is especially valuable for crops like wheat, where multiple genes control stress responses, making it faster and more efficient than traditional breeding or single-gene modification approaches.



Advantages of CRISPR in Wheat Improvement

- 1. Precision:** Targets specific genes without affecting other parts of the genome, reducing unintended traits.
- 2. Efficiency:** Speeds up breeding cycles, producing improved varieties faster than traditional methods.
- 3. Multiplex Editing:** Allows simultaneous modification of multiple genes for complex traits like drought and heat tolerance.
- 4. Stress Tolerance:** Enables development of wheat varieties resistant to drought, heat, salinity, and diseases.
- 5. Non-GMO Potential:** Can edit genes without introducing foreign DNA, easing regulatory concerns.
- 6. Cost-Effective:** Requires fewer resources and field trials compared to conventional breeding.
- 7. Sustainability:** Supports climate-resilient agriculture and global food security.

Challenges and Limitations of CRISPR/Cas9

- 1. Complex Genome of Wheat:** Wheat is polyploid (having multiple sets of chromosomes), making precise editing more difficult.
- 2. Off-Target Effects:** Unintended edits can occur, potentially affecting other genes and traits.
- 3. Regulatory and Ethical Issues:** Gene-edited crops face varying regulations globally, and public acceptance can be a challenge.
- 4. Limited Field Validation:** Most CRISPR-edited wheat varieties are still in research stages, requiring extensive field trials.
- 5. Technical Expertise Required:** Effective genome editing needs advanced laboratory infrastructure and skilled personnel.
- 6. Cost and Accessibility:** While cheaper than some methods, initial setup and technology access can be limiting for some regions.

Future Prospects of CRISPR/Cas9 in Wheat Improvement

The future of CRISPR/Cas9 in wheat improvement is highly promising, with the potential to revolutionize crop breeding. By integrating CRISPR with advanced tools like genomics, transcriptomics, and artificial intelligence, scientists can precisely identify and edit target genes for complex traits such as drought, heat, and disease resistance. This technology enables the development of climate-resilient wheat varieties,

improves nutritional quality, and supports sustainable agriculture by reducing dependency on chemical inputs and conserving water. Furthermore, CRISPR can play a crucial role in ensuring global food security by enhancing productivity and stability under changing environmental conditions. Continued research, field validation, and adoption of CRISPR-edited wheat will further accelerate the creation of resilient and high-yielding varieties for the future.

Conclusion

CRISPR/Cas9 represents a revolutionary advancement in wheat improvement, enabling the precise and efficient development of varieties that can withstand drought, heat, salinity, and diseases. By accelerating the breeding process and allowing targeted edits of multiple genes, this technology addresses the complex challenges posed by climate change. Its potential extends beyond stress tolerance, contributing to higher yields, improved nutritional quality, and sustainable agricultural practices. To fully realize these benefits, ongoing research, supportive regulatory frameworks, and active adoption by farmers are essential. Integrating CRISPR with modern tools like genomics, transcriptomics, and artificial intelligence will further enhance wheat resilience, ensuring global food security for the growing population under changing environmental conditions.

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Coconut-Based Integrated Farming for Sustainable Income

Article ID: 72076

Swarda Prashant Parab¹, Dr. Sumed B. Thorat²

¹Ph.D. Scholar, Plantation, Spices, Medicinal and Aromatic crops, College of Horticulture, Dapoli, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.

²Associate Professor (CAS), College of Horticulture, Dapoli, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.

Abstract

Coconut-based integrated farming systems (CBIFS) combine coconut with other crops, livestock, aquaculture and agroforestry, which provide smallholder farmers a greater sustainability and profitability. In this article, we provide a detailed perspective on CBIFS with particular emphasis on its principles, components, economic benefits, environmental impacts and case studies in India and Sri Lanka. Traditional coconut monocropping is not resource use efficient and is involved with low productivity (1,378 nuts/0.2 ha in Kerala) and economic risks to farmers from market forces and climate change. CBIFS comes with 80% land use efficiency and can be net profitable with a return 2-10 times more through multiple sources of income. From an environmental perspective, it captures carbon (18,297 kg CO₂ eq. 0.02 ha/year) with net negative greenhouse gas emissions. Success stories from Kerala and Goa show how it can increase both productivity and food security. We need answers for the challenges pests and pathogens, start-up costs and greying trees thrown up by farmer-led optical growth through integrated pest management and policy support. CBIFS is smart climate agriculture, a scalable model for sustainable rural development.

Introduction

The coconut palm (*Cocos nucifera* L.), also called the "tree of life," is the most important crop in the tropics for over 10 million people in India, spreading over an area of 2.2 million hectares, mainly in Kerala, Tamil Nadu and Karnataka (Sudha et al., 2021a). Despite such an extensive area underneath this traditional monocropping practice, its inherent inefficiencies lead to the use of only 20–30% of the available land (palm spacing 7.5 m × 7.5 m) as this practice results in low yield alongside vulnerability to pests, climate variability, and price fluctuations (Sudha et al., 2021b). A case in point is the average yield in Kerala, which is as low as 1,378 nuts/0.2 ha which cannot be economically viable (Subramanian et al., 2014).

Coconut-based integrated farming systems (CBIFS) can solve these problems by integrating coconuts with complementary enterprises in a resource-efficient and income-diversified way. Thus, in this form of utilization, utilization efficiency could be increased over 80% (Sudha et al., 2021b), by utilizing the deep root, provide tall canopy and shade tolerant by introducing other crops, livestock under palm and manner of agroforestry. CBIFS contributes to the sustainable development goals (SDGs), which most notably involves SDG 2 Zero Hunger (Baudron et al., 2021) and SDG 13 Climate Action (Choudhary et al., 2025), as it increases food security while enhancing the capacity of ecosystems to resist climate disturbances. CBIFS have been found to increase net returns over monocropping by 2-fold with BCR often >1.3 (Subramanian et al., 2014) at both national and regional scales (ICRISAT, 2003, Reddy et al., 2013).

In this article, an overview of the principles and components, economic advantages, environmental advantages, case studies, challenges and solutions with respect to CBIFS are discussed. This paper synthesizes recent studies which can be used as a guide for farmers, extension workers and policymakers on ways to progress to this climate-smart model to generate sustainable incomes.

Coconut-Based Integrated Farming Concept and Principles

CBIFS is an integrated farming system that enables coconut production with a variety of enterprises in a sustainable manner towards creating a self-sufficient farm system (Sudha et al. 2021a). The basic principle of it is diversity which minimizes risks arising from the dependence on the production of single-crops such as fluctuations in market prices and sudden pest outbreaks (Subramanian et al., 2014). By more vertically

and horizontally efficiently integrating multi-tiered cropping and livestock into its system, the coconut palm optimizes numerous interspaces that would otherwise remain underutilized (70-80% in monocrops) (Sudha et al., 2021b).

Key Principles Include

- 1. Efficient Deployment of Resources:** Well-established coconut trees when coupled with short-duration shallow-rooted intercrops like vegetables or spices reduce competition among tree and intercrops leading to higher yields (Sudha et al., 2021b).
- 2. Nutrient Cycling:** Upcycling of farm waste like dairy manure and biogas slurry results in 50% savings on external inputs while improving the fertility of the soil (Subramanian et al.
- 3. Biodiversity and Resilience:** The integration of agroforestry and livestock enhances ecological balance, agri-biodiversity for pollination, and climate resilience (Choudhary et al., 2025).
- 4. Economic Sustainability:** Continuous income from staggered harvests from crops and enterprises form the hedge against the long juvenile period of coconut (Sudha et al., 2021a).
- 5. Sustainability:** Organic fertilization and reduced forms of soil tillage under low-input systems preserve soil health and are consistent with nature-based solutions (Sudha et al., 2021b).

CBIFS converts the farm into a closed-loop systems, where outputs (e.g. manure) are inputs to other components leading to the sustainability of the production system over time and are aligned to the long-run sustainable production system based on local agro-climatic characteristics (Subramanian et al., 2014).

Components and Practices in Coconut-Based Integrated Farming

CBIFS include crops, livestock, and allied enterprises based on regional requirements.

Crop Components:

- 1. Major Plantation Crop:** Coconut (West Coast Tall and other varieties) at a distance of 7.5 m x 7.5 m.
- 2. Intercrops:** Banana (195 suckers/ha), black pepper (trailed on coconut trunks), vegetable 1 crops (cowpea, amaranthus, ash gourd), spices (ginger & turmeric), fruit crops (pineapple and papaya), tuber crops etc., Beverage crop - cocoa (Sudha et al., 2021b).
- 3. Fodder crops:** Hybrid Bajra Napier (117 t/ha/year), Guinea grass (85 t/ha/year), and Stylosanthes for livestock feed (Subramanian et al., 2014).
- 4. Agroforestry:** Peripheral planting of teak, mango, jackfruit; An Aloe vera too enhance biodiversity as well as income (Choudhary et al., 2025).

Livestock and Allied Enterprises

- 1. Milk:** 8-10 crossbred cows (Holstein Friesian-Jersey) yield 14,977 liters milk per year, fed with 25-30 kg green fodder at daily basis (Sudha et al., 2021a).
- 2. Poultry and Quail** – 100 broilers (4-6 batches/ year d) and 100 quail layers (7,000 eggs/year).
- 3. Aquaculture:** Ponds with 1,000 fingerlings (Fish, Catla, Rohu) gives about 400 kg fish/year.
- 4. Goatery :** 20-21 Malabari for meat and manure.
- 5. Biogas and azolla:** A 3 m³ biogas unit is set up using cow dung; slurry is used as manure for crops, and azolla pits are constructed to produce paddy straw (Sudha et al., 2021a).



Image source : (<https://india.mongabay.com/2022/11/coconut-based-integrated-farming-could-help-sequester-carbon-improve-farm-productivity-study/>
https://discoveragriculture.com/integrated-coconut-and-fish-farming/#google_vignette)

Practices

1. Nutrient Management -Organic recycling such as manure and Coir pith and soil test-based fertilization were found to Increase the productivity (Sudha et al., 2021b).
2. Water Management: Aquaculture ditches are irrigation canals as well.
3. Pest Control: There are biopesticides and biological control methods, which can minimize chemical application.
4. Field implementation with phased adoption, complemented by refresher training to allow for scalability (Subramanian et al., 2014).

These combinations of components will result in robust systems with reduced wastage and need for external factors (Choudhary, et.al., 2025).

Economic Benefits and Sustainable Income

CBIFS has significantly increased farm economics due to diversified income and cost reduction. In Kerala, BCR to the tune of 1.37 was derived from a 0.2-ha model that marketed gross returns worth Rs.2,19,982 and net returns amounted to Rs.58,454 compared with Gross monetization of Rs.agina or monocropping (Sudha et al., 2021b). Systems of more than one storey, such as coconut + pineapple + passion fruit generate a net return at the rate of USD 1,558.5/ha and BCR value is 1.99 (Choudhary et al., 2025). Total returns of Rs.6,75,212/ha can be realized from coconut (Rs.1,31,250), milk and (Rs.2,85,491) intercrops (Sudha et al., 2021a).

Productive for employment, providing 780-1,000 person-days/year per hectare and alleviating rural unemployment (Subramanian et al., 2014). Recycling and Rs. 8,236/year reductions in fertilizer costs it sustainable against market fluctuations (Sudha et al., 2021b). Profitability is increased by community associations through mass marketing and added value (Choudhary et al., 2025).

Environmental and Social Impacts

It is under the environmental dimension where CBIFS stands out capturing 18,297 kg CO₂ eq. /0.2 ha/year through agro-forestry with net negative GHG emissions (Sudha et al. 2021b). Organic farming enhances soil organic carbon, water holding capacity (21%) and microbial activity cumulating to reduction in GWP (Subramanian et al., 2014). Climate resilient: management of water through trenches (Choudhary et al., 2025).

From the social perspective, CBIFS provides nutrition security by producing excess food (> 116 kg coconut oil; >2,672 ltr milk/year for a family) (Sudha et al., 2021a). It strengthens smallholders through capacity building and participatory approaches, resulting in poverty reduction and community resilience (Choudhary et al., 2025).

Case Studies

In Kerala, from a 0.2-ha CBIFS model at IFSRS, Karamana has resulted in harvesting of 13,227 coconut equivalent nuts ten-typed as that much of state average yield with net negative GHGs emissions and family food surplus (Sudha et al., 2021b). In Goa, economies of the coconut + pineapple + passion fruit system were considered high (USD 1,558.5/ha) and ecofriendly (Choudhary et al., 2025). The ICAR-CPPRI's model was also scalable and net returns of Rs. 2,85,512/ha were obtained when dairy was integrated with aquaculture (Sudha et al., 2021a).

Challenges and Solutions

Barriers include scaling need; initial expenses pests (e.g., rhinoceros beetle); old trees; and climate risk (Subramanian et al. The solutions include subsidy, integrated pest management, resistant varieties and extension services. Alliances and partnerships such us the Sustainable Coconut Partnership focus on market access and supply chain (Choudhary et al., 2025).

Conclusion

Coconut-Integrated Farming is one such model that could transform rural livelihood from subsistence to sustainable income with eco-social development. Its integrated model also provides smallholders with

resilience, as the case studies elucidate. The enhancement of the potential for tropical agriculture, through research, training and support to policy development on scaling up CBIFS is an issue of priority.

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Agrobacterium radiobacter as a Biocontrol Agent in Plant Disease Management

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Surush Das¹, Shravan Kumar², Shradha Subba¹, Vishal Srivashtav¹

¹Plant Biotechnology, RGSC, Banaras Hindu University, Barkachha (U.P.)-231307.

²Mycology and Plant Pathology, RGSC, Banaras Hindu University, Barkachha (U.P.)-231307.

Abstract

Agrobacterium radiobacter (Beij. & Delden) Conn. has become an essential microbial tool for biologically controlling plant diseases, particularly crown gall caused by *Agrobacterium tumefaciens*. The development and extensive application of strains such as K84 and its modified variant K1026 makes this bacterium a prime example of dependable and environmentally friendly disease control methods. This review weaves together the most recent advancements in molecular genetics and biotechnological innovations to examine its historical background, underlying biological processes, molecular and genomic progress, commercial and regulatory evolution, demonstrated efficacy, and promising future directions as a biocontrol agent.

Keywords: *Agrobacterium radiobacter*, Biocontrol mechanisms, Agrocin 84, Crown gall disease, and K84.

Introduction

In sustainable agriculture, biological control agents (BCAs) are essential because they provide safe substitutes for chemical pesticides while drastically lowering health risks and environmental contamination. Among these biocontrol agents, *Agrobacterium radiobacter* is unique because it has been used extensively to control crown gall and related diseases in a variety of woody crop and horticultural systems (Ryder & Jones, 1991; Vicedo *et al.*, 1993). *Agrobacterium tumefaciens* is the main causative agent of crown gall disease, which presents as characteristic tumor-like growths that appear on plant roots and stems (Figure-1). The multifaceted strategy of *A. radiobacter* accounts for its remarkable biocontrol effectiveness: it uses specific gene-mediated mechanisms to suppress pathogenic bacterial strains, actively competes for vital root colonization sites, and produces potent antagonistic compounds (Kerr & Htay, 1974).

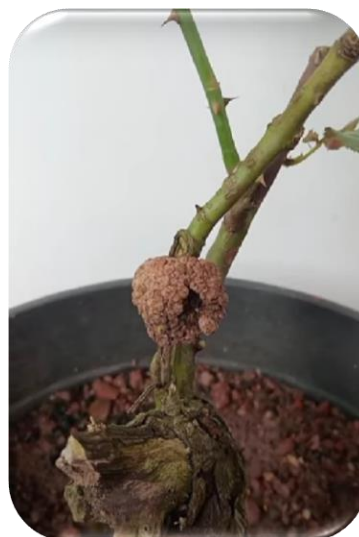


Figure 1: Crown gall disease in Rose

Taxonomy and Biology of *Agrobacterium radiobacter*

A member of the *Rhizobiaceae* family, *A. radiobacter* is a Gram-negative, motile bacterium that grows well in soil environments (Gan *et al.*, 2019). With high genomic similarity and notable differences in pathogenic potential and particular metabolic traits, this microbe and *A. tumefaciens* have an exceptionally close

evolutionary relationship (**Gan *et al.*, 2019**). Agrocin 84, which is the primary antibiotic compound that powers the bacterium's biocontrol abilities, is produced by the pAgK84 plasmid (**URL-1**), one of several plasmids the bacterium carries within its cellular structure (**Kim *et al.*, 2006**).

Classification (DKPCOFGS): Bacteria> Pseudomonadati> Pseudomonadota> Alfa proteobacteria>Hyphomicrobiales>Rhizobiaceae>*Agrobacterium* > *radiobacter*

Cryptogram: G^{-ve}: Rode shaped/ Obligate Aerobic/ Degenerate peritrichous:5-10µm/ Non-spore forming: Non-pigmented/colony-Round, Convex, Entire, Mucoid: 0.6-1.0 by 1.5-3.0 µm.

Mechanisms of Biocontrol

1. Inhibition of Pathogens: *Agrobacterium radiobacter* efficiently inhibits harmful agrobacteria through a variety of methods. Its main strategy is antibiosis, in which it secretes agrocin 84, a cunning Trojan Horse antibiotic that enters vulnerable *A. tumefaciens* cells via opine transporters and changes into the toxic TM84, which in turn inhibits the activity of tRNA synthetase (**Chopra *et al.*, 2016; Kim *et al.*, 2006**). ALS 84, a bacteriostatic compound that targets agrocin 84-resistant variants and other plant-pathogenic bacteria, is also produced by some strains, such as K84 and K1026 (**Peñalver *et al.*, 1994**). Furthermore, *A. radiobacter* outcompetes pathogens to secure vital space and resources in the plant rhizosphere, demonstrating superiority in competition for niche and nutrients (**AgBioChem, Inc. & New Bioproducts, Inc., 2000; Stockwell *et al.*, 1993**).

2. Genetic Basis of Biocontrol: According to genetic research, the pAgK84 plasmid contains distinct loci for immunity functions and at least five transcriptional units that are essential for the biosynthesis of agrocin 84 (**Ryder *et al.*, 1987; Wang *et al.*, 1994**). Scientists have demonstrated the complexity of this biosynthetic pathway through mutagenesis and transcript analyses (**Kim *et al.*, 2006; Wang *et al.*, 1994**). In the meantime, more stable and environmentally friendly variations, such as the well-known K1026 strain, have been created by targeted genetic modifications to transfer regions (**Bio-Care Technology Pty Limited, 1999**).

Commercial Application and Regulatory Status

1. Strains K84 and K1026: K84 is still used commercially throughout the world for the prevention of crown gall disease. Numerous crops and geographical areas have reliably demonstrated its efficacy (**Rhouma *et al.*, 2004; Ryder & Jones, 1991**). However, concerns regarding the possibility of horizontal transfer of resistance genes through plasmids prompted the development of K1026, a modified version with a deletion that inhibits conjugal transfer while maintaining its capacity to generate antibiotics and provide potent biocontrol outcomes (**Bio-Care Technology Pvt Limited, 1999; Kim *et al.*, 2006**).

2. Regulatory Approvals and Safety: Products based on *A. radiobacter* have been thoroughly evaluated for risk by organizations like the US EPA. Results show that under labeled use patterns, there is very little risk to people, non-target organisms, and the environment. To maintain safety and efficacy standards, regulatory agencies demand product-specific data and periodic reregistration (**United States Prevention, Pesticides EPA, 1995**).

3. Field Efficacy: K84 and K1026 strains efficiently reduce gall occurrence, size, and pathogen presence in susceptible plants, according to numerous studies conducted in both lab and field settings (**Ryder & Jones, 1991; URL-2**). Significant gall suppression results from *A. radiobacter* treatment during planting or through root dipping (**Rhouma *et al.*, 2004; Oksel *et al.*, 2024**). These commercial formulations are notable for their ability to target infection sites and blend in seamlessly with integrated pest management strategies (**URL-3**).

4. Application procedure for seeds and seedlings: The application process involves creating a suspension of the *A. radiobacter* culture and treating seeds, cuttings, or bare-root stock. NOGALL is highly effective prevention of crown gall disease in non-food bearing almond, pecan, apricot, caneberry, cherry, nectarine, peach, plum, walnut, non-food euonymus, and rose (**URL-4**). Specific instructions from a product like Nogall (strain K1026) detail the process:

a. Prepare the suspension: Mix the concentrated peat culture with cool, clean, chlorine-free water. For example, a 100-gram pack can be mixed with one gallon of water. Stir the solution vigorously. Replace treatment suspension after treating the equivalent of 200 plants/L of suspension

or sooner when larger trees are dipped or when the suspension becomes excessively dirty. Larger plants may require 45-60 liters of suspension per 5,000 plants.

b. Treat fresh wounds: The treatment should be applied within 2 hours of any handling or pruning that might have wounded the plant.

c. Use as a dip or spray:

i. Dip method: Dip bare-root seedlings or cuttings into the suspension to completely wet all root surfaces and the stem above the bud or graft union.

ii. Spray method: Use a coarse spray to cover the plant tissue to the point of runoff.

d. Protect treated plants: After treatment, keep the plants in a cool, humid area away from direct sunlight until planting.

e. Follow time limits: The bacterial suspension is only viable for a limited time and should be replaced. For instance, a Nogall suspension should not be held for more than 8 hours.

Current Challenges and Future Perspectives

Agrobacterium radiobacter is now a more dependable and secure biocontrol option thanks to recent advancements in genomics, molecular biology, and regulatory systems (Chen *et al.*, 2024). The risk of pathogens becoming resistant over time (Bio-Care Technology Pty Limited, 1999; Kim *et al.*, 2006), the need for consistent performance in various farming environments (Rhouma *et al.*, 2004; Stockwell *et al.*, 1993), the integration of cutting-edge tools like CRISPR for improved biocontrol features (Tang *et al.*, 2023), and the need to fine-tune product formulations, delivery systems, and regulatory updates are some of the ongoing challenges. Looking ahead, gene editing and multi-omics techniques have a lot of promise for creating sophisticated BCAs that can cover more hosts, withstand challenging field conditions, and adhere to higher safety regulations.

Conclusion

Through the production of antibiotics and competition, *A. radiobacter* efficiently manages crown gall, serving as an example of sustainable biocontrol in agriculture. Improved strains with increased safety and efficacy are anticipated thanks to developments in gene editing and genomics. Its incorporation into pest management will be improved by addressing formulation issues and resistance. In the end, *A. radiobacter* promotes environmentally friendly farming by lowering the need for chemicals while enhancing crop health and safeguarding the environment. Its function in managing plant diseases sustainably will be further enhanced in future by incorporation of precision molecular genetics, better formulations, and commercial scalability.

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Vertical Gardens: Transforming Urban Spaces into Sustainable Green Oases

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Bashaboina Sunil¹, Talari Sangeetha²

^{1&2}Department of Floriculture and Landscape Architecture, College of Horticulture, Rajendranagar, Hyderabad, SKLTGHU, Telangana, India.

Abstract

Rapid urbanization has led to shrinking green spaces, increased air pollution, rising urban temperatures, and reduced biodiversity, posing significant environmental and social challenges. Vertical gardens, also known as living walls, have emerged as an innovative solution to integrate greenery into limited urban spaces. By cultivating plants on walls, facades, and vertical panels, these gardens transform unused areas into productive and aesthetically pleasing green ecosystems. Vertical gardens offer multiple environmental benefits, including air purification, mitigation of the urban heat island effect, energy efficiency through natural insulation, and noise reduction. They also support urban biodiversity by providing habitats for pollinators and other species. Beyond ecological advantages, vertical gardens enhance mental well-being, reduce stress, and improve the quality of urban life. With modern techniques such as modular panels and hydroponics, vertical gardens are increasingly accessible, making cities greener, healthier, and more sustainable.

Keywords: Vertical Garden, living walls, urban sustainability, biodiversity, green architecture.

Introduction

As cities grow rapidly, urban landscapes are increasingly dominated by concrete, asphalt, and glass. This rapid urbanization brings numerous challenges: shrinking green spaces, poor air quality, rising temperatures due to the urban heat island effect, and even a reduction in urban biodiversity. Such changes not only affect the environment but also impact human health, mental well-being, and overall quality of life. Amid these challenges, vertical gardens, also known as living walls, are emerging as a creative and sustainable solution. Unlike traditional gardens that require horizontal space, vertical gardens utilize walls, facades, and other vertical structures to grow plants. This innovation allows cities to reintroduce greenery where space is scarce, transforming otherwise dull walls into lush, vibrant ecosystems. Vertical gardens are not just decorative. They offer multifaceted benefits—from improving air quality and reducing urban temperatures to enhancing mental health and promoting biodiversity. Globally, cities like Singapore, Milan, and Paris have embraced living walls in public spaces and residential buildings, showcasing how nature and architecture can coexist harmoniously. By integrating greenery into vertical spaces, these gardens turn urban challenges into opportunities, making cities healthier, more resilient, and more beautiful.

What Are Vertical Gardens?

Vertical gardens, often referred to as living walls or green walls, are an innovative approach to growing plants on vertical surfaces rather than traditional horizontal spaces. These walls can be made using a variety of structures, including trellises, modular panels, hanging pockets, or hydroponic systems, allowing plants to flourish even in areas with limited land. One of the most remarkable features of vertical gardens is their versatility.

They can accommodate a wide range of plants from ornamental flowers and shrubs that beautify urban spaces to edible crops like herbs, leafy greens, and small vegetables, which can contribute to urban food security.

Vertical gardens are increasingly being integrated into residential buildings, office facades, schools, hospitals, and public spaces, turning walls into thriving green ecosystems that improve both aesthetics and environmental quality.

Environmental Benefits (Yehuda and David, 2003; Bakhtyari *et al.*, 2024)

1. Air Purification: Plants are natural air purifiers. In vertical gardens, foliage **absorbs harmful pollutants** such as carbon dioxide, nitrogen oxides, and particulate matter, while releasing fresh oxygen into the surroundings. Studies have shown that green walls can significantly **reduce urban air pollution**, creating healthier environments for city dwellers. For instance, buildings in **Singapore and Milan** equipped with living walls have reported measurable improvements in local air quality.

2. Mitigation of Urban Heat Island Effect: Concrete and asphalt absorb and retain heat, raising urban temperatures a phenomenon known as the **urban heat island effect**. Vertical gardens help counteract this by providing **shade and cooling through evapotranspiration**, where plants release moisture into the air. This natural cooling can reduce surrounding temperatures by several degrees, making streets, balconies, and indoor spaces **more comfortable during hot months**.

3. Energy Efficiency: Green walls act as **natural insulators**, reducing the energy required for heating and cooling buildings. During summer, they **shade walls and limit heat absorption**, lowering indoor temperatures and reducing air-conditioning costs. In winter, the foliage adds a layer of insulation, helping retain warmth. Cities incorporating vertical gardens into building facades have reported **energy savings of 10–20%**, demonstrating both ecological and economic benefits.

4. Noise Reduction: Urban noise pollution is a growing concern, especially in busy streets and densely populated areas. The dense layers of plants in vertical gardens can **absorb and deflect sound waves**, acting as natural sound barriers. This makes them particularly valuable near **highways, airports, and commercial zones**, where they not only enhance visual appeal but also contribute to a quieter, more peaceful urban environment.

Urban and Social Impact (Sheweka *et al.*, 2011; Goel *et al.*, 2022)

1. Space Optimization: In many cities, land is scarce and property prices are high, leaving little room for traditional gardens. Vertical gardens offer an ingenious solution by utilizing walls, facades, and other vertical spaces that would otherwise remain unused. This allows urban planners and homeowners to create lush, green areas without requiring additional land, making cities not only more beautiful but also more functional. For example, apartments in Tokyo, New York, and Barcelona have transformed exterior walls into vertical gardens, turning concrete surfaces into vibrant pockets of greenery.

2. Biodiversity Enhancement: Vertical gardens do more than beautify they also support urban biodiversity. By planting a mix of native flowers, shrubs, and climbing plants, these green walls create habitats for pollinators like bees, butterflies, and birds, which are often scarce in urban environments. This contributes to healthier ecosystems within the city, helping maintain ecological balance while encouraging residents to reconnect with nature.

3. Mental Well-being: Numerous studies have shown that exposure to greenery has positive effects on mental health, reducing stress, anxiety, and even fatigue. Vertical gardens bring nature closer to city dwellers, whether in offices, schools, hospitals, or public spaces, offering a calming visual and psychological experience. In addition to their aesthetic appeal, they provide a sense of tranquility and connection with nature, which is increasingly valuable in the fast-paced urban lifestyle. Cities like Singapore and Paris have successfully incorporated living walls in public spaces to promote community well-being and enhance quality of life.

Design and Implementation (Dominici *et al.*, 2022; Farrokhirad *et al.*, 2024)

Creating a successful vertical garden is more than just hanging plants on a wall it requires **careful planning, the right materials, and thoughtful design**. The key factors to consider include:

1. Plant Selection: Choosing the right plants is critical. Factors such as **sunlight exposure, climate, maintenance requirements, and growth patterns** must be considered. Common choices include **ferns, ivy, mosses, succulents, herbs, and flowering plants**, depending on whether the garden is primarily decorative or edible. Native plant species are often preferred as they are **well-adapted to local conditions** and require less care.

2. Irrigation and Maintenance: A consistent water supply is essential for vertical gardens. Most modern systems use **automated drip or hydroponic irrigation**, which delivers water directly to plant roots

while conserving water. These systems often include **nutrient solutions** to ensure plants grow healthy and vibrant. Regular maintenance, such as pruning, replacing dead plants, and checking irrigation systems, keeps the garden flourishing year-round.

3. Structural Support: The supporting structure must be strong enough to hold the weight of plants, soil (or growing medium), and water. Materials such as **metal frames, wooden panels, and modular pockets** are commonly used. Lightweight systems like **modular panels** and **hydroponic setups** make installation easier and reduce load on walls.

4. Innovative Solutions: Modern vertical gardens are increasingly **modular and adaptable**, allowing panels to be pre-planted and easily installed on walls. Hydroponic vertical gardens, which grow plants without soil using nutrient-rich water, are becoming popular in urban settings where space and weight are constraints. Such innovations make vertical gardens accessible for **homes, offices, schools, and public spaces**, even in densely populated cities.

By carefully balancing **aesthetic appeal, environmental benefits, and practical considerations**, vertical gardens can thrive as **living, breathing installations** that enhance urban spaces both visually and ecologically.

Table: Plant species suitable for vertical gardening:

Plant	Type / Use	Sunlight Requirement	Water Needs	Ideal Vertical Garden Placement
Boston Fern (<i>Nephrolepis exaltata</i>)	Ornamental Foliage /	Partial shade	Moderate	Indoor walls, shaded balconies
Maidenhair Fern (<i>Adiantum spp.</i>)	Ornamental Foliage /	Shade	High	Indoor living walls, humid areas
English Ivy (<i>Hedera helix</i>)	Ornamental Creeper /	Partial shade to full sun	Moderate	Facades, fences, indoor/outdoor walls
Pothos (<i>Epipremnum aureum</i>)	Ornamental Foliage /	Low to bright indirect	Low	Indoor walls, offices, low-light areas
Spider Plant (<i>Chlorophytum comosum</i>)	Ornamental Foliage /	Indirect sunlight	Moderate	Indoor walls, office spaces
Rex Begonia (<i>Begonia rex</i>)	Ornamental Flowering /	Partial shade	Moderate	Shaded walls, indoor vertical gardens
Coleus (<i>Plectranthus scutellarioides</i>)	Ornamental Foliage /	Partial shade	Moderate	Indoor and outdoor vertical walls
Petunia (<i>Petunia spp.</i>)	Flowering	Full sun	Moderate	Outdoor walls, balconies
Geranium (<i>Pelargonium spp.</i>)	Flowering	Full sun	Moderate	Outdoor vertical panels
Nasturtium (<i>Tropaeolum majus</i>)	Flowering Edible /	Full sun	Moderate	Outdoor vertical gardens
Basil (<i>Ocimum basilicum</i>)	Herb / Edible	Full sun	Moderate	Kitchen walls, balconies
Mint (<i>Mentha spp.</i>)	Herb / Edible	Partial shade to sun	High	Indoor/outdoor vertical planters
Lettuce (<i>Lactuca sativa</i>)	Leafy vegetable / Edible	Partial to full sun	Moderate	Hydroponic or pocket gardens
Spinach (<i>Spinacia oleracea</i>)	Leafy vegetable / Edible	Partial to full sun	Moderate	Indoor/outdoor vertical walls
Cherry Tomato (<i>Solanum lycopersicum</i> var. <i>cerasiforme</i>)	Small vegetable / Edible	Full sun	High	Sunny vertical gardens, balconies
Strawberries (<i>Fragaria × ananassa</i>)	Fruit / Edible	Full sun	Moderate	Hanging pockets, outdoor walls

Sedum (<i>Sedum spp.</i>)	Succulent / Drought-tolerant	Full sun	Low	Sunny walls, rooftops
Aloe Vera (<i>Aloe barbadensis</i>)	Succulent / Medicinal	Full sun	Low	Sunny vertical panels
Bougainvillea (<i>Bougainvillea spp.</i>)	Creeper / Flowering	Full sun	Moderate	Outdoor walls, fences
Jasmine (<i>Jasminum spp.</i>)	Creeper / Flowering	Full sun to partial shade	Moderate	Trellises, balconies
Passionflower (<i>Passiflora spp.</i>)	Creeper / Ornamental	Full sun	Moderate	Fences, vertical panels
Morning Glory (<i>Ipomoea spp.</i>)	Creeper / Flowering	Full sun	Moderate	Outdoor walls, trellises

Conclusion

Vertical gardens are more than just a trend they are a practical and inspiring solution for modern cities striving to balance urban growth with environmental sustainability. By transforming blank walls and unused vertical spaces into lush, green ecosystems, these gardens improve air quality, reduce urban heat, save energy, and dampen noise, while simultaneously creating habitats for pollinators and urban wildlife. Beyond environmental benefits, vertical gardens also enhance mental well-being, offering city dwellers a daily connection with nature in otherwise concrete-dominated surroundings. They provide a creative way to maximize space, making even the smallest urban areas productive, beautiful, and environmentally friendly. As cities around the world continue to grapple with challenges like pollution, limited green spaces, and climate change, vertical gardens stand out as a symbol of harmony between architecture and nature. By embracing living walls, urban planners, architects, and residents can reimagine cities as greener, healthier, and more vibrant places to live, proving that even in the heart of a bustling metropolis, nature can thrive.

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The Multifaceted Role of Lawns: Ecological, Cultural, and Urban Perspectives

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Bashaboina Sunil¹, Talari Sangeetha²

^{1&2}Department of Floriculture and Landscape Architecture, College of Horticulture, Rajendranagar, Hyderabad, SKLTGHU, Telangana, India.

Abstract

Lawns, traditionally viewed as ornamental green spaces, have evolved into multifunctional components of urban landscapes that offer a range of ecological, social, and cultural benefits. Ecologically, lawns contribute to biodiversity, carbon sequestration, urban cooling, and stormwater management, serving as critical elements of sustainable green infrastructure. Socially, they provide recreational areas that promote physical health, mental well-being, and community interaction, while culturally, they reflect societal values, traditions, and identity, often symbolizing status and aesthetic preferences. Despite their advantages, lawns present significant challenges, including high water and energy demands, reliance on fertilizers and pesticides, vulnerability due to monoculture practices, and potential displacement of indigenous landscaping traditions. Understanding the multifaceted roles of lawns, alongside these limitations, is essential for developing sustainable management practices. Integrating ecological, social, and cultural considerations can transform lawns into resilient, multifunctional landscapes that enhance urban life and environmental sustainability.

Keywords: Lawns, Urban Ecology, Biodiversity, Cultural Significance, Sustainable Landscaping, Urban Planning, Green Infrastructure.

Introduction

Lawns, often perceived simply as stretches of grass surrounding homes and public spaces, have undergone a profound transformation in their role and significance over time. Historically valued primarily for their ornamental appeal and as symbols of social status, lawns have now emerged as critical components of urban and peri-urban landscapes. Beyond their aesthetic charm, well-designed and maintained lawns contribute significantly to environmental sustainability, playing a role in air purification, temperature regulation, and stormwater management. Moreover, they provide essential spaces for recreation, social interaction, and mental well-being, thereby enhancing the quality of life in densely populated urban areas. From an ecological perspective, lawns are no longer mere green carpets; they function as micro-ecosystems supporting soil health, biodiversity, and carbon sequestration. Socially and culturally, they reflect evolving human values and lifestyle practices, shaping community identities and cultural landscapes. This article aims to explore the multifaceted dimensions of lawns including their ecological, social, and cultural significance drawing insights from high-quality scientific research and contemporary urban studies, thereby highlighting how lawns have transitioned from simple ornamental features to vital, multifunctional elements of sustainable urban living.

Ecological Contributions of Lawns (Ignatieva *et al.*, 2020)

Lawns are more than aesthetic features they are vital components of urban ecosystems, providing multiple ecological functions that enhance environmental quality.

1. Enhancing Biodiversity: While lawns are often monocultures, incorporating a variety of turfgrass species, wildflowers, and native plants can transform them into microhabitats that support insects, pollinators, and soil microorganisms. This contributes to urban biodiversity and helps sustain ecological networks within cities³

2. Mitigating Urban Heat: Urban areas often experience higher temperatures than surrounding rural regions, a phenomenon known as the urban heat island effect. Lawns help counter this by cooling the

environment through evapotranspiration. Turfgrasses release water vapor into the air, which reduces surface and ambient temperatures, improving thermal comfort for residents.

3. Carbon Sequestration: Well-maintained lawns act as carbon sinks by capturing atmospheric CO₂ and storing it in soil organic matter. Deep-rooted turfgrass species enhance soil carbon storage, making lawns an important tool in mitigating climate change within urban landscapes.

4. Soil and Water Regulation: Lawns improve soil structure, reduce erosion, and increase water infiltration, which helps in groundwater recharge and stormwater management. By intercepting rainfall and reducing runoff, lawns contribute to better urban water management and reduce the burden on drainage systems.

In essence, lawns function as dynamic green infrastructure, providing critical ecological services that benefit both humans and the environment.

Lawns in Urban Planning

In urban landscapes, lawns extend far beyond decorative purposes; they play a critical role in shaping sustainable, livable cities. Thoughtfully designed and maintained lawns serve as multifunctional spaces that enhance both human well-being and ecological resilience.

1. Recreational Spaces: Lawns provide accessible green areas for a wide range of recreational activities, including walking, jogging, picnicking, and outdoor sports. These spaces promote physical health by encouraging exercise, while also supporting mental well-being by offering residents opportunities to relax, reduce stress, and connect with nature within the urban environment.

2. Aesthetic Value: Visually appealing lawns contribute significantly to the character and attractiveness of neighborhoods, parks, and public spaces. They create a sense of openness and order, soften the harshness of built environments, and elevate the overall quality of life for urban dwellers. The aesthetic appeal of green spaces has also been linked to increased property values and community pride.

3. Stormwater Management: Properly designed lawns play a vital role in urban hydrology by intercepting rainfall, enhancing infiltration, and reducing surface runoff. Lawns help mitigate flooding risks, recharge groundwater, and filter pollutants before they enter waterways. When integrated with other green infrastructure, such as bioswales or rain gardens, lawns become a key component of sustainable urban water management.

Overall, lawns in urban planning are not merely ornamental they are strategic tools that promote health, well-being, and ecological sustainability in cities.

Cultural Significance of Lawns (Ignatieva *et al.*, 2015)

Lawns are not only ecological and recreational assets they also carry profound cultural and social meanings that vary across regions and communities. Their design, maintenance, and use reflect historical traditions, societal values, and collective identities.

1. Symbol of Status: Historically and even today, a meticulously maintained lawn is often viewed as a symbol of wealth, prestige, and social status. Expansive, lush lawns surrounding residential properties or public institutions convey prosperity and careful stewardship of resources. This symbolic function has been widely documented across cultures, influencing perceptions of social hierarchy and aesthetic taste.

2. Cultural Practices: The practices associated with lawn care including planting, mowing, watering, and fertilization are deeply rooted in local cultural traditions. For example, European and North American lawn aesthetics prioritize uniformity and manicured appearance, whereas other regions may incorporate native grasses and ornamental plants that reflect local heritage. These practices not only maintain the lawn's visual appeal but also serve as expressions of cultural identity and lifestyle.

3. Community Identity and Social Cohesion: Shared lawns in parks, residential complexes, or public squares foster interaction and a sense of belonging among community members. They act as neutral, open spaces where people from diverse backgrounds can gather for social, recreational, or cultural activities. Such communal lawns contribute to social cohesion, encourage civic engagement, and strengthen neighborhood identity.

In essence, lawns are cultural landscapes that mirror societal values, traditions, and collective experiences, making them integral to both personal and communal identity.

Lawn Grass Species with Key Details

Table 1: Lawn grass species with key details:

Category	Species (Scientific Name)	Climate Preference	Texture	Growth Rate	Maintenance Level	Key Uses
Cool-Season	Kentucky Bluegrass (<i>Poa pratensis</i>)	Temperate	Fine	Moderate	Medium	Lawns, parks, sports fields
	Perennial Ryegrass (<i>Lolium perenne</i>)	Temperate	Medium	Fast	Medium	Overseeding, high-traffic lawns
	Tall Fescue (<i>Festuca arundinacea</i>)	Temperate	Coarse	Moderate	Low	Lawns with low water, drought-prone areas
	Creeping Red Fescue (<i>Festuca rubra</i>)	Temperate, Shade	Fine	Slow	Low	Shaded lawns, mixed seed blends
Warm-Season	Bermudagrass (<i>Cynodon dactylon</i>)	Tropical/Subtropical	Medium	Fast	Medium-High	Sports fields, sunny lawns
	Zoysiagrass (<i>Zoysia japonica</i>)	Subtropical	Medium	Slow	Low	Dense lawns, erosion control
	Buffalograss (<i>Bouteloua dactyloides</i>)	Dry, Temperate	Medium	Moderate	Low	Low-water lawns, eco-friendly landscapes
	St. Augustinegrass (<i>Stenotaphrum secundatum</i>)	Humid Subtropical	Coarse	Moderate	Medium	Coastal lawns, shade-tolerant areas
Specialty/Ornamental	Creeping Bentgrass (<i>Agrostis stolonifera</i>)	Temperate	Fine	Fast	High	Golf greens, ornamental lawns
	Seashore Paspalum (<i>Paspalum vaginatum</i>)	Coastal, Saline	Medium	Moderate	Medium	Coastal lawns, salt-tolerant areas

Challenges and Considerations

While lawns provide numerous ecological, social, and cultural benefits, their widespread implementation is accompanied by several challenges that must be addressed to ensure sustainability and resilience.

1. Resource Intensity: Maintaining aesthetically pleasing lawns often requires substantial inputs of water, fertilizers, pesticides, and energy. In regions facing water scarcity or environmental stress, high irrigation demands and chemical use can exacerbate resource depletion and contribute to pollution. Moreover, frequent mowing and maintenance involve fuel consumption and carbon emissions, highlighting the need for more sustainable management practices.

2. Monoculture and Biodiversity Limitations: Many lawns are dominated by a single turfgrass species, creating a monoculture that diminishes ecological diversity. Such uniformity reduces habitat availability for pollinators, soil microorganisms, and other wildlife. Monocultures are also more susceptible to pests, diseases, and extreme weather events, making lawns fragile and dependent on intensive management for health and resilience.

3. Cultural Hegemony and Ecological Overshadowing: The global spread of traditional lawn culture, particularly the uniform “European-style” lawn, can displace indigenous landscaping practices and native plant species. This cultural and ecological homogenization may undermine local biodiversity and erase culturally significant landscaping traditions, limiting opportunities for ecological and cultural adaptation.

4. Environmental Trade-offs: Even with well-intentioned management, lawns can contribute to environmental trade-offs, such as increased fertilizer runoff, soil compaction, and greenhouse gas emissions from maintenance activities. Balancing the benefits of lawns with these environmental costs is a critical consideration for urban planners, landscape architects, and homeowners alike.

Conclusion

Lawns transcend their traditional role as mere decorative features to become multifunctional landscapes that intertwine ecological, social, and cultural dimensions. Ecologically, they contribute to biodiversity, carbon sequestration, temperature regulation, and stormwater management, making them vital components of resilient urban ecosystems. From a social perspective, lawns provide spaces for recreation, relaxation, and community interaction, enhancing physical and mental well-being while fostering neighborhood cohesion. Culturally, they reflect societal values, traditions, and aesthetic preferences, serving as symbols of identity and status.

At the same time, lawns present challenges, including high resource demands, monoculture vulnerabilities, and the potential overshadowing of indigenous landscaping practices. Recognizing both the benefits and limitations of lawns is essential for designing sustainable, multifunctional green spaces. By integrating ecological knowledge, cultural sensitivity, and innovative management practices, lawns can be transformed into dynamic, resilient, and inclusive landscapes that enhance urban life while supporting environmental sustainability.

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Cost of Cultivation as a Decision-Making Tool for Farmers, Banks, and Policy Makers

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D.A. Rajini Devi¹, B. Mohan Uday Raj²

^{1,2}Cost of Cultivation Scheme, Professor Jayashankar Telangana Agricultural University, Hyderabad, Telangana, India.

Introduction

For any farmer, knowing the exact cost of production of crops or livestock is as important as knowing the yield. Unless we understand where and how much money is being spent, it is difficult to judge whether farming is profitable or not. Cost of cultivation studies are therefore an important tool for both farmers and policy makers. These studies help in fixing the Minimum Support Price (MSP), planning farm budgets, and guiding government schemes.

Classification of Cost Components

The total cost of producing a crop includes several elements. Broadly, these can be divided into:

- 1. Cash Costs:** These are costs where the farmer spends money directly. Examples include:
 - a. Buying seed, fertilizer, pesticides, or feed.
 - b. Paying hired labour (human, bullock, tractor).
 - c. Paying for irrigation, rent of leased land, veterinary medicines, etc.
- 2. Non-Cash Costs:** These are costs where no direct money is spent but they still have value. Examples include:
 - a. Family labour (men, women, children).
 - b. Home-grown seeds and farmyard manure.
 - c. Exchange labour (work exchanged between neighbours).
 - d. Depreciation of implements, interest on capital, etc.

In developing countries like India, non-cash costs form a big share because small farmers rely heavily on family labour and home-produced inputs.

- 3. Fixed vs. Variable Costs:**
 - a. Variable costs change with production (seeds, fertilizers, hired labour, irrigation, pesticides).
 - b. Fixed costs remain the same whether or not production happens (land rent, depreciation of machinery, maintenance of cattle, land revenue).

Both cash and non-cash costs can be fixed or variable.

Measuring Input Costs

Accurate measurement of costs is very important. Different methods are used:

1. Purchase price method – actual price paid for items like seeds, fertilizers, pesticides, veterinary medicines.
2. Market value method – for items like home-grown seeds, manure, or family labour (valued at local wage rate).
3. Net selling price – sale price minus marketing expenses.
4. Imputed value – for items not bought in the market, such as family labour.
5. Depreciation methods – for machinery, buildings, and implements.
6. Allocation of joint costs – when resources are used for multiple crops (e.g., bullock labour or tractor time shared between paddy and maize).

This ensures that even non-cash contributions are fairly valued.

Cost Concepts Used in Agriculture

To simplify comparison, agricultural economists classify costs into standard categories. The cost of cultivation (C2) covers not only paid out costs (out-of-pocket expenses) (A2) but also imputed value of owned assets including rental value of owned land, family labour and interest on owned fixed capital for which the farmers do not incur cash expenses.

The cost items currently considered in India are:

Paid-out costs:

- a. Hired labour (human, animal and machinery).
- b. Maintenance expenses (owned animals and owned machinery).
- c. Expenses on material inputs such as seed (home grown and purchased), fertilizer, manure (owned and purchased), pesticides and irrigation.
- d. Depreciation of implements and farm buildings (such as cattle sheds, machine sheds, storage sheds etc.).
- e. Land revenue.
- f. Rent paid for leased- in land.
- g. Interest on working capital
- h. Miscellaneous expenses

Imputed Costs:

- a. Value of family labour,
- b. Rental value of owned land,
- c. Interest on owned fixed capital, for which the farmer does not incur any cash expenses
- d. Managerial cost.

The paid-out costs and imputed costs are further classified as under:

Cost A1:

- a. Value of hired human labour.
- b. Value of hired bullock labour.
- c. Value of owned bullock labour.
- d. Value of owned machinery labour.
- e. Hired machinery charges.
- f. Value of seed (both farms produced and purchased).
- g. Value of insecticides and pesticides.
- h. Value of manure (owned and purchased).
- i. Value of fertilizer.
- j. Depreciation of implements and farm buildings.
- k. Irrigation charges.
- l. Land revenue, cess and other taxes.
- m. Interest in working capital.
- n. Miscellaneous expenses (Artisans etc.).

Cost A2: Cost A1 + Rent paid for leased land.

Cost B1: Cost A1 + Interest on value of owned fixed capital assets (excluding land).

Cost B2: Cost B1+ Rental value of owned land (net of land revenue) and rent paid for leased-in land.

Cost C1: Cost B1 + Imputed value of family labour.

Cost C2: Cost B2 + Imputed value of family labour.

Cost C2: Cost C2 adjusted to take into account valuation of human labour at market rate or statutory minimum wage rate whichever is higher.

Cost C3: Cost C2* + Management Cost at 10 percent of total cost (C2*).

For MSP fixation, Cost C2 is the most important benchmark as it includes both cash and imputed costs.

Cost Indicators are Important

1. For Farmers – Helps in deciding whether farming a crop is profitable and how to reduce expenses.
2. For Policy Makers – Provides basis for fixing MSP and designing support schemes.
3. For Researchers – Helps to compare efficiency of different regions and identify problem areas.
4. For Credit Institutions – Guides banks in estimating loan requirements for farmers.

In short, cost concepts like A2, B2, and C2 are not just academic definitions but practical tools shaping agricultural policies in India.

Conclusion

Agriculture is not just about production but also about economics. Farmers who clearly know their costs can make better crop choices, negotiate for better prices, and demand fair MSP. For governments, understanding cost structures helps in making policies that truly benefit farmers. Thus, cost of cultivation studies are like an “economic health check-up” of farming – essential for strengthening rural livelihoods and ensuring food security.

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Organic Mulching: A Sustainable Technique to Improve Soil Quality

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J. B. Vasave¹, R. R. Sisodiya², Jyoti Valvi³

¹Assistant Professor, Polytechnic in Agriculture, NAU, Vyara.

²Assistant Professor, NMCA, Dept. of Soil Sci. and Ag. Chem, NAU, Navsari.

³Junior Executive, National Co-operative Dairy Federation of India Limited, Anand.

Abstract

Soil health is the foundation of sustainable agriculture, yet it is increasingly threatened by degradation, erosion, nutrient depletion and climate variability. Organic mulching, the practice of covering soil with natural materials such as crop residues, straw, leaves, compost or agro-industrial by-products, has emerged as a cost-effective and eco-friendly strategy to restore soil quality. Multifaceted benefits of organic mulching, including improvements in soil physical, chemical and biological properties, enhanced moisture retention, weed suppression, reduced soil erosion, carbon sequestration, and increased crop productivity. Role of mulching in promoting microbial diversity, organic matter buildup and resilience against climate extremes. Challenges such as labour requirements, material availability and potential pest risks are also addressed. Ultimately, organic mulching stands out as a sustainable soil management practice that can contribute to food security, climate change mitigation, and agro-ecological sustainability.

Keyword: Sustainable, Organic mulching, Soil quality, Crop residues, Straw.

Introduction

Soil degradation is a major global challenge threatening agricultural productivity and food security. Intensive cultivation, overuse of chemical inputs, deforestation and improper land management practices have accelerated the depletion of soil organic matter, fertility loss and erosion. To counter these threats, sustainable practices that restore soil functions while maintaining productivity are urgently needed.

Mulching is an ancient agricultural practice, but its systematic use with organic materials has gained renewed attention due to its potential to enhance soil quality and reduce reliance on synthetic inputs. Organic mulches are bio-degradable, recyclable and locally available in most farming systems, making them affordable for both smallholders and large-scale farms.

Concept and Types of Organic Mulching

Organic mulching involves spreading bio-degradable materials on the soil surface to protect and improve soil conditions. Common sources include:

- 1. Crop residues:** Wheat straw, rice husks, maize stover, sugarcane trash.
- 2. Agro-industrial by-products:** Sawdust, bagasse, coir pith.
- 3. Animal by-products:** Farmyard manure, composted litter.
- 4. Forestry and urban waste:** Leaf litter, bark chips, shredded branches.

Different mulches decompose at varying rates, influencing nutrient release and soil amendment. High-carbon materials like straw decompose slowly, while nitrogen-rich residues decompose faster.

Mechanisms of Organic Mulch Action

Organic mulching benefits soil through physical, chemical and biological mechanisms:

- 1. Physical protection:** Reduces soil temperature fluctuations, prevents crusting, lowers erosion and improves infiltration.
- 2. Moisture regulation:** Acts as a barrier against evaporation, enhances water storage and reduces irrigation needs.

3. **Nutrient cycling:** Decomposition adds organic matter and nutrients, enhancing soil fertility.
4. **Biological stimulation:** Provides habitat and food for soil microorganisms, earthworms and beneficial insects.
5. **Carbon dynamics:** Enhances carbon sequestration and organic matter buildup.

Effects of Organic Mulching on Soil Properties

Soil Physical Properties:

- a. **Temperature moderation:** Mulch keeps soils cooler in summer and warmer in winter, reducing heat stress.
- b. **Soil structure:** Improved aggregation due to increased organic matter and microbial activity.
- c. **Bulk density:** Reduced compaction through root-microbe-organic matter interactions.
- d. **Water retention:** Increased porosity and infiltration enhance available soil moisture.

Soil Chemical Properties:

- a. **Nutrient enrichment:** Gradual release of N, P, K and micronutrients during decomposition.
- b. **pH regulation:** Organic acids from decomposition buffer soil pH.
- c. **Cation exchange capacity (CEC):** Organic matter enhances nutrient holding capacity.
- d. **Salinity reduction:** Mulch minimizes surface salt accumulation in arid zones.

Soil Biological Properties:

- a. **Microbial activity:** Organic carbon inputs stimulate beneficial bacteria and fungi.
- b. **Soil fauna:** Mulched soils harbor higher populations of earthworms, ants and beetles.
- c. **Enzyme activity:** Elevated levels of dehydrogenase, phosphatase and urease enhance nutrient cycling.

Role of Organic Mulching in Sustainable Agriculture

1. **Water Conservation and Drought Mitigation:** By reducing evaporation and improving infiltration, mulching ensures higher water use efficiency, 15–25% reduction in irrigation needs for mulched crops.
2. **Weed Suppression:** Mulch creates a physical barrier against weed seed germination, reducing herbicide dependency and manual weeding labour.
3. **Soil Erosion Control:** By cushioning raindrop impact and reducing runoff velocity, mulch reduces topsoil loss and conserves nutrients.
4. **Crop Yield and Productivity:** Research shows significant yield increases in cereals, vegetables and fruit crops under mulched conditions due to improved moisture and nutrient availability.

Climate Change Mitigation

Organic mulch sequesters atmospheric carbon into soils, enhancing resilience against climate variability.

Challenges and Limitations

Despite proven benefits, organic mulching faces practical barriers:

1. **Material availability:** Competing uses for crop residues (fodder, fuel).
2. **Labour and transport costs:** Collecting and spreading mulch can be time-intensive.
3. **Pest and disease risks:** Some mulches harbor termites, rodents or fungal pathogens.
4. **Slow decomposition:** May immobilize nitrogen temporarily, requiring supplementary fertilization.
5. **Scalability:** Large mechanized farms may find residue management difficult.

Integration with Other Practices

1. **Conservation Agriculture:** Mulching combined with minimum tillage improves soil carbon sequestration.
2. **Organic Farming:** Complements compost and bio-fertilizer application.
3. **Agroforestry:** Leaf litter mulching supports nutrient recycling.
4. **Climate-Smart Agriculture:** Enhances resilience against heat, drought and heavy rainfall.

Future Prospects and Research Needs

- 1. Material innovation:** Use of agro-industrial waste (coir pith, bagasse pellets) as mulch alternatives.
- 2. Biodegradable mulch composites:** Blending residues with biochar or microbial inoculants.
- 3. Mechanized application methods:** Development of residue spreaders for large farms.
- 4. Long-term soil health monitoring:** Quantifying impacts on soil carbon stocks and biodiversity.
- 5. Policy support:** Incentives for crop residue recycling to discourage burning and promote mulching.

Conclusion

Organic mulching is a proven, eco-friendly technique for improving soil quality. It enhances soil structure, nutrient cycling, water retention and biological activity while reducing erosion, weeds, and input dependency. Its integration into cropping systems can help address soil degradation, climate change and food security challenges. However, scaling adoption requires addressing constraints related to material availability, labour and pest risks. With supportive policies, technological innovations and farmer training, organic mulching can serve as a cornerstone of sustainable soil management and resilient agriculture.

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Kokedama - A Unique and Eco-Conscious Way of Beauty of Indoor Plants

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Bhanu Murthy K. C¹, Dr. Sapna Panwar²

¹Scientist, RHRS, Tirupati, Andhra Pradesh.

²Senior Scientist, FLS, ICAR-IARI, New Delhi.

What is Kokedama?

Kokedama is a ball of soil covered with moss on which ornamental plants are grown. It is also called poor man's bonsai. It's made of wet soil and a cocopeat formed into a ball. The plant is set into the ball and afterward, the moss is wrapped around it. Aluminum wire or nylon wire fixes the whole bundle and is sometimes used to hang the Kokedama in the air.

Kokedama: The Japanese Way of Indoor Gardening

Kokedama is also one of the means of indoor gardening, which is a centuries-old Japanese form of garden art that is closely tied to the practice of bonsai. Kokedama's term is derived from "Koke" which means moss, and "dama" which means ball. Kokedama or Japanese moss ball is a favorite among plant decoration enthusiasts who are also passionate about sustainability. Indoor gardening is gaining importance in this modern world due to its multiple benefits like environment, positivity, decoration, health, etc. It is a decorative art of encasing a plant's root in a ball of soil covered with moss. Kokedamas aren't just trendy plant decor; they make the best gifts for plant lovers and are sustainable because they eliminate the use of plastic.

Things are Required to make Kokedama

1. A plant of our choice
2. Sheet moss
3. Sphagnum moss
4. Water
5. Thin thread of cotton/jute
6. Light potting mix
7. Scissors
8. Mug
9. Big bowl.



How to make Kokedama?

Step-by-step guide on how to make a homemade Kokedama with the materials

1. Mould a mud ball: The first thing is to make a Kokedama, add the 10 cups of potting soil into a big bowl then mix in some water and firmly stir the soil to a muddy consistency. Don't add too much water, the potting soil has to become mud that can be molded into a ball.

2. Prepare the indoor plant: In this step, remove the plant from its original pot and gently shake off the soil that it has around its roots. After this, we should have a plant with roots and without soil. Take the 4 cups of sphagnum moss, make it damp, and gently put it around the roots of the plant. Then take a thin cotton thread and wrap it very loosely around the sphagnum moss.

3. Put the plant inside the mud ball: Now take the ball of mud and divide the ball into two pieces with a simple and gentle twist. And place the plant between the two halves and firmly reform the ball around the plant. Continue to give shape to the unity between the new compost mix and the plant until you have a solid ball sustaining the plant.

4. Wrap the Sheet moss around the mud ball: Once the mud ball is holding together firmly, wrap the sheet of carpet moss around it and gather the moss around the stem of the plant. Then, it's time to wrap the thin thread of jute/cotton around the ball. Wrap the thread firmly around the moss ball until the ball is round. You might have to squeeze the ball to make it around. Lastly, if we want to hang the kokedama, wrap another piece of twine around the neck of the ball, and Kokedama will be ready to hang anywhere you like.





Plants to Grow in Kokedama

Hardy houseplants that stay small, grow slowly and are tolerant to less than ideal conditions are the best houseplants for Kokedama. Avoid plants that grow too large or too quickly. The following are the few plants that can grow well in Kokedama

1. Pothos (*Epipremnum pinnatum*)
2. Bromeliad (*Noeregelia ampullacea*)

3. Money Plant (*Pilea polybotrya*)
4. ZZ Plant (*Zamioculcas zamiifolia*)
5. Peperomia (*Peperomia griseoargentea*)
6. Croton (*Codiaeum variegatum*)
7. Peace Lily (*Spathiphyllum wallisii*)
8. Super Dwarf Red Vine (Philodendron)
9. Spider Plant (*Chlorophytum comosum*)
10. Pineapple Mint (*Mentha suaveolens*)
11. Ficus Tree Bonsai (*Ficus retusa bonsai*)
12. Succulents
13. Portulaca.

Where to Put a Kokedama?

To suspend a Kokedama, always depends on the plant that is growing and area of hanging it. It is always better to avoid Kokedama in sunny spots because it is very prone to sunlight and dry out fast, once exposed to the sun. Also, if we are in a very cold area then place our Kokedama inside the house.

How to Care for Kokedama?

1. Every day we should lightly mist the plant with a spray bottle and also place the Kokedama ball in a tray of pebbles and water underneath the plant to add the necessary humidity. Ideally, the Kokedama plant needs to be soaked in a water bowl at room temperature for 10 minutes. Later drain the ball by hanging it somewhere till it stops dripping.
2. As the plants start to grow bigger roots will start poking out of the ball and this indicates that it needed to be re-potted into a bigger moss ball. Kokedama shares a very decorative way to grow your plants that will give your home a very calm and serene vibe. They will also freshen up the air in the room and eliminate bad energies.

Significance of Kokedama

1. Unique natural influence
2. Peacefulness
3. Sustainability and eco-friendly
4. An excellent air purifier
5. Relieves stress and helps tranquillity
6. Gives interior a mystic effect
7. Easy to maintain
8. Saves space
9. Gives outdoor also a great look

Using the Kokedama culture, the harmonious blend of tradition, sustainability and adaptability, one can enjoy unique and eco-conscious way of beauty of indoor plants.





Gender Issues in Consumerism

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Dr. Swetha Kodali¹, Ch. Tejaswi², Ch. Sneha Latha³

¹Scientist (FRM), AICRP on WIA, PJTAU, Rajendranagar, Hyderabad.

²Research scholar, Department of Resource Management and Consumer Science, College of Community Science, PJTAU, Saifabad, Hyderabad.

³Assistant Professor, Department of Resource Management and Consumer Science, College of Community Science, PJTAU, Saifabad, Hyderabad.

Abstract

Gender-related concerns in consumerism are complex, reaching beyond conventional marketing to affect product development, pricing strategies, and societal norms. This paper investigates several crucial areas where gender interacts with consumer behavior. It starts with a discussion on gender stereotypes in marketing and advertising, emphasizing the continued presence of outdated archetypes such as the "domestic goddess" and "macho man," along with the "pink and blue" distinction in children's products. The paper then examines the "pink tax," a type of gender-based pricing bias that results in higher costs for female-targeted products compared to those aimed at men. Additionally, it delves into the negative effects of consumerism on body image and self-esteem for both genders, by endorsing unrealistic standards of beauty and physique. The text additionally highlights the impact of gender roles on sustainable consumption habits, creating an unequal responsibility for women regarding eco-friendly actions at the household level. In conclusion, the document examines the shifting environment, where consumer pushback, the need for inclusive representation, and the emergence of gender-neutral marketing are contesting conventional norms and encouraging brands to adopt a more equitable and genuine strategy for engaging with consumers.

Introduction

Gender matters in consumerism are intricate and profoundly embedded in our economic and social environments. They encompass much more than merely promoting distinct products for men and women. Gender affects every aspect, from the design and pricing of products to the advertising we encounter and the cultural norms that guide our buying choices.

1. Gender Stereotypes in Marketing and Advertising: This is arguably the most prominent and heavily debated gender issue in consumerism. Advertisers have traditionally depended on strict gender stereotypes to market their products, and although some advancements have occurred, these stereotypes continue to exist.

- a. Advertisements frequently depict women as the main caregivers, homemakers, and emotional guides for the family, whereas men are often portrayed as mainly concentrating on work and leisure activities. This perpetuates old-fashioned gender roles and restricts how both men and women perceive themselves and their positions in society.
- b. Marketing for products typically linked to men, like cars or tools, usually highlights strength, dominance, and independence. Conversely, women are often shown as requiring protection or assistance, which reinforces a power imbalance.
- c. This phenomenon is especially apparent in products designed for children. Items such as toys, clothing, and even literature are frequently marked with strong gender associations through their colors, themes, and messaging. Such practices not only restrict a child's creativity and curiosity but also instill the notion from an early age that specific interests and professions are designated for "boys" while others are reserved for "girls."

2. The "Pink Tax" and Variations in Pricing: The "pink tax" is the term used to describe the situation where products aimed at women, particularly personal care products, are priced higher than comparable items aimed at men. For instance, a woman's razor or shampoo might work the same as a man's version,

yet it costs more because of marketing and packaging. This represents a type of price discrimination based on gender that affects female consumers more than others.

3. Gender and Eco-Friendly Consumption: Gender roles influence our approach to sustainability. Studies indicate that women are frequently depicted and expected to handle household sustainable practices, such as recycling or using environmentally friendly cleaning products. Conversely, men are typically linked to larger sustainability initiatives, like setting up solar panels or overseeing a family's transportation decisions. This separation can strengthen conventional gender roles and impose an unfair burden on women regarding environmental conservation.

4. The Changing Landscape: Questioning the Norms: As society's view of gender becomes more complex and inclusive, consumerism is gradually being compelled to change.

a. Gender-Neutral Marketing: Numerous forward-thinking brands are shifting away from gender-specific advertising and products. They are developing campaigns that emphasize the product's purpose and worth, rather than who "should" use it. The emergence of gender-neutral clothing lines and toy sections is a small yet important advancement in this area.

b. Inclusive Representation: Consumers, especially Gen Z and Millennials, are increasingly insisting on seeing diverse and genuine portrayals of gender in advertising. This involves showcasing individuals of various body types, ages, and backgrounds, as well as recognizing and celebrating non-binary and gender-diverse people.

c. Consumer Backlash: Social media has provided consumers with a strong platform to hold brands responsible for sexist or stereotypical messages. Public backlash can swiftly prompt a brand to reassess its marketing approach and can act as a warning for others.

Conclusion

The gender issues in consumerism are not just about who buys what. They are about how marketing and advertising shape our identities, reinforce social norms, and can create systemic inequalities. As consumers become more aware and critical, the push for a more equitable and inclusive marketplace is gaining momentum, forcing brands to move beyond outdated stereotypes and embrace a more authentic and respectful approach.

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Italian Basil: An Exotic Salad Vegetable

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Gudiya Manisha Sahu¹, Priyanka Nayak¹, Tanmoy Mondal², Santunu Mohanty³

¹B.Sc. (Agriculture) Student, MITS Institute of Professional Studies, Rayagada, Odisha, India-765017.

²Assistant Professor, MITS Institute of Professional Studies, Rayagada, Odisha, India-765017.

³Dean, MITS Institute of Professional Studies, Rayagada, Odisha, India-765017.

Introduction

Italian Basil (*Ocimum basilicum* L.), a member of the family Lamiaceae, is commonly referred to as Sweet Basil and is often regarded as the “king of herbs”. It is a fragrant, tender annual herb native to the tropical regions of Asia and Africa and is now widely cultivated worldwide for its culinary, medicinal, and industrial applications. The leaves are extensively used as a flavoring agent in sauces, pesto, salads, and other preparations. Phytochemically, basil leaves are rich in essential oils, predominantly containing Linalool and Methyl chavicol, along with polyphenols and flavonoids. These constituents are largely responsible for its anti-inflammatory, antioxidant, and antimicrobial properties. Traditionally, Italian basil has been employed in the treatment of a wide range of ailments, while its mucilaginous seeds exhibit thickening and stabilizing properties comparable to plant-derived gums.



Figure 1: Italian Basil plant

Plant Botany

Italian basil is an erect, much-branched, perennial, aromatic plant growing 20 - 80cm tall with ovate to oblong, glossy, fragrant leaves oppositely arranged on square stems. The plant is often grown as an annual, especially in cooler climates. Terminal flower spikes reaching 4-8" tall emerge in summer. The small, white to purple flowers are attractive to insect pollinators.

Origin and Distribution

Italian Basil (sweet basil) is an exotic plant in Italy, as it is native to tropical and subtropical Asia, specifically the Indian subcontinent and Southeast Asia. It is an annual plant widely cultivated and distributed across the world. It is grown well in tropical regions such as China, Indian subcontinent, Myanmar, Thailand, Cambodia, Laos, Vietnam, Malaysia, Indonesia, Philippines, and New Guinea.

Uses

Italian basil is highly valued for both its leaves and flowers, which can be enjoyed raw or lightly cooked. The tender, aromatic leaves are commonly used as a fresh herb to impart a distinctive sweet, peppery flavor with hints of clove and anise. When cooked, the flavor mellows yet remains vibrant, making it an essential ingredient in Mediterranean cuisine. It also enhances tomato-based dishes, bringing balance and freshness to pasta sauces, soups, and stews. In salads or as a garnish, the raw leaves provide a burst of freshness, while in cooked dishes they infuse warmth and complexity. Both the leaves and the edible flowers of Italian basil are treasured as a classic seasoning herb, often referred to as the “soul of Italian cooking.”

The seed can be eaten on its own or added to bread dough as a flavouring. When soaked in water it becomes mucilaginous and can be made into a refreshing beverage called 'sherbet tokhum' in the Mediterranean. An essential oil obtained from the plant is used as a food flavouring in mustards, sauces, vinegars etc.

An essential oil obtained from the whole plant is used as a food flavouring and in perfumery, dental applications etc. An average yield of 1.5% essential oil is obtained from the flowering tops. When applied to the skin it makes a good mosquito repellent. The growing or dried plant is an effective insect repellent. It is a good plant to grow in the home, where it repels flies, or in the greenhouse where it can keep all manner of insect pests away from nearby plants. It has been used in the past as a strewing herb.

Health Benefits

Italian basil, is recognized for its broad spectrum of therapeutic properties, acting predominantly on the digestive and nervous systems. The leaves and flowering tops possess antispasmodic, aromatic, carminative, digestive, galactagogue, stomachic, and tonic activities. Traditionally, internal administration has been reported to alleviate flatulence, stomach cramps, colic, indigestion, abdominal discomfort, and gastroenteritis. Moreover, basil preparations are employed in the management of feverish conditions, migraine, nausea, insomnia, depression, and physical exhaustion. Externally, topical application of basil leaves has been documented for the treatment of acne, anosmia (loss of smell), insect stings, snake envenomation, and superficial skin infections.



Figure 2: Nursery of Italian Basil

The mucilaginous seeds of Italian basil are traditionally administered in infusion form for the treatment of gonorrhoea, dysentery, and chronic diarrhoea, and are reputed to ameliorate ocular conditions such as corneal opacity and conjunctival films.

Phytochemical investigations have revealed that extracts of basil exhibit bactericidal properties and demonstrate efficacy against certain internal parasites. Furthermore, the essential oil, rich in bioactive volatile compounds, is extensively utilized in aromatherapy owing to its antimicrobial and neuroprotective potential.

Nutritional and Phytochemical Composition

Sweet basil contains over 200 bioactive phytochemical compounds from various families. In addition to macronutrients, carbohydrate, lipids, proteins and mucilages, basil contains micronutrients including vitamins, minerals, and secondary metabolites such as polyphenols, flavonoids, flavones. The leaves contain a complex mixture of bioactive compounds, including essential oils (notably linalool, methyl chavicol, limonene, geraniol, caryophyllene, and α -cadinol), flavonoids (quercetin, rutin, kaempferol, luteolin, catechin), and phenolic acids (rosmarinic, caffeic, chicoric, coumaric, gallic, and chlorogenic acids). Basil seeds are rich in mucilages with thickening, stabilizing, and emulsifying properties, making them valuable in food and pharmaceutical industries.

Cultivation

Cultivars: Thai and Genovese basil are cultivars of this plant. The fragrant edible leaves are great in soups, stews, and other meat dishes.

Extension Master Gardener volunteers from across the state of North Carolina conducted a trial of resistance to basil downy mildew and leaf flavor. They evaluated plant performance and taste using the cultivar 'Genovese' as the standard of reference. They found clear winners that were resistant to basil downy mildew and performed well in the garden and in the kitchen. The top cultivars were:

1. 'Prospera' – This cultivar was the overall favorite among the mildew-resistant cultivars. Because of its taller stature, it required staking in some gardens, and some volunteers reported stems breaking during storms.

2. 'Rutgers Passion' – This cultivar performed well in terms of its color, aroma, plant vigor, and good branching habit.

3. 'Rutgers Obsession' – This cultivar was highly rated for its color and compact growth habit. It exhibited strong resistance to basil downy mildew and was the highest rated variety in taste tests.

Soil and climate: Sweet basil prefers full sun in moderately rich, evenly moist, well-draining soils. Apply mulch to help retain soil moisture. Prefers a rich light well-drained to dry soil with pH in the range 6 - 7, tolerating 4.3 - 8.2.

A plant of the tropics, it can also be grown in the subtropics and as an annual in the warm temperate zone. It is a tender plant that is intolerant of frost and often grown as an annual in temperate zones. It grows best in areas where annual daytime temperatures are within the range 18 - 27°C, but can tolerate 7 - 36°C. It prefers a mean annual rainfall in the range 1,000 - 1,600mm, but tolerates 600 - 4,300mm.

Propagation

Ocimum basilicum L. is propagated primarily by seeds or stem cuttings. Seeds should be sown in containers or nursery seedbeds and lightly covered with a thin layer of soil, as germination is generally rapid and uniform. Seedlings grown in containers are pricked out and transplanted into individual pots once they are sufficiently developed for handling. Transplanting into permanent field positions is typically carried out when seedlings reach a height of 5–8 cm. Vegetative propagation through stem cuttings is also a reliable and widely adopted method.



Figure 3: Planting of Italian Basil

Planting

Basil cultivation is seasonal and sensitive to low temperatures. It can be established either from seeds or through transplantation. Sowing is generally performed indoors during early spring, and seedlings are transplanted to the field after the risk of frost has passed. Alternatively, market-purchased seedlings may also be transplanted directly. Pinching of the apical meristems is recommended to encourage lateral branching and to promote a compact, bushy plant architecture.



Figure 4: Irrigation of Italian Basil

Harvesting and Yield

The crop generally requires 60–110 days from germination to the first harvest. Subsequent harvests can be performed up to three times at approximately 60-day intervals, with harvesting carried out just before the onset of flowering to maximize essential oil content and biomass quality. The average dry yield of cleaned basil herbage is reported to range between 1.2–1.5 t ha⁻¹. Regular pruning, achieved by pinching the tips of elongated stems and removing flower buds, enhances branching and extends the productive life of the crop.



Figure 5: Harvested leaves of Italian Basil

Insects, Diseases, and Other Plant Problems

Aphids and Japanese beetles are occasional insect problems. Fusarium wilt and basil downy mildew are disease problems. There are several cultivars that are resistant to basil downy mildew.

Conclusion

Ocimum basilicum L. remains one of the most valued salad and medicinal herbs worldwide. Its rich phytochemical profile underpins diverse therapeutic applications, ranging from traditional remedies to

modern pharmacological uses. Further research into environmental modulation and targeted utilization of plant parts may enhance its pharmacological value and industrial applications.

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Indigenous Technical Knowledge (ITK)

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Mr. Vinay Kumar Hardaha¹, Dr. Neeraj Nath Parihar², Mr. Ankush Bisen³, Miss Dhvani Hanwat⁴

¹Assistant Professor, Sardar Patel University, Dongariya, Balaghat [M.P.] 481331.

²Assistant Professor, Sardar Patel University, Dongariya, Balaghat [M.P.] 481331.

³Assistant Professor, Sardar Patel University, Dongariya, Balaghat [M.P.] 481331.

⁴Assistant Professor, Sardar Patel University, Dongariya, Balaghat [M.P.] 481331.

Abstract

Indigenous Technical Knowledge (ITK) encompasses a wealth of skills and practices developed by indigenous peoples across generations to address their specific needs, particularly in agriculture. These practices, deeply rooted in local environments and cultures, offer sustainable solutions to various challenges. For instance, techniques like summer ploughing for moisture conservation, Ad-Bandh for rainwater harvesting, and Halod for water management in paddy fields are examples of ITK applied in agriculture. Other practices include Mahuda for land preparation, sprinkling honey for pollination enhancement, and soil fertility management through methods like nutrient recycling with ash and household waste. Pest and disease management techniques, such as termite control using kerosene or preventing termite attacks with salt and ash, are also part of ITK. Traditional farm implements like the Hal plow and Kudali spade, along with post-harvest technologies like drying seeds and crop threshing, reflect indigenous knowledge adapted to local contexts. Furthermore, indigenous methods of grain and seed storage, such as using neem and eucalyptus leaves for pest control or constructing storage chambers from bamboo or earthen materials, highlight the ingenuity and sustainability of ITK in preserving food resources. Overall, ITK in agriculture represents a rich tapestry of knowledge that not only addresses practical needs but also embodies cultural values, community collaboration, and environmental stewardship. It underscores the importance of recognizing, respecting, and preserving indigenous knowledge systems for sustainable development and conservation efforts worldwide.

Keywords- Moisture Conservation, Post Harvest Technology, Environments.

Introduction

Indigenous technical knowledge (ITK) refers to the skills, innovations, and practices developed by indigenous peoples over generations to address their specific needs and challenges. It encompasses a wide range of traditional knowledge related to agriculture, medicine, architecture, crafts, and various other fields.

Unlike formal scientific knowledge, which often relies on systematic experimentation and analysis, ITK is typically passed down orally or through direct demonstration within indigenous communities. It is deeply rooted in the local environment, culture, and social structures of the community.

Indigenous technical knowledge is often highly sustainable and adapted to local conditions, making it invaluable for sustainable development and environmental conservation. However, it's important to recognize and respect the intellectual property rights of indigenous peoples when engaging with and benefiting from their knowledge.

The Indigenous Technical Knowledge (ITK) is the local knowledge that is unique to a given culture or society where its knowledge passes from generation to generation. It is the knowledge that people have gained through inheritance from their ancestors. ITK is “the sum total knowledge and practices which are based on peoples accumulated experiences in dealing with situations and problems in various aspects of life and such knowledge and practices are special to a particular culture.”

Some Indigenous Technical Knowledge used in Agriculture

1. Soil and Water Conservation
2. Rain Water Management

3. Tillage and Intercultural Management
4. Crops and Cropping Systems
5. Pest and Disease Management
6. Soil Fertility Management
7. Farm Implements
8. Post-harvest Technology
9. Grain/seed Storage

Soil and Water Conservation

Summer ploughing for moisture conservation: Summer ploughing for moisture conservation is a traditional agricultural technique used in various parts of the world, particularly in regions with hot and dry summers. This practice involves tilling the soil during the summer months to create furrows or ridges that help capture and retain moisture from summer rains or irrigation, preventing it from evaporating too quickly. Farmers use baliram ploughs for off-season ploughing between February and March, before the monsoon season begins. They plough up to 20-30 cm deep. This approach conserves soil moisture, reduces soil loss, and controls weed and insect populations. **[Anonymous (2000)]**

One example of indigenous technical knowledge related to summer ploughing for moisture conservation comes from the ancient agricultural practices of the Indian subcontinent, particularly in regions like India and Pakistan. Here, farmers have long used techniques such as "Zing" or "Zabo" ploughing, which involve ploughing the fields during the summer months to trap moisture in the soil.

In this technique: Shallow Ploughing: Farmers use a lightweight plough to till the soil to a shallow depth, typically around 3 to 4 inches. This helps to break up the surface crust, allowing water to penetrate the soil more easily.

Creating Furrows: Instead of completely overturning the soil, farmers create furrows or ridges along the contours of the land. These furrows act as channels to direct and trap rainwater or irrigation runoff, preventing it from running off the surface too quickly.

Soil Mulching: After ploughing, farmers may also apply a layer of organic mulch, such as crop residues, straw, or grass clippings, to the soil surface. This mulch helps to further conserve moisture by reducing evaporation and suppressing weed growth.

Rain Water Management

1. Ad-Bandh for rain water harvesting- "Ad-Bandh" is a traditional rainwater harvesting technique used in various parts of India, particularly in the state of Rajasthan, where water scarcity is a significant issue. The term "Ad-Bandh" translates to "dams made of stone" in Hindi. **[Singh and Khan (1999)]**

Here's how Ad-Bandh works:

Stone Structures: Ad-Bandh involves the construction of small stone check dams or bunds across seasonal streams, rivers, or water channels. These stone structures are built using locally available materials, such as rocks, stones, and boulders.

Diverting Water Flow: The primary purpose of Ad-Bandh is to slow down the flow of rainwater during the monsoon season. When rainfall occurs, the stone dams intercept the flow of water, causing it to spread out and pool behind the dam.

Recharge of Groundwater: By slowing down the flow of rainwater and allowing it to collect behind the stone dams, Ad-Bandh helps recharge groundwater aquifers in the surrounding area. The stored water gradually percolates into the soil, replenishing underground water resources.

Soil Conservation: In addition to harvesting rainwater, Ad-Bandh also helps prevent soil erosion by reducing the velocity of water flow. The stone structures trap sediment and debris, preventing them from being washed away downstream.

Community Effort: Ad-Bandh projects are often community-driven initiatives, with local residents coming together to plan, construct, and maintain the stone dams. This fosters a sense of ownership and responsibility among community members towards water conservation efforts.

2. Khatri: A water harvesting structure- "Khatri" is a traditional water harvesting structure commonly found in the Thar Desert region of India, particularly in the state of

Rajasthan. It is an indigenous technique designed to capture and store rainwater for agricultural and domestic purposes in arid environments. [Chandan (2000)]

Here's how a Khatri works:

Design: A Khatri typically consists of a circular or rectangular depression dug into the ground, usually lined with impermeable materials such as clay or plastic sheets to prevent water seepage into the soil. The size of a Khatri can vary depending on the local topography and water requirements.

Catchment Area: Surrounding the depression, there is usually a sloping catchment area constructed to channel rainwater towards the Khatri. This catchment area may be built using soil bunds or low walls to direct the flow of rainwater into the depression.

Rainwater Collection: During the monsoon season, when rainfall occurs, the catchment area collects rainwater runoff and directs it towards the Khatri. The impermeable lining of the Khatri prevents water from percolating into the ground, allowing it to accumulate in the depression.

Water Storage: The Khatri serves as a storage reservoir for rainwater, holding it in reserve for use during dry periods. The stored water can be used for various purposes, including irrigation of crops, watering livestock, and meeting household needs.

Community Management: Khatri structures are often managed and maintained by local communities or village committees. Community involvement is crucial for the success of Khatri projects, as it fosters a sense of ownership and responsibility towards water conservation efforts.

Nutritional and Phytochemical Composition

1. Halod or bushening in standing paddy- "Halod" or "bushening" is a traditional agricultural practice used in the cultivation of paddy (rice) in regions like West Bengal, India. It involves the manual removal of excess water from paddy fields during the growing season to promote better aeration and nutrient uptake by the rice plants. [Singh (2000)]

Here's how halod or bushening works in standing paddy fields:

a. Identifying Excess Water: In paddy fields where water levels are too high, either due to excessive rainfall or irrigation, farmers may notice stagnant water accumulating around the rice plants. This excess water can lead to oxygen deprivation in the soil and hinder the root development of the rice plants.

b. Manual Removal: To address this issue, farmers perform halod or bushening by manually removing the excess water from the paddy fields. Workers typically use tools such as wooden or metal scoops to scoop out water from around the base of the rice plants.

c. Creating Channels: In addition to removing water directly around the rice plants, farmers may also create small channels or furrows between the rows of paddy to facilitate drainage and improve water circulation within the field.

d. Timing: Halod or bushening is usually done during specific stages of the rice growth cycle such as during the vegetative stage or early reproductive stage, when excessive water can be particularly detrimental to plant health.

Benefits: By reducing waterlogging and improving soil aeration, halod or bushening helps enhance nutrient uptake by the rice plants, promoting healthier growth and higher yields. It also helps prevent the occurrence of waterborne diseases and pests that thrive in waterlogged conditions.

2. Mahuda to facilitate land preparation- Mahuda, also known as "mahua" or "Madhuca longifolia," is a tree native to the Indian subcontinent, particularly prevalent in states like Madhya Pradesh, Chhattisgarh, Jharkhand, and Odisha. It holds cultural, economic, and ecological significance in these regions. In traditional agriculture, Mahuda leaves, along with their branches, are used for facilitating land preparation, especially in tribal and rural communities. [Sartanbhai (1993)]

Here's how Mahuda facilitates land preparation:

Mulching: Mahuda leaves are collected and spread over the soil surface to create a protective layer of mulch. This mulch serves several purposes:

a. Moisture Retention: The mulch helps retain soil moisture, especially during dry periods, reducing the need for frequent irrigation.

b. Weed Suppression: By covering the soil, Mahuda mulch suppresses weed growth, thereby reducing competition for nutrients and water.

c. Soil Protection: The mulch protects the soil from erosion caused by wind and water, helping to maintain soil structure and fertility.

Soil Enrichment: As Mahuda leaves decompose, they release nutrients into the soil, enriching it and enhancing its fertility. This natural fertilization process improves soil health and promotes better crop growth.

Soil Conditioning: Mahuda branches are sometimes used as natural soil conditioners. They are buried in the soil to improve its structure, aeration, and drainage. Over time, as the branches decompose, they contribute organic matter to the soil, making it more suitable for cultivation.

Sustainable Practice: The use of Mahuda for land preparation aligns with sustainable agricultural practices. It utilizes locally available resources, reduces dependence on chemical inputs, and promotes ecological balance in farming systems.

Cultural Significance: Mahuda holds cultural importance in many tribal communities, where it is revered as a sacred tree. The use of Mahuda in agriculture reflects the deep connection between indigenous knowledge, cultural traditions, and sustainable land management practices.

Crops and Cropping Systems

1. Sprinkling honey for better pollination in ridge gourd- Sprinkling honey for better pollination in ridge gourd is an indigenous agricultural technique used to enhance fruit set and yield in this crop. Ridge gourd (*Luffa acutangula*) is a vine plant that produces long, ribbed fruits commonly used in cooking across Asia. [Sharma (1996)]

2. Soil burning (sudu mannu) to raise vegetable nursery- Soil burning, known as "sudu mannu" in some regions, is a traditional agricultural practice used to prepare soil for raising vegetable nurseries in certain parts of India, particularly in states like Tamil Nadu and Andhra Pradesh. This technique involves burning organic materials such as dried leaves, crop residues, and cow dung cakes on the soil surface to sterilize and enrich the soil for seed germination and early plant growth.[Anonymous (1999)]

3. Ratooning of rice- Ratooning of rice, also known as rice ratooning or rice stubble management, is an agricultural practice where rice plants are regrown from the stubble remaining after the initial harvest. This practice is particularly common in regions where rice is a staple crop and where water resources are limited

Pest and Disease Management

1. Termite control by using kerosene with irrigation water-Using kerosene mixed with irrigation water for termite control is a traditional agricultural practice that has been used in some regions to manage termite infestations in crops, particularly in rice paddies. While this method may have been practiced historically, it's important to note that it can have environmental and health implications, and its effectiveness may vary.[Anonymous (2000)]

2. Preventing termite attack in dry fodder storage by use of salt and ash-Preventing termite attacks in dry fodder storage by using salt and ash is a traditional method that has been practiced in some agricultural communities. While this method may offer some level of termite control, its effectiveness can vary, and it's essential to consider potential drawbacks and alternative strategies.

3. Rat control by smoking with dry chillies: Using smoking with dry chillies for rat control is a traditional method employed in some agricultural and rural settings.

4. Rodent control through live wire- Using a live wire for rodent control is a method aimed at deterring or electrocuting rodents, typically rats and mice, by exposing them to an electrified wire. This method is often employed in agricultural and industrial settings where rodent infestations pose a threat to crops, stored goods, or infrastructure. [Patel (1991)]

5. Seed treatment with eucalyptus seed extracts to control pest and disease: reating seeds with eucalyptus seed extracts to control pests and diseases is a traditional agricultural practice that harnesses

the natural properties of eucalyptus plants for crop protection. Eucalyptus extracts contain various bioactive compounds that have been found to have insecticidal, fungicidal, and antimicrobial properties.

Soil Fertility Management

1. Enhancement of soil fertility through animal bones- The use of animal bones to enhance soil fertility is a traditional agricultural practice that has been employed in various cultures for centuries. Animal bones contain a variety of nutrients, including calcium, phosphorus, and trace minerals, which can contribute to soil fertility and plant growth when incorporated into the soil.

2. Improvement of soil fertility by animal staying- Improving soil fertility through animal staying, also known as animal grazing or animal manuring, is a traditional agricultural practice that has been used for centuries in various farming systems around the world.

3. Nutrient recycling with ash, household waste and human excreta- Nutrient recycling with ash, household waste, and human excreta is a sustainable agricultural practice that involves returning organic matter and nutrients to the soil to improve soil fertility and enhance crop productivity.

4. Preparation of vermi compost- Vermicomposting is a sustainable and environmentally friendly method of composting organic waste using earthworms. It involves the decomposition of organic materials by earthworms and microorganisms to produce nutrient-rich vermicompost, also known as worm castings. [Dasanakoppa (1999)]

5. Green leaf manuring with pongamia- Green leaf manuring with Pongamia (Pongamia pinnata) involves incorporating fresh or partially decomposed leaves of the Pongamia tree into the soil to improve soil fertility and enhance crop productivity. Pongamia, also known as Indian Beech or Karanja, is a leguminous tree native to India and other parts of Asia. [Lakshmana (2000)]

Farm Implements

1. Hal for land preparation- "Hal" is a term used in Indian agriculture, particularly in the context of traditional farming practices. In this context, "hal" refers to a type of plow or plowshare traditionally used for land preparation in agriculture.

2. Kudali (Spade) for digging and weeding- "Kudali," also known as a spade, is a traditional hand tool used for digging, cultivating, and weeding in agriculture. It consists of a long handle typically made of wood or metal, attached to a flat, narrow blade at one end. The blade of the kudali is usually sharp and pointed, allowing for efficient penetration into the soil.

3. Wooden muna plough in Punjab for seed bed preparation- The wooden muna plough is a traditional agricultural tool used for seed bed preparation in the Punjab region of India. This type of plough is primarily made of wood and is well-suited for breaking up and preparing soil for planting seeds or transplanting seedlings.

4. Mai for land levelling- In the context of agriculture in Punjab, "mai" refers to a traditional agricultural tool used for land leveling. It is a wooden implement that resembles a large rake or leveling board.

5. Tyned hoe (Papattam) for interculture in upland paddy- The tyned hoe, known as "Papattam" in some regions, is a traditional agricultural tool used for intercultivation in upland paddy fields. This tool consists of a long handle with a flat blade at one end and several tines or prongs extending from the blade.

Post-Harvest Technology

1. Method of drying cucumber and pumpkin seed- Drying cucumber and pumpkin seeds is a straightforward process that can help preserve them for longer periods. Seeds are mixed with wood ash and placed on a plate (Thali) in the open sun. This facilitates faster drying since wood ash probably absorbs excess water from the seed and prevents the seeds from sticking together (Mandi, Himachal Pradesh).

2. Drying of food grains - Drying food grains is a crucial step in their processing to extend their shelf life and prevent spoilage.

3. Threshing by using wooden sticks - Threshing using wooden sticks, also known as flailing or beating, is a traditional method employed to separate grains from their husks or stalks.

3. Post-harvest management of paddy- Post-harvest management of paddy, or rice, is crucial for preserving its quality, preventing losses, and ensuring its market value.

4. Crop threshing in 'Khaliyan'- Crop threshing in "Khaliyan" refers to a traditional method of threshing crops that is commonly practiced in some rural areas, particularly in South Asia.

Grain/Seed Storage

1. Storage pest control by neem and Eucalyptus leaves-

a. Neem Leaves:

i. Neem leaves contain azadirachtin, a compound known for its insecticidal properties. It disrupts the growth and development of pests, inhibiting their ability to feed and reproduce.

ii. Dry neem leaves thoroughly and crush them into a fine powder.

iii. Place the neem powder in small sachets or bags made of porous material like cloth or paper.

iv. Scatter these neem sachets among stored grains or other susceptible items. The odor released by the neem powder acts as a natural repellent against pests, deterring them from infesting the stored goods.

v. Replace the neem sachets periodically, especially if their effectiveness diminishes over time.

b. Eucalyptus Leaves:

i. Eucalyptus leaves contain eucalyptol, a compound with insecticidal and repellent properties. It is effective against a wide range of storage pests.

ii. Similarly, dry eucalyptus leaves and crush them into small pieces or powder.

iii. Place the eucalyptus leaves in sachets or bags and distribute them throughout the storage area.

iv. The strong aroma of eucalyptus acts as a natural deterrent against pests, discouraging them from infesting the stored grains or other items.

v. Like with neem, replace the eucalyptus sachets periodically to maintain their effectiveness.

b. Grain storage in 'Darauntha'- Grain storage in "Darauntha" is a traditional method used in some rural areas, particularly in parts of India. Darauntha refers to a specific type of storage structure, typically constructed using locally available materials like mud, clay, or bricks.

c. Grain storage in gunny bag, drum, pot, pattarai and kulumai- Grain storage in gunny bags, drums, pots, pattarai, and kulumai are common traditional methods used in various parts of the world, especially in rural areas. Each method offers unique advantages and is suited to different types of grains and storage conditions.

d. Bamboo storage chamber for grains- Poor farmers in some parts of temperate Himalayas have grain storage made of Bamboo. They are built in the safe vicinity of the farmhouse at some distance to protect from fire which was a common feature in the early days as the entire structure is fabricated from wood (Temperate Himalayas of Himachal Pradesh).

e. Grain storage in earthen rooms- In Lahaul and Spiti, special earthen rooms are constructed for storing cereal crops immediately after harvesting. Storage in such rooms also provides a cool temperature so essential for storage of grain.

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Nature's Secret Signals: The Role of Semiochemicals in Pest Management

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Lipsa Dash¹

¹Assistant Professor, College of Horticulture, Odisha University of Agriculture and Technology, Odisha.

In the modern world, agriculture faces one of its greatest challenges—how to protect crops from pests while minimizing harm to the environment. Chemical pesticides, though effective, have created a series of problems such as pesticide resistance, pollution, and loss of beneficial insects. Scientists and farmers are now turning to nature itself for solutions. One of the most fascinating tools in this search comes in the form of semiochemicals—the invisible language of insects.

Semiochemicals are naturally occurring chemical signals used by living organisms to communicate with each other. The term is derived from the Greek word 'semeion' meaning “sign” or “signal.” Just as humans use speech, insects use chemical signals to find food, locate mates, or avoid danger. Insects have evolved highly sensitive antennae that can detect even a single molecule of these signals in the air. By understanding and applying this chemical communication system, scientists can “speak the language of pests” and use it to manage them in an eco-friendly way.

Semiochemicals are broadly divided into two categories:

Pheromones: Signals exchanged between individuals of the same species, such as sex pheromones that help males locate females.

Allelochemicals: Signals exchanged between different species, such as repellents that drive pests away or attractants that lure them toward traps.

Working Methodology of Semiochemicals

Semiochemicals are not poisons. Instead, they modify insect behavior—attracting, repelling, or confusing pests. This makes them an environmentally safe alternative to pesticides. Some of the most common ways they use include:

1. Monitoring Pest Populations: One of the earliest and most widespread uses of semiochemicals is in pest surveillance. For example, pheromone traps are placed in crop fields to attract specific pests. The number of insects trapped gives farmers a clear idea of the pest population in their fields. This helps in making timely decisions about whether pesticide application is necessary, reducing indiscriminate spraying.

2. Mass Trapping: In some cases, semiochemicals are used to lure pests into traps in such large numbers that the population is significantly reduced. This is particularly effective for pests with strong pheromone responses, such as fruit flies.

3. Mating Disruption: Perhaps one of the most exciting applications of semiochemicals is in disrupting insect reproduction. By flooding the field with synthetic sex pheromones, male insects are unable to locate females. This reduces mating success and gradually brings down the pest population. Mating disruption has been successfully used against pests like the pink bollworm in cotton and the codling moth in apples.

4. Push-Pull Strategies: Allelochemicals can be used to repel pests from crops (push) while attracting them to trap crops (pull). This clever combination has been tested in maize fields in Africa, where certain plants release chemicals that repel stem borers, while others attract them away from the main crop.

5. Attract-and-Kill Techniques: Here, semiochemicals are combined with a small amount of pesticide. The attractive scent lures the pest to a bait station where it consumes or contacts the insecticide. Because only targeted insects are affected, the amount of chemical used is minimal.

Success Stories from Around the World

The use of semiochemicals in pest management is no longer just a research idea; it is being applied in real-world farming systems.

Cotton Protection in India: The pink bollworm, a major pest of cotton, has been managed using pheromone-based mating disruption. Farmers report reduced pesticide use and healthier crops.

Fruit Fly Control in Orchards: Semiochemical-based traps are widely used in mango, guava, and citrus orchards to control fruit flies, improving fruit quality for both local markets and export.

Codling Moth in Apples: In countries like the USA and Europe, pheromone dispensers placed in apple orchards have drastically reduced pesticide use while keeping moth populations under control.

African Push-Pull Technology: Farmers in Kenya and Uganda have adopted push-pull methods for managing stem borers and fall armyworm, combining semiochemical signals with crop diversification. This not only controls pests but also improves soil health and livestock fodder availability.

Advantages of Semiochemical-Based Pest Management

- 1. Eco-friendly:** They leave no toxic residues in soil, water, or food.
- 2. Target-specific:** Semiochemicals affect only the target pest species, sparing beneficial insects like pollinators.
- 3. Resistance Management:** Because they alter behavior instead of killing directly, the risk of pests developing resistance is much lower.
- 4. Reduced Chemical Use:** They complement or reduce the need for chemical pesticides, lowering production costs and environmental impact.
- 5. Safe for Farmers and Consumers:** Handling semiochemicals does not expose farmers to harmful toxins, and consumers get cleaner food.

Challenges in Wider Adoption

Despite their benefits, semiochemicals are not yet as widely used as they could be. Some of the main challenges include:

High Initial Costs: Developing and synthesizing pheromones for each pest species requires advanced technology, making them expensive at first.

Limited Awareness: Many farmers, especially in developing countries, are still unfamiliar with semiochemical-based methods.

Short Field Life: Some semiochemicals degrade quickly in sunlight or high temperatures, requiring frequent replacement.

Species-Specific Nature: A pheromone effective for one pest will not work for another, meaning multiple solutions are needed for multi-pest environments.

The Road Ahead

Research is ongoing to make semiochemical applications cheaper, more durable, and more farmer-friendly. Scientists are exploring slow-release formulations that last longer in the field, as well as blends of pheromones and plant-derived attractants to target multiple pests at once.

The future of pest management may lie in integrating semiochemicals with other eco-friendly approaches such as biological control and habitat management. This holistic strategy, often called Integrated Pest Management (IPM), combines the strengths of various methods to keep pests below damaging levels without harming the ecosystem.

Conclusion

Semiochemicals represent a powerful, nature-inspired solution to one of agriculture's biggest challenges i.e. pest control. By "hacking" the communication systems of insects, we can manage pests in a way that is safe, sustainable, and farmer-friendly. From pheromone traps in orchards to push-pull strategies in maize fields, these invisible signals are proving that small molecules can make a big difference. As agriculture

seeks to balance productivity with sustainability, semiochemicals offer a path forward. They remind us that sometimes the best innovations are not synthetic inventions but lessons borrowed from nature itself.

Switching Genes On: The Secret Role of Transcription Factors in Medicinal Plants

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V. Shajeeda Banu¹, Awadhesh Kumar Pal¹, Rima Kumari¹, Pankaj Kumar¹, Anil Kumar Singh¹,
Duniya Ram Singh¹

¹Bihar Agricultural University, Sabour, Bhagalpur, Bihar-813210.

Introduction

Medicinal plants are extraordinary biochemical factories that synthesize a vast range of secondary metabolites such as alkaloids, flavonoids, terpenoids and phenolics. Unlike primary metabolites, which are essential for plant growth and survival, these compounds often serve ecological roles such as deterring herbivores, attracting pollinators or defending against pathogens. For humans, however, they form the basis of some of the most important drugs: vinblastine from *Catharanthus roseus* (anticancer), artemisinin from *Artemisia annua* (antimalarial) and morphine from *Papaver somniferum* (analgesic). The production of these molecules is not random. At the core of this tightly regulated metabolic system are transcription factors (TFs), they are the molecular switches that sense environmental and developmental signals and reprogram gene expression. These proteins determine how much of a bioactive compound is synthesized, when it is produced and in which tissue it accumulates.

What are Transcription Factors?

Transcription factors are proteins that bind to specific DNA motifs, usually in the promoter or enhancer regions of genes. They contain structural domains such as a DNA-binding domain (DBD), which recognizes cis-regulatory elements and a transactivation or repression domain (TAD/RD), which recruits co-factors to either activate or repress transcription. Some TFs also contain dimerization domains that allow them to form complexes with other proteins. In medicinal plants, transcription factors play a pivotal role in controlling inducible metabolic pathways, those that are switched on by stress, light signals or developmental cues. This inducible nature ensures that the plant conserves energy while still being able to activate a defence when necessary. It means that the most valuable compounds often appear in response to stress, making TFs the key to unlocking and enhancing their production.

Families of Transcription Factors in Medicinal Plants

Among the numerous TF families in plants, some have been studied extensively for their roles in medicinal species. The MYB family is one of the largest and best characterized. MYB proteins regulate flavonoid, anthocyanin and alkaloid biosynthesis. In *Catharanthus roseus*, *CrMYB2* has been shown to activate terpenoid indole alkaloid (TIA) pathway genes, directly influencing vinblastine and vincristine production. MYBs often form part of the MBW complex (MYB–bHLH–WD40), which provides tight control of pathway specific gene expression. The bHLH (basic Helix-Loop-Helix) family is another important group. In *Artemisia annua*, bHLH factors like *AaMYC2* regulate artemisinin biosynthesis by activating genes such as *ADS* (amorpha-4,11-diene synthase). In *C. roseus*, bHLH factors BIS1 and BIS2 control iridoid pathway genes, providing the necessary precursors for alkaloid synthesis. WRKY transcription factors are recognized by their conserved WRKYGQK motif and are strongly linked to stress responses. In *Withania somnifera*, *WsWRKY1* enhances withanolide production, demonstrating how these regulators link defense signals to medicinal compound biosynthesis.

The AP2/ERF family is well known for its involvement in jasmonate signaling. In *C. roseus*, ORCA2 and ORCA3 activate critical TIA pathway genes such as *STR* (strictosidine synthase). In opium poppy, AP2/ERFs regulate morphinan alkaloid biosynthesis. Other families like NAC and bZIP are less explored but are increasingly associated with phenylpropanoid and stress-linked regulation of secondary metabolism in medicinal plants.

Environmental Signals and Plant Intelligence

One of the most fascinating aspects of transcription factors is their responsiveness to environmental cues. When plants encounter drought, pathogen attack or UV stress, hormones such as jasmonic acid (JA) and salicylic acid (SA) are produced. These hormones activate TFs that switch on defense related genes, which in turn lead to increased accumulation of protective metabolites. For example, in *Catharanthus roseus*, jasmonate responsive ORCA transcription factors upregulate multiple TIA pathway genes, resulting in enhanced alkaloid production. Similarly, in *Artemisia annua*, jasmonate induces TFs like *AaERF1* and *AaMYC2*, leading to increased artemisinin biosynthesis. Transcription factor regulation is also spatiotemporal. Many bioactive compounds are localized to specific tissues or developmental stages. Artemisinin, for instance, is synthesized in glandular trichomes of *A. annua* and this tissue-specific expression is controlled by TFs that are active only in trichome cells. Such precise regulation illustrates the plant's "intelligence" in balancing metabolic costs with ecological benefits.

Biotechnology and Applications

Modern biotechnology has begun to exploit transcription factors as tools for metabolic engineering. Overexpression of key TFs can significantly enhance the yield of valuable metabolites. For example, overexpressing ORCA3 in *C. roseus* leads to increased accumulation of strictosidine, vindoline and catharanthine. Similarly, introducing *AaMYC2* in *A. annua* boosts artemisinin content. With CRISPR/Cas9 genome editing, researchers can now manipulate TF genes with remarkable precision. Deleting repressor TFs or strengthening activator TFs can redirect metabolic flux toward higher production of desired compounds. Synthetic biology has taken this a step further by reconstructing plant metabolic pathways, including their TF regulation, inside microbial hosts like yeast and *E. coli*. This allows scalable production of plant-derived drugs under controlled conditions. Promoter engineering is another promising strategy. By inserting strong TF-binding motifs into synthetic promoters, scientists can design plant cell cultures that express biosynthetic genes more efficiently, closely imitating natural control mechanisms while reducing metabolic constraints.

Future Prospects

The study of transcription factors is now moving into a systems biology era. Using multi-omics approaches, combining genomics, transcriptomics, proteomics and metabolomics, research efforts are mapping gene regulatory networks (GRNs) that illustrate how TFs coordinate secondary metabolism. These models make it possible to predict how altering one TF can influence entire pathways, providing a foundation for rational metabolic engineering. Epigenetic regulation of TFs, including histone modifications and DNA methylation, represents an exciting frontier. Such layers of control may explain why certain biosynthetic pathways remain "silent" under normal conditions. Unlocking these hidden pathways through TF manipulation has the potential to reveal entirely new classes of therapeutic compounds. Looking to the future, TF engineering may enable the development of designer medicinal plants. Turmeric could be optimized for higher curcumin levels, Ashwagandha for more potent withanolides, or even rare species could be engineered to yield compounds that are currently too scarce for pharmaceutical use.

Conclusion

Transcription factors are far more than passive regulators, they are the molecular masterminds of medicinal plants. By sensing environmental signals and orchestrating complex gene networks, they ensure that plants produce bioactive metabolites precisely when needed. For humanity, this translates into a powerful opportunity, by decoding and harnessing TFs, we can create sustainable pipelines for natural medicines. In a world increasingly seeking eco-friendly healthcare solutions, transcription factors stand as the bridge between plant intelligence and human well-being.

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Root-Knot Nematode: A Hidden Enemy for Tomatoes Production

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Akhila Mathew^{1,2}, Gowri G Lal^{1,3}, Sudheer Kumar Reddy P^{1,4}, Suresh Reddy Yerasu¹,
Manjunatha T. Gowda¹, Nagenran K⁵

¹ICAR-Indian Institute of Vegetable Research, Varanasi-221305

²Sam Higginbottom University of Agriculture, Technology and Sciences Prayagraj - 211007, ³Odisha University of Agriculture and Technology, Bhubaneswar -751003

⁴Dr. YSRHU-College of Horticulture, Anantharjupeta

⁵ICAR-National Research Centre on Banana, Tiruchirappalli- 620 102.

Introduction

Tomato is one of the most economically imported crops in the Solanaceae family and is cultivated worldwide for its multifaceted uses. It is the second most widely cultivated vegetable after potatoes in global food production. Tomatoes are grown both in open fields and under protected cultivations systems across the world. They are also rich in lycopene, a powerful antioxidant known to reduce the risk of various cancers and neurological disorders. In India, tomatoes are cultivated on 0.849 million hectares with an annual production of 20.45 million tonnes (FAOSTAT, 2023). However, the productivity and quality are significantly limited by plant-parasitic nematodes (PPNs), in addition to multiple abiotic and biotic stress factors. Among these, root-knot nematodes (*Meloidogyne* spp.) are the most destructive PPNs affecting vegetable crops. Tomatoes are particularly susceptible to root-knot nematodes, with *Meloidogyne incognita* being the most commonly prevalent species, followed by *M. javanica*. In India, RKN infestations account for an estimated 23% reduction in tomato yields, leading to an annual monetary loss of 6035.20 million rupees (Kumar et al., 2020). Besides, they act as predisposing agents for soil-borne fungal and bacterial pathogens, leading to disease complexes that further increases yield losses.

Life Cycle and Damage Symptoms

The life cycle of RKN begins with eggs and progresses through four juvenile stages before reaching it to adult stage. An egg undergoes embryonic development and hatches into the first stage juvenile (J1), which then moults into the infective second stage juvenile (J2). These microscopic and motile J2 juveniles move freely in the soil searching for a suitable host. They penetrate plant roots at their tips and subsequently alter the root vascular tissues into permanent feeding sites composed of giant cells. This modifications lead to the typical knotted or galled appearance of infected plant roots. Above ground, symptoms of nematode infection often include stunted growth, overall poor health, yellowing of leaves (chlorosis), premature wilting, and delayed recovery even in improved soil moisture. These symptoms resemble nutrient deficiency. The J2 juveniles continue to feed for about 2 to 3 weeks and undergo a series of three quick successive moults. In many species, most juveniles develop into pyriform sedentary females, while the some become males. The females deposit their eggs into a gelatinous matrix. The entire life cycle typically completes in 25 to 28 days at soil temperature of 25 to 30 °C, though duration may vary considerably with temperature and host (Gowda et al., 2019; Rawal 2020).



Figure 1: stained female nematode inside root tissue



Figure 2: Eggmass



Figure 3: galls on tomato roots

Management

Cultivation of nematode resistant tomato cultivars: Growing nematode resistance cultivars is an effective approach to suppress root-knot nematode invasion and reproduction. The identification of natural resistance genes against nematode parasitism has accelerated the development of resistant plant varieties and serves as an effective and economical strategy for minimizing the losses. In modern tomato cultivars, root-knot nematode resistance is exclusively derived from the *Mi-1* nematode resistance gene. Over the last three decades, this gene extensively exploited as a key nematode management strategy worldwide. In India, tomato cultivars such as Hissar Lalit, Sl-120 and PNR-7 are known to possess nematode resistance. However, *Mi-1* mediated resistance has a problem of temperature sensitivity. This genetic resistance is ineffective above 28 °C of soil temperature. The breakdown of *Mi-1*-mediated resistance under greenhouse and open-field condition has been well documented (Yerasu et al., 2023).

Cultural methods: Successful management of RKN also relies on cultural practices such as crop rotation with non-host crops like mustard, sesame, maize, wheat and millets; allowing fields fallow; incorporating organic materials into the soil; planting trap crops; and adjusting planting times. These approaches to nematode management are the oldest and sustainable strategies used to mitigate the damage inflicted by RKN (Gowda et al., 2017; 2019).

Biological methods: Biological methods are cost-effective, easy to implement and offer added benefit of enhancing soil structure and nutrient content. Several organisms, including bacteria, fungi, and plant extracts, have been recognized for their ability to antagonize RKNs. Notably, neem cake, mustard cake and pongamia cake have been reported to possess nematicidal properties against RKNs. The use of organic amendments enriched with nematicidal bio-agents such as *Purpureocillium lilacinum*, *Pochonia chlamydosporia* *Trichoderma* spp., *Pseudomonas fluorescens*, and *Bacillus* spp., has been found effective in managing root-knot nematodes (Gowda et al., 2017; 2019).

Chemical methods: Among chemical pesticides, Fluopyrum 34.48% SC, has been recommended nematicide at the rate of 1250 ml/1000 litre for 1 ha for the management of RKNs in tomatoes. Nevertheless, chemicals provide rapid and effective control, it should be used judiciously to avoid pesticide residue load in fruits and soil. Indiscriminate use poses considerable threat to human health, non-target organisms, and the environment (Yerasu et al., 2025).

Conclusion

In summary, the standalone methods employed for RKN management have their own drawbacks. As we understand, relying solely on individual methods makes it challenging to manage the losses. Therefore, an integrated approach combining two or more effective strategies is essential for sustainable and efficient management of root-knot nematodes in tomato cultivation.

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Bionematicidal Attributes of *Bacillus* Spp. and their Potential Utilization in the Management of Root Knot Nematodes in Vegetable Crops

Article ID: 72089

Gowri G. Lal^{1,2}, Akhila Mathew^{1,3}, Sudheer Kumar Reddy Pesala^{1,4}, Manjunatha T. Gowda¹, Suresh Reddy Yerasu¹, Nagendran K⁵

¹ICAR-Indian Institute of Vegetable Research, Varanasi-221305

²Odisha University of Agriculture and Technology, Bhubaneswar -751003

³Sam Higginbottom University of Agriculture, Technology and Sciences Prayagraj - 211007, ⁴Dr. YSRHU-College of Horticulture, Anantharajupeta

⁵ICAR-National Research Centre on Banana, Tiruchirappalli- 620 102.

Introduction

Root-knot nematodes (*Meloidogyne* spp.) are the most frequently observed and damaging plant-parasitic nematodes in vegetable production (Koenning et al., 1999). Root-knot nematode (RKN) damage can be easily diagnosed by farmers through the presence of galls on the roots. These galls developed as a result of physiological disturbances in root tissues caused by the trophic interactions of RKN. Among the identified RKN species, *Meloidogyne incognita* and *Meloidogyne javanica*. *Meloidogyne arenaria* and *Meloidogyne hapla* are the four major species reported to cause extensive economic damages in vegetable crops. Trudgill and Blok (2001) reviewed that the apomictic species *M. incognita* is the single most crop damaging pathogen worldwide. In India, vegetable crops are highly prone to RKN with an estimated average annual loss of 19.6% equivalent to Rs. 14,461.22 million rupees. Crop losses due to RKN in major vegetable crops are summarized in Table 1 (Kumar et al., 2020). Traditionally chemical nematicides have been the preferred method to combat these pests. However, due to concerns on human health and environmental safety, chemical nematicides are increasingly replaced by biological control agents (BCA). In recent years, *Bacillus* spp., have emerged as promising candidate for the biocontrol of RKN, offering a cost effective, eco-friendly and sustainable solution to agriculture.

Table 1. Estimated crop losses due to root-knot nematodes in major vegetable crops in India:

Crop	% loss	Monetary loss (millions rupees)
Bitter Gourd	13.5	252.82
Bottle Gourd	22	403.78
Brinjal	21	3499.12
Capsicum	10	52.92
Carrot	34	754.12
Chilli	15	744.90
Cucumber	12	110.46
Okra	19.5	2480
Tomato	23	6035.20

Bacillus spp. and their Bionematicidal Attributes

Bacillus (Latin "stick") is a genus of Gram-positive, rod-shaped bacteria, belonging to the phylum *Firmicutes*. *Bacillus* species can be either obligate aerobes (oxygen dependent) or facultative anaerobes. They are ubiquitous in the rhizosphere and produce plethora of secondary metabolites, including lipopeptides, polyketides, lantibiotics, lytic enzymes and volatile compounds. In addition, *Bacillus* species are capable of forming highly resistant endospores that are tolerant to extreme environmental conditions such as high temperatures, nutrient and water deficiencies, and unfavorable pH levels. Besides, they are known to promote plant growth (Engelbrecht et al., 2018). In particular, *Bacillus* spp., antagonize nematode directly through the production of toxins, enzymes and other bioactive

compounds that impair nematode mobility, development and reproduction. These compounds disrupt physiological processes by degrading structural elements such as cuticles, and interfering with key metabolic pathways essential for nematode survival. Besides, they enhance defensive mechanism in plants against nematode attack. For instance, *Bacillus thuringiensis* produces Cry proteins that cause cell lysis and death by creating pores in nematode gut cells (Vasanth-Srinivasan et al., 2025). Several *Bacillus* species such as *B. subtilis*, *B. thuringiensis*, *B. firmus*, *B. cereus*, *B. pumilus*, *B. amyloliquefaciens*, *B. licheniformis*, *B. velezensis*, *B. megaterium*, *B. nematocida*, etc., have been extensively exploited for the RKN management (Gowda et al., 2022; Gowda et al., 2024; Vasanth-Srinivasan et al., 2025).

Application Methods

From a technological perspective, the ability of *Bacillus* to produce heat and desiccation resistant endospores is highly advantageous for the preparation of a stable formulation. However after preparation, the timing of application and the appropriate delivery method are critical for achieving the desired bio efficacy under field conditions. One widely used approach is seed treatment, where seeds are coated with a *Bacillus* formulation before sowing. This protects plants from nematode penetration during the early stages of plant growth. Besides, nursery treatment of transplanted vegetable crops helps in early-stage protection, which reduces the severity of nematode problems in the main field. Another approach is the use of *Bacillus* as a soil amendment. This can be achieved by applying *Bacillus*-enriched organic matter such as compost or manure, or by soil drenching at intervals of 15 or 30 days in the rhizosphere region. These methods enhance root colonization throughout the crop growth period. Additionally, the biomolecules reduce the nematode penetration and damage by interfering with nematode behaviour, feeding, and reproduction. Beyond nematode control, these applications also improve soil health by enhancing beneficial microbial communities (Gowda et al., 2022; 2024).



Fig. 1: Different application methods for root-knot nematode management

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Regenerative Agriculture: A Way Forward Towards Carbon Credit Farming

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Sharanabasava¹, Veeresh H¹, Prakash H Kuchanur², S N Bhat¹, S R Balanagoudar¹, Sridhara M R³, Sharan Bhoopal Reddy¹

¹Department of Soil Science, University of Agricultural Sciences, Raichur- 584104 (Karnataka), India.

²Department of Genetics and Plant Breeding, University of Agricultural Sciences, Raichur- 584104 (Karnataka), India.

³Department of Agronomy, University of Agricultural Sciences, Raichur – 584104 (Karnataka), India.

Agriculture has long been recognized as the backbone of India, supporting the livelihoods of a majority of its population and playing a pivotal role in ensuring food security, generating employment, and driving economic development. Nearly 65 per cent of the Indian population depends on agriculture, either directly or indirectly, for sustenance and income. Despite its importance, the sector is increasingly confronted with serious challenges such as soil degradation, declining soil fertility, overexploitation of natural resources, and the adverse impacts of climate change. These issues not only threaten the productivity and sustainability of Indian agriculture but also the socioeconomic stability of millions of rural households.

In response to these challenges, there is growing global and national interest in adopting sustainable and climate-resilient farming practices. Among these, regenerative agriculture has emerged as a transformative approach that emphasizes soil restoration, biodiversity enhancement, water-use efficiency, and reduced dependence on chemical inputs. Beyond environmental benefits, regenerative agriculture also provides farmers with new avenues for income generation through participation in carbon credit markets, wherein carbon sequestration achieved by improved agricultural practices can be monetized.

Regenerative Agriculture: Regenerative agriculture is an advanced farming approach that focuses on restoring soil health, enhancing biodiversity and reducing carbon emissions. It goes beyond sustainability by actively improving the ecosystem. One of its key benefits is carbon sequestration, which enables farmers to participate in carbon credit markets, providing both environmental and financial incentives.

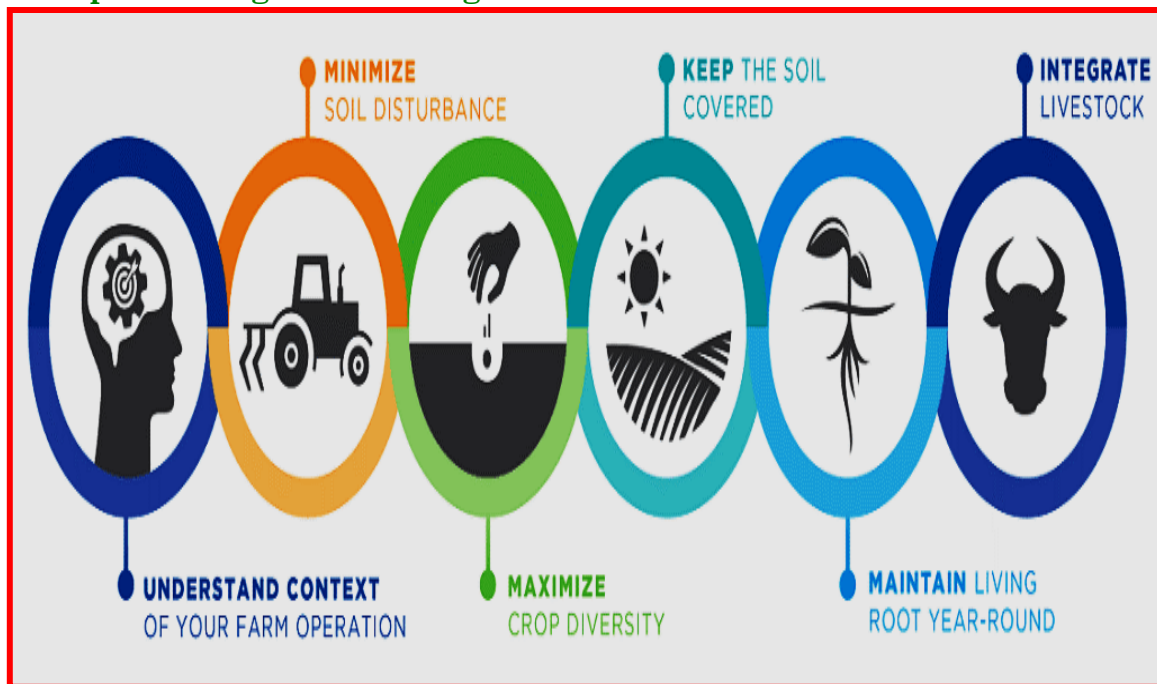
Major Techniques in Regenerative Agriculture

- 1. Agroforestry** is a sustainable farming method that combines trees, crops and livestock on the same land to improve soil health, boost biodiversity and capture carbon, making farms more productive and environmentally friendly.
- 2. No-Till Farming** is a sustainable agricultural practice where crops are planted without plowing the soil, preserving its structure, reducing erosion, improving moisture retention and enhancing soil health.
- 3. Cover Cropping** is a farming practice where plants are grown to protect and improve soil health by preventing erosion, adding nutrients, retaining moisture and suppressing weeds.
- 4. Managed Grazing** is a farming practice where livestock are moved strategically across pastures to prevent overgrazing, improve soil health, boost plant growth and enhance ecosystem sustainability.
- 5. Composting** is the process of recycling organic waste, like food scraps and leaves into nutrient-rich soil to improve soil health, reduce waste and support sustainable farming.
- 6. Polyculture Farming** is a sustainable method of growing multiple crops together in the same space to improve soil health, increase biodiversity, reduce pests and enhance farm resilience.
- 7. Biochar** is a fine-grained black carbon material produced through pyrolysis of plant biomass. Improve soil fertility by improving the moisture retention quality of soil and allowing soil to retain nutrients for long time period.

Benefits of Regenerative Agriculture for Climate Change

1. Carbon Sequestration
2. Reduction in Emissions
3. Resilience to Climate Impacts
4. Enhanced Biodiversity
5. Lower Dependency on Fossil Fuel-Based Inputs
6. Support for Carbon Markets
7. Cooling Effect

6 Core Principles of Regenerative Agriculture



- 1. Understand Context of Your Farm Operation:** Every farm is unique, and practices should be adapted based on location, climate and ecosystem needs.
- 2. Minimize Soil Disturbance:** Avoid excessive ploughing or tilling to protect soil structure, retain moisture and support beneficial microbes.
- 3. Maximize Crop Diversity:** Growing multiple crop varieties enhances soil fertility, reduces pests and increases resilience.
- 4. Keep the Soil Covered:** Using cover crops or mulch prevents erosion, retains moisture and improves soil health.
- 5. Maintain Living Roots Year-Round:** Keeping plants in the soil year-round stabilizes it, promotes microbial activity and enhances nutrient cycling.
- 6. Integrate Livestock:** Managed grazing and animal integration improve soil fertility, increase biodiversity and reduce reliance on synthetic inputs.

Carbon credit farming leverages regenerative agriculture by quantifying the amount of carbon stored in soil and vegetation. Farmers earn carbon credits, which industries purchase to offset their carbon emissions, creating an additional revenue stream. Governments, corporations and environmental bodies are investing in carbon markets, making regenerative agriculture a financially viable and environmentally sustainable model for the future.

Carbon credit farming involves farmers earning income by implementing practices that reduce **Greenhouse Gas Emissions** or **Sequester Carbon** in the soil, leading to the generation of tradable **carbon credits**.

- 1. Carbon Credit Farming: A Financial Opportunity:** farmers to **earn credits** by capturing and **storing carbon** in soil and biomass.

2. These credits can be sold to companies seeking to offset their carbon footprint.
3. Governments and private organizations are investing in carbon markets, making regenerative agriculture economically viable.



Carbon Credit Trading Scheme

In India, the government has introduced the Carbon Credit Trading Scheme (CCTS) in December 2023. This scheme allows farmers and entities to register GHG mitigation projects and earn carbon credit certificates.

The Ministry of Agriculture & Farmers Welfare has also developed a framework for promoting Voluntary Carbon Markets (VCM) in the agricultural sector. This framework aims to:

1. Encourage small and marginal farmers to adopt eco-friendly practices.
2. Provide additional income through carbon credits.
3. Enhance natural capital, such as soil health, water resources and biodiversity.

India's broader carbon market initiatives include compliance mechanisms like the Perform, Achieve and Trade (PAT) scheme and voluntary mechanisms under the Indian Carbon Market Framework. These initiatives aim to incentivize sustainable practices and support the country's climate goals.

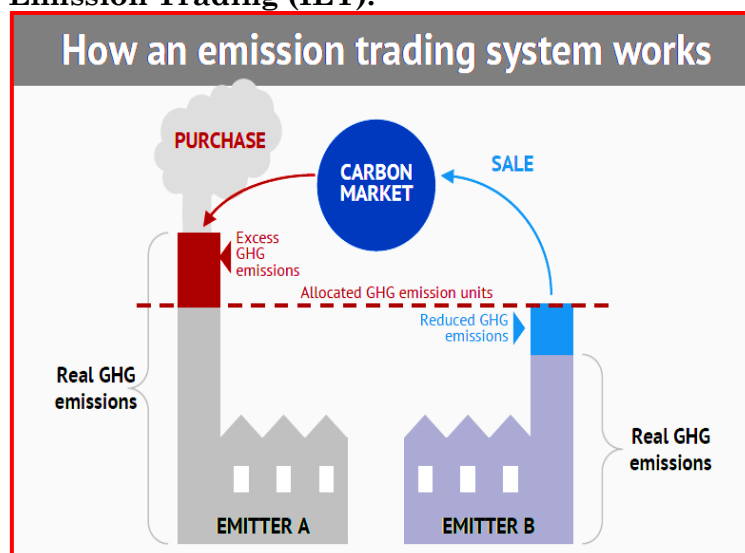
Carbon Trading Options in Indian Agriculture

Permits that allow the owner to emit a certain amount of carbon dioxide or other greenhouse gases.

The Kyoto Protocol introduced three market-based mechanisms, thereby creating what is known as the “carbon trading”.

The three Kyoto mechanisms includes:

- a. **Joint Implementation (JI)**
- b. **Clean Development Mechanism (CDM)**
- c. **International Emission Trading (IET).**



Emission trading system (ETS) also known as a carbon market or cap-and-trade system functions to reduce greenhouse gas (GHG) emissions in an economically efficient manner. The core concept of an ETS is to set a limit (cap) on the total amount of emissions allowed from all participating entities, and then allocate or sell emission permits (also called allowances) to each emitter based on this cap. These permits represent the right to emit a specific amount of GHGs.

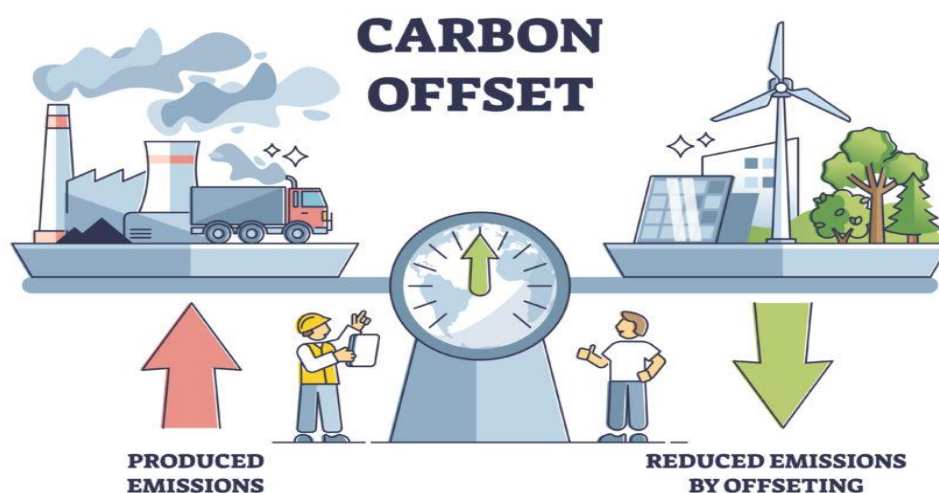
In the diagram, Emitter A emits more GHGs than the allocated limit, resulting in excess emissions. Since it has exceeded its allowed quota, Emitter A must purchase additional emission units from the carbon market to comply with regulations. This purchase incurs a cost, thus acting as a penalty for emitting more than allowed. On the other hand, Emitter B has managed to reduce its GHG emissions and emits less than its allocated limit. The excess or unused allowances can be sold to other emitters, such as Emitter A. This sale creates a financial incentive for Emitter B to invest in green technologies and reduce its carbon footprint further.

The carbon market serves as a platform that facilitates the trading of these emission allowances. It enables a flexible and cost-effective approach to environmental regulation by allowing companies that can reduce emissions more cheaply to sell their surplus allowances to others. This market-based approach ensures that overall emissions are kept within the environmental cap, while businesses have the flexibility to choose how to meet their targets. In essence, an ETS promotes innovation, rewards cleaner operations, and helps nations move toward their climate goals in a systematic and economically viable way.

Carbon Offset in Market System

1 Carbon Credit = 1 ton of CO₂ emission

Carbon Offset in Market System” illustrates the concept of carbon offsetting and how it functions within a carbon credit trading system. The central idea behind carbon offsetting is to compensate for carbon dioxide (CO₂) emissions produced by one entity by funding or supporting activities that reduce or remove an equivalent amount of CO₂ elsewhere. In this system, industries or organizations that produce greenhouse gas emissions—such as factories, power plants, or transportation sectors—can offset their emissions by investing in projects that reduce emissions, like renewable energy, reforestation, or energy efficiency programs.



The graphic shows two sides: on the left, emissions are produced by industrial activities, and on the right, emissions are reduced through cleaner alternatives such as wind energy or planting trees. The central concept of a carbon credit is highlighted, where 1 carbon credit equals the reduction or removal of 1 ton of CO₂ emissions. By purchasing carbon credits, polluters essentially neutralize their carbon footprint and comply with environmental regulations or corporate sustainability goals. This system creates a market-driven approach to climate action, encouraging investment in green technology and climate-friendly projects. It also allows flexibility for companies that find it difficult or expensive to reduce emissions directly, enabling them to support global emission reduction efforts instead. Overall, carbon offsetting helps

bridge the gap between current industrial practices and long-term sustainability targets by placing a tangible value on emission reductions.

Conclusion

Regenerative agriculture offers a scalable and sustainable pathway to carbon credit farming. By adopting soil carbon enhancing techniques, farmers not only improve productivity but also generate financial benefits through carbon credits in coming days. As the demand for carbon offsets rises, integrating regenerative practices with carbon markets can drive a more resilient and climate-friendly agricultural system.

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Food Drying: Uncovering the Benefits and Hidden Drawbacks

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Ashish Kumar¹, Naval Kishore Meena², Naresh Lamba³, Shahinur Alam⁴

^{1, 2}Department of Horticulture, Ph.D Scholar, RCA (MPUAT), Udaipur, Raj.

³Department of M.Tech in dairy technology, Dairy science and food technology, BHU, U.P.

⁴Department of Agriculture, Dilapakhara bahumukhi HS, Guwahati, Assam.

Food Drying

Food drying, one of the oldest preservation methods, has been used worldwide for centuries to extend the shelf life of various foods. Evidence of drying techniques has been found across ancient civilizations, where sun-drying was the primary method, utilized by cultures ranging from the Egyptians and Romans to Indigenous populations in North America and Asia (Mujumdar & Law, 2010). This method involves removing moisture from food to inhibit the growth of microorganisms, thereby reducing spoilage and allowing for safe, long-term storage (Rahman, 2020).

The purpose of this paper is to explore both the benefits and potential drawbacks of food drying. While drying offers advantages such as improved convenience, prolonged shelf life, and retained nutritional value in certain contexts, it also presents challenges such as potential nutrient losses and quality changes due to dehydration processes (Ahmed & Ratti, 2016).

In recent years, food drying has regained popularity in modern food processing, largely for its ability to enhance convenience and extend the storage life of foods. Techniques such as freeze-drying, spray drying, and vacuum drying are widely used in the industry today, reflecting its evolution from ancient methods to sophisticated, controlled processes designed to meet consumer demands for convenient, shelf-stable foods (Mujumdar, 2006).

There are several common methods of food drying:

- 1. Sun Drying:** This is the most ancient and natural form of drying, relying on direct sunlight and open air to remove moisture. Sun drying is widely used in regions with a hot, dry climate and requires minimal equipment, though it can be slow and dependent on weather conditions (Mujumdar & Law, 2010).
- 2. Oven Drying:** In this method, controlled heat from an oven is used to dry food at a relatively consistent temperature, typically between 50-70°C. Oven drying is faster and more reliable than sun drying, making it suitable for home and small-scale drying applications (Ahmed & Ratti, 2016).
- 3. Freeze-Drying:** Also known as lyophilization, freeze-drying involves freezing the food and then placing it under low pressure, causing the frozen water in the food to sublime directly from ice to vapor. This method retains more nutrients and is widely used for high-value foods like coffee and fruits (Kowalski et al., 2018).
- 4. Dehydrating with Electric Dehydrators:** Electric dehydrators circulate warm air over food placed on trays, gradually removing moisture. This method is popular in home drying because it provides a consistent, controlled environment for drying a wide variety of foods (Mujumdar, 2014).

The drying process -removing moisture to inhibit microbial growth and extend shelf life:

The drying process is a critical preservation technique that removes moisture from food to prevent microbial growth and prolong shelf life. By lowering the water activity level in food products, drying makes the environment unfavorable for bacteria, yeasts, and molds, which need moisture to thrive. This process not only maintains food safety but also helps retain nutritional value for extended storage. Different drying methods—such as hot air drying, freeze-drying, and spray drying—are used based on the food's properties and desired quality attributes (Barbosa-Cánovas & Vega-Mercado, 1996; Michailidis and Krokida, 2014).

Drying also stabilizes food by slowing down enzymatic and oxidative reactions that can lead to deterioration. As a result, dried foods, including fruits, vegetables, and meat products, remain consumable

for long periods without refrigeration, making it an essential technique in the food processing industry (Alibaş, 2019; McMinn, 2006).

Types of Foods Commonly Dried

The drying process is widely applied to preserve various types of foods, and different categories of products—such as fruits, vegetables, herbs, and meats—are commonly dried due to their diverse applications in cooking, snacking, and long-term storage. Below is a detailed overview of each category:

1. Fruits: Fruits are one of the most common types of food that undergo drying. This process reduces the moisture content of the fruit, thus inhibiting microbial growth and enzymatic reactions, both of which are responsible for spoilage.

a. Examples: Apples, bananas, apricots, grapes (raisins), mangoes, berries, and plums (prunes).

b. Drying Methods: The most popular methods for drying fruits are sun drying, air drying, freeze drying, and spray drying (Ratti, 2001). Freeze drying is particularly useful for preserving the color, flavor, and nutritional content of fruits like strawberries and raspberries.

c. Benefits: Dried fruits retain much of their nutritional value, including vitamins, minerals, and fiber, but their shelf life is significantly extended. They are also more compact, making them ideal for long-term storage or for use in space food.

d. Challenges: Some fruits, such as those high in sugar content (e.g., grapes for raisins), can become sticky or caramelized during drying, which may affect texture and shelf life.

2. Vegetables: Vegetables are dried to preserve their nutritional value and extend their shelf life for convenience in off-season use. Drying vegetables also helps in reducing the bulk and weight, making them easy to store and transport.

a. Examples: Tomatoes, carrots, peas, corn, onions, and mushrooms.

b. Drying Methods: Vegetables are commonly dried using methods like hot air drying, freeze drying, and vacuum drying. Freeze drying is especially useful for delicate vegetables like mushrooms and peas, as it better preserves texture and nutrients.

c. Benefits: Dried vegetables are commonly used in soups, stews, and ready-to-eat meals. They provide a concentrated source of nutrients, especially minerals and antioxidants, even after the drying process.

d. Challenges: Some vegetables, such as leafy greens, can lose their texture or become overly tough when dried. Also, certain vegetables may require pretreatment (e.g., blanching) to inactivate enzymes that could lead to degradation.

Effect of Drying on the Quality of Vegetables

Drying is one of the most commonly used preservation methods for vegetables. However, the drying process can significantly impact various quality attributes, including color, texture, nutritional content, and flavor. Understanding these effects helps in optimizing drying conditions to retain the quality of vegetables.

1. Color and Appearance: Color is a critical quality attribute in dried vegetables, as it affects consumer perception and acceptance. During drying, color degradation can occur due to oxidation and the breakdown of pigments like chlorophyll, carotenoids, and anthocyanins. High temperatures and prolonged drying can intensify this color loss.

a. Research Insight: Krokida and Maroulis (2003) found that high-temperature drying, especially with hot air, often leads to browning reactions and pigment loss in vegetables like spinach and carrots, resulting in a less vibrant appearance.

b. Prevention: Methods like freeze drying and vacuum drying can help preserve color better than conventional air drying due to lower exposure to oxygen and heat.

2. Texture: Texture changes in dried vegetables can vary depending on the method and conditions used for drying. The removal of water from cell structures often leads to shrinkage and a tough or leathery texture, which may not be desirable for some applications.

a. Research Insight: Sablani *et al.* (2007) noted that freeze-dried vegetables generally retain a better texture than hot-air-dried vegetables, due to the lower drying temperatures and minimal cellular damage. However, freeze drying is more costly.

b. Application: Freeze-dried vegetables are often used in products where texture is critical, like instant soups, as they quickly rehydrate to a nearly fresh texture.

3. Nutritional Content: Nutritional losses, especially in vitamins sensitive to heat (like vitamin C and certain B vitamins), are common in the drying of vegetables. The retention of nutrients depends heavily on the drying method and the temperature applied.

a. Research Insight: According to a study by **Ratti (2001)**, freeze drying preserves nutrients more effectively than hot air drying, with minimal losses in vitamins and antioxidants. High-temperature drying can cause significant degradation of vitamins and even some minerals.

b. Implications: Freeze-dried vegetables are often recommended for applications where nutrient preservation is essential, such as emergency foods or high-quality snack products.

4. Flavor: Flavor compounds in vegetables can be affected by drying, as volatile aroma compounds may be lost or altered, particularly with high-temperature methods. Additionally, prolonged drying can sometimes lead to the development of off-flavors.

a. Research Insight: Studies by **Lewicki** and others (**2006**) suggest that freeze-drying preserves the volatile compounds in vegetables more effectively than conventional drying methods, maintaining a fresher taste in the dried product.

b. Consideration: For vegetables used in cooking or food products where flavor is critical, freeze drying or vacuum drying may be preferred, though these methods are generally more expensive.

5. Microbial and Enzymatic Actions:

a. Shelf Life Extension: Drying decreases the water activity in vegetables, reducing the likelihood of microbial growth and enzymatic degradation. This extends the shelf life of the product.

b. Enzyme Activity: Some enzymatic reactions that can cause spoilage are reduced or halted through drying; however, pre-drying treatments like blanching are often necessary to inactivate these enzymes effectively.

6. Rehydration Properties: Rehydration Quality: The ability of dried vegetables to absorb water and regain their original texture is crucial for quality. The drying method and the extent of drying impact how well they rehydrate. Freeze-dried vegetables typically rehydrate better compared to those dried through other methods (**Marques et al., 2007**).

7. Quality Assessment Methods:

a. Sensory Evaluation: Quality of dried vegetables can be accessed through taste tests, texture analysis, and visual assessments to determine overall consumer acceptability.

b. Chemical Analysis: Measuring nutrient content and analyzing for any off-flavors or undesired chemical changes provide an understanding of the drying effect on quality.

Herbs

Herbs are dried primarily to preserve their aromatic and flavorful oils, which are key to their culinary use. Drying extends the shelf life of herbs, making them available year-round.

1. Examples: Basil, thyme, oregano, mint, rosemary, parsley, and sage.

2. Drying Methods: Herbs are typically dried using air drying, oven drying, or freeze drying. Air drying is often the simplest and most cost-effective method for herbs, particularly in warm climates. Freeze drying, however, preserves the flavor and aroma better than other methods.

3. Benefits: Dried herbs retain much of their flavor, although some loss of aroma and taste can occur during the drying process. They are a convenient way to store herbs without refrigeration, offering extended usability in cooking.

4. Challenges: Over-drying can lead to the loss of volatile oils, which are crucial to the flavor and aroma of herbs. Care must be taken to avoid over-drying, especially in delicate herbs.

Meats

Meats are dried to preserve them without refrigeration and to enhance their flavor and texture. The drying process significantly extends the shelf life of meats, making them ideal for long-term storage or as snacks.

1. Examples: Beef jerky, turkey jerky, and biltong (South African dried meat).

2. Drying Methods: Meat drying is usually done through hot air drying, freeze drying, or smoking followed by drying. Smoking imparts a distinctive flavor and color to the meat, while freeze drying better preserves the meat's original texture.

3. Benefits: Dried meats are compact and rich in protein, making them convenient for use in various recipes or as a high-energy snack. They are often used in emergency food supplies and in hiking or camping.

4. Challenges: Dried meats must be carefully handled to prevent microbial contamination before and during the drying process. The risk of spoilage can also be influenced by the drying time, temperature, and humidity.

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High-Density Planting: A New Era in Fruit Cultivation

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Naval Kishore Meena¹, Suntilla Hajong², Vikash Meena³, Ritik Kumar⁴

¹Department of Horticulture, Ph.D Scholar, RCA (MPUAT), Udaipur, Raj.

²Department of Horticulture, College of NEHU, Tura campus.

³MSc. Scholar, Department of Vegetable Science, College of Rani Lakshmi Bai central agriculture University, Jhansi, UP.

⁴M.sc Scholar, Department of Fruit science, School of Agriculture Science Medziphema, Nagaland Central University.

Introduction

India is the second-largest producer of fruits in the world, with diverse agro-climatic regions supporting the cultivation of mango, banana, guava, pomegranate, citrus, apple, grapes, papaya, and many other fruits. Traditionally, fruit trees were grown at wide spacing, resulting in large-sized trees, delayed bearing, and low productivity per unit area. While such orchards lived long, their economic returns were often unsatisfactory for farmers in the short term.

With shrinking land holdings, increasing demand for fruits, and the need for higher profitability, High-Density Planting (HDP) has emerged as a revolutionary approach in fruit cultivation. HDP allows farmers to grow more plants per hectare with scientific canopy management, dwarfing rootstocks, fertigation, and training systems, leading to early returns, higher yield, and better fruit quality.

Thus, HDP is rightly called a “New Era in Fruit Cultivation” as it combines science, technology, and sustainability in orcharding.

Concept of High-Density Planting

1. Traditional planting: Trees are spaced widely (e.g., mango at 10 × 10 m = 100 plants/ha). Trees grow tall, making pruning, spraying, and harvesting difficult.

2. High-Density Planting: Trees are planted more closely (e.g., mango at 3 × 2 m = 1,666 plants/ha). With proper pruning, training, and dwarfing rootstocks, trees remain small, manageable, and highly productive.

The basic principle is “**more number of trees per unit area with better light interception, resource utilization, and canopy management.**”

Objectives of HDP

- 1. To increase productivity per unit area.**
- 2. To induce early bearing** and quick returns.
- 3. To improve fruit quality** through uniform light distribution.
- 4. To utilize land, water, and nutrients more efficiently.**
- 5. To facilitate mechanization** in orchard operations.

Objective	Extended Meaning / Benefits
1. Increase productivity per unit area	By accommodating more plants per hectare with proper canopy management, overall yield increases 2–3 times compared to traditional orchards.
2. Induce early bearing and quick returns	Dwarf varieties, pruning, and fertigation promote flowering within 2–3 years, giving farmers faster income and reducing financial risk.
3. Improve fruit quality through uniform light distribution	Smaller, well-pruned trees allow sunlight to reach all branches, leading to better fruit size, color, sweetness, and market value.
4. Utilize land, water, and nutrients more efficiently	HDP combines drip irrigation and fertigation, saving 40–60% water and 25–40% fertilizers, ensuring sustainable use of resources.

5. Facilitate mechanization in orchard operations

Manageable tree size allows use of modern tools (sprayers, pruners, harvesters, drones), reducing labor costs and improving efficiency.

Advantages of High-Density Planting

1. **Early Bearing:** Dwarf rootstocks and canopy management allow trees to bear fruit within **2–3 years** (instead of 5–7 years).
2. **Higher Productivity:** HDP orchards produce **2–3 times more yield** per hectare than conventional orchards.
3. **Better Quality:** Due to uniform sunlight exposure, fruits develop better **color, size, shape, and sweetness**.
4. **Efficient Resource Use:**
 - a. **Water:** Drip irrigation reduces water use by 40–60%.
 - b. **Fertilizer:** Fertigation increases fertilizer efficiency by 30–40%.
5. **Ease of Management:**
 - a. Small trees are easier to prune, spray, and harvest.
 - b. Reduces cost of labor in the long run.
6. **High Profitability:** Farmers get **returns within 3–4 years** instead of waiting for 7–8 years.

Key Components of HDP

1. Selection of Variety and Rootstock:

- a. **Dwarf varieties and rootstocks** are essential for HDP.
- b. Examples:
 - i. **Mango:** Amrapali, Mallika on dwarfing rootstocks (Bappakai, Vellaikolamban).
 - ii. **Apple:** M9, M26 dwarfing rootstocks.
 - iii. **Citrus:** Flying Dragon (dwarf), Rough Lemon (semi-dwarf).
 - iv. **Guava:** Lalit, Shweta on dwarfing rootstocks.

2. Planting Geometry: **Varies crop to crop** depending on vigor and rootstock.

Crop	Traditional Spacing	Plants/ha	HDP Spacing	Plants/ha
Mango	10 × 10 m	100	3 × 2 m	1,666
Guava	6 × 6 m	277	3 × 3 m	1,100
Banana	1,800–2,000	—	5,000–6,000	—
Apple	7 × 7 m	204	3 × 1 m	3,333
Citrus	6 × 6 m	277	2.5 × 2.5 m	1,600

3. Canopy Management

- a. Regular **pruning and training** are crucial.
- b. Systems used:
 - i. **Modified Central Leader** (mango, apple)
 - ii. **Spindle Bush** (apple, pear)
 - iii. **Palmette & Espalier** (grapes, apple, guava)
 - iv. **Meadow Orchard** (guava, apple)

4. Drip Irrigation and Fertigation:

- a. HDP orchards depend on **precise water and nutrient supply**.
- b. Fertigation ensures balanced nutrition, reduces waste, and improves fruit size and sweetness.

5. Use of Growth Regulators:

- a. Paclobutrazol in mango for controlling vegetative growth and inducing flowering.
- b. NAA in guava to control fruit drop.

Examples of HDP in Fruit Crops

1. Mango (UHDP in India):

- a. Traditional: 100 plants/ha, yield = 8–10 t/ha.

- b. HDP: 1,600 plants/ha, yield = 25–30 t/ha.
- c. Ultra-High Density Planting (UHDP) in mango has been highly successful in states like Andhra Pradesh, Uttar Pradesh, and Maharashtra.

2. Guava:

- a. Traditional: 277 plants/ha, yield = 8–10 t/ha.
- b. HDP (3 × 3 m): 1,100 plants/ha, yield = 20–25 t/ha.
- c. **Meadow Orchard System** (2 × 1 m = 5,000 plants/ha) is gaining popularity.

3. Banana:

- a. Normal: 1,800–2,000 plants/ha.
- b. HDP: 5,000–6,000 plants/ha with drip + fertigation.

4. Apple:

- a. Traditional orchards: 200–300 plants/ha.
- b. On dwarf rootstocks (M9, M26): 2,500–3,300 plants/ha.
- c. Himachal Pradesh and Jammu & Kashmir are adopting HDP with success.

5. Citrus:

- a. HDP spacing 2.5 × 2.5 m (1,600 plants/ha).
- b. Improves uniform fruit quality and ease of harvesting.

Economic Benefits

1. **Early returns:** Farmers start earning in 3–4 years.
2. **Higher net profit:** Yield is 2–3 times more per hectare.
3. **Better marketability:** Uniform fruits fetch higher prices.
4. **Export potential:** HDP orchards produce export-quality fruits.

Limitations/Challenges

1. **High Initial Cost** – Drip irrigation, fertigation, training structures are costly.
2. **Technical Skill Requirement** – Farmers need training in pruning, fertigation, and canopy management.
3. **Short Orchard Life** – Profitable up to 15–20 years compared to 40–50 years of traditional orchards.
4. **Market Risk** – High yield can cause glut if marketing channels are not developed.

Success Stories

1. **Mango UHDP in Andhra Pradesh:** Farmers achieved yields of 25–30 t/ha with uniform fruit quality, compared to 8–10 t/ha in traditional orchards.
2. **Guava Meadow Orchards in Uttar Pradesh:** Adoption of 5,000 plants/ha system resulted in 40–50 t/ha yield with high market returns.
3. **Apple in Himachal Pradesh:** Super high-density apple planting on M9 rootstock gave three times higher yield per hectare and better fruit color for exports.

Future Prospects

1. HDP is the **future of Indian horticulture**.
2. Combining HDP with **precision farming, protected cultivation, sensors, drones, and AI** will make fruit cultivation more sustainable.
3. Government schemes are increasingly supporting HDP under MIDH (Mission for Integrated Development of Horticulture).
4. Private companies are also investing in UHDP orchards for contract farming and processing industries.

Conclusion

High-Density Planting represents a **paradigm shift in fruit cultivation**. It allows farmers to achieve **early returns, higher yield, superior quality, efficient use of resources, and better market**

opportunities. Though it requires initial investment and technical knowledge, its long-term profitability and sustainability make it the future of horticulture.

By integrating modern technologies and providing training to farmers, HDP can transform Indian orchards into highly productive, resource-efficient, and globally competitive systems.

Innovative Input Strategies for Enhanced Crop Productivity

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Naval Kishore Meena¹, Shahinur Alam², Rohit Meena³, Riya Jajoo⁴

¹Department of Horticulture, Ph.D Scholar, RCA (MPUAT), Udaipur, Raj.

²Department of Agriculture, College of Dilapakhara bahumukhi HS, Biswanath Assam.

³M.Sc Scholar, Agronomy, School of agriculture medziphema campus, Nagaland Central university.

⁴M.Sc Scholar, Department of Agronomy, College of Junagadh Agricultural University.

Crop Productivity

Crop productivity is described as the increase in crop yield per unit area due to improved inputs, including modern crop varieties, fertilizers, and enhanced farming practices. It reflects the effectiveness of agricultural innovation in increasing food production (**Evenson and Gollin, 2003**).

Donald (1968) Crop productivity is defined as the biological yield per unit area, influenced by the genetic characteristics of the crop variety and the environment, which interact to determine the total biomass produced.

Crop productivity is defined as the yield of a crop per unit area that maximizes output while aiming for sustainable practices. This definition emphasizes the balance between high production and minimizing environmental impact.

The Food and Agriculture Organization (FAO) defines crop productivity as the capacity of a crop to produce output per unit area, influenced by genetic potential, input quality, and management practices. It underlines the role of sustainable intensification in achieving higher yields (**FAO, 2011**).

Need for Enhanced Crop Productivity

Enhanced crop productivity is essential for meeting the increasing global demand for food, optimizing land use, and promoting sustainable agricultural practices. Here are the key reasons for enhancing crop productivity:

- 1. Population Growth and Food Security:** - With the global population projected to reach 9.7 billion by 2050, the demand for food will continue to rise. Enhanced crop productivity is critical to meet this demand without expanding farmland excessively, which would otherwise lead to deforestation and biodiversity loss.
- 2. Resource Efficiency and Land Use Optimization:** - Increased productivity helps maximize output per unit of land, water, and nutrient resources, allowing for more efficient use of agricultural inputs. This is particularly crucial in regions with limited arable land and water resources (**Tilman *et al.*, 2011**).
- 3. Climate Change Adaptation:** - Crop productivity enhancements can help farmers adapt to the impacts of climate change, such as altered rainfall patterns, temperature fluctuations, and increased frequency of extreme weather events. Improved crop resilience through productivity-focused innovations can ensure stable food supplies.
- 4. Reducing Environmental Impact:** - Enhanced productivity enables sustainable intensification, reducing the need for land conversion and minimizing environmental degradation. Higher yields on existing land can help conserve natural habitats and reduce emissions associated with land-use change.
- 5. Economic Stability for Farmers:** - Increasing crop productivity can improve farm income by boosting yields without significantly raising input costs. This economic stability is especially important for smallholder farmers, who are often vulnerable to market and climate fluctuations.
- 6. Meeting Dietary and Nutritional Needs:** - Enhanced crop productivity, particularly of nutrient-rich crops, is essential for addressing malnutrition and improving global dietary health. It enables better access to a variety of crops, supporting balanced and healthy diets (**Pingali, 2012**).

7. Supporting Sustainable Development Goals (SDGs): - Enhanced crop productivity aligns with several UN Sustainable Development Goals, particularly SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production), helping ensure food security and sustainable agricultural practices globally (United Nations, 2015).

Some Strategies for Enhanced Crop Productivity are Given Below

1. Precision agriculture: - Precision agriculture (PA) is a farming management concept that uses advanced technologies to optimize crop and soil health, aiming to enhance productivity, efficiency, and sustainability by making data-driven decisions. Precision agriculture involves collecting detailed information on soil, weather, crop health, and field variability, allowing for the precise application of inputs such as water, fertilizers, and pesticides based on specific needs.

Precision agriculture uses a range of technologies to collect, analyze, and respond to field-level data. Here are some core technologies that support precision agriculture:

a. Global Positioning System (GPS) and Geographic Information Systems (GIS): - GPS and GIS provide precise location data and mapping capabilities, allowing for the spatial analysis of fields to understand field variability and apply inputs accordingly.

b. Remote Sensing and Drones: - Satellite and aerial imagery from drones enable the monitoring of crop health, soil moisture, and nutrient levels, providing real-time data to help farmers address issues before they impact yield (Hunt and Hively, 2019).

c. Soil Sensors and IoT Devices: - Soil sensors measure properties like moisture, pH, and nutrient content. Paired with IoT networks, these sensors provide real-time data, enabling precise water and nutrient management to optimize soil health and crop yield.

d. Variable Rate Technology (VRT): - VRT equipment allows for the variable application of inputs like fertilizers, water, and pesticides across a field based on specific needs. This targeted approach conserves resources and reduces environmental impact.

e. Big Data and Artificial Intelligence (AI): - Big data analytics and AI help process large datasets from sensors, satellites, and historical records, providing insights into optimal planting times, crop rotation strategies, and yield predictions (Kamilaris *et. al.*, 2017).

Integrated Nutrient Management (INM)

Integrated Nutrient Management (INM) is a holistic approach to managing soil fertility and crop nutrition through the combined use of chemical fertilizers, organic manures, compost, green manures, and bio-fertilizers. INM aims to enhance soil health, optimize crop yields, and sustain productivity while minimizing environmental impacts.

Biological Crop Protection

Biological crop protection refers to the use of natural organisms or biological agents, such as predators, parasitoids, pathogens, and antagonists, to control pest populations, diseases, and weeds in agricultural systems. This method aims to reduce dependency on chemical pesticides, thereby promoting environmental sustainability and enhancing biodiversity within agroecosystems.

Key Principles of Biological Crop Protection: -

1. Biopesticides: Biopesticides are natural pest control agents derived from biological sources, including microorganisms (such as bacteria, fungi, and viruses), biochemical substances (such as insect pheromones), and plant-derived compounds (such as neem extract).

2. Biofertilizers: Biofertilizers are living microbial products that promote plant growth by fixing atmospheric nitrogen, solubilizing phosphorus, or enhancing nutrient availability in the soil. They include nitrogen-fixing bacteria (e.g., *Rhizobium*), phosphate-solubilizing bacteria (e.g., *Pseudomonas*), and mycorrhizal fungi that improve nutrient uptake by plants, thereby reducing reliance on chemical fertilizers (Malusa and Vassilev, 2014).

3. Integrated Pest Management (IPM): Integrated Pest Management (IPM) is a sustainable approach to pest control that combines biological, cultural, mechanical, physical, and chemical control methods to manage pest populations.

Advanced Seed Technology

Advanced seed technology encompasses innovative practices and techniques aimed at improving the quality, performance, and resilience of seeds. This includes genetic enhancement, seed treatment, precision breeding, and biotechnology applications that contribute to higher crop yields, pest and disease resistance, and adaptability to changing environmental conditions.

Key Components of Advanced Seed Technology:

1. Genetic Modification (GM): Genetic modification involves altering the DNA of seeds to introduce desired traits such as pest resistance, herbicide tolerance, and enhanced nutritional content. This technology allows for faster breeding cycles and the development of crops that can thrive in adverse conditions (ISAAA, 2020).

2. Hybrid Seed Production: Hybrid seeds are produced by cross-breeding different parent lines to create offspring with superior traits, including increased yield, disease resistance, and better adaptability. This technology is widely used in major crops like corn and rice.

3. Seed Coating and Treatment: Seed coating involves applying a layer of nutrients, fungicides, insecticides, or growth-promoting substances to seeds before planting. This practice enhances seed performance by improving germination rates and protecting against pathogens and pests.

4. Precision Breeding Techniques: Techniques like CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) and genomic selection allow breeders to make precise modifications in plant genomes, facilitating the development of varieties with specific traits more efficiently than traditional breeding methods (Zhang and Zhang, 2020).

5. Drought and Stress Tolerance: Advanced seed technologies are focusing on developing seeds with enhanced tolerance to abiotic stresses such as drought, salinity, and extreme temperatures. This helps ensure food security in the face of climate change.

Water Management Innovations

Water management innovations refer to the novel techniques, technologies, and practices designed to optimize the use, conservation, and quality of water resources in agricultural, urban, and industrial contexts. These innovations aim to improve water efficiency, reduce wastage, enhance sustainability, and address challenges related to water scarcity and climate change.

Key Innovations in Water Management:

1. Drip Irrigation Systems: Drip irrigation delivers water directly to the root zone of plants through a network of tubing and emitters, minimizing evaporation and runoff. This system increases water-use efficiency, reduces water consumption, and improves crop yields.

2. Rainwater Harvesting: This technique involves collecting and storing rainwater for agricultural or domestic use, thus reducing dependency on conventional water sources. It helps improve water availability and mitigates the impacts of drought.

3. Soil Moisture Monitoring Technologies: Advanced soil moisture sensors and remote sensing technologies provide real-time data on soil moisture levels, allowing for precise irrigation scheduling and reducing water waste.

4. Subsurface Irrigation: Subsurface irrigation involves placing irrigation pipes below the soil surface, allowing for efficient water application directly to the root zone while reducing evaporation losses. This method is particularly useful in arid regions.

5. Water Recycling and Reuse: Treating and reusing wastewater for agricultural irrigation or industrial processes conserves freshwater resources and promotes sustainable water management. This approach is increasingly vital in water-scarce regions.

6. Smart Irrigation Systems: These systems utilize IoT devices, weather data, and machine learning algorithms to optimize irrigation scheduling based on real-time conditions, ensuring that water is applied only when and where it is needed (Kacira and Tamer, 2015).

Controlled Environment Agriculture (CEA)

Controlled Environment Agriculture (CEA) refers to the practice of growing plants in controlled environments, such as greenhouses, indoor farms, or vertical farms, where factors such as temperature, humidity, light, carbon dioxide levels, and nutrients can be precisely managed.

Key Features of CEA:

- 1. Environmental Control:** CEA systems allow for the manipulation of environmental conditions to create optimal growth conditions for plants. This includes the use of heating, cooling, lighting, and humidity control systems to maintain ideal conditions year-round (Al-Kodmany, 2018).
- 2. Hydroponics and Aquaponics:** CEA often employs soilless growing methods like hydroponics (growing plants in nutrient-rich water) and aquaponics (combining fish farming with plant cultivation). These systems can reduce water use and increase efficiency (Resh, 2022).
- 3. Energy Efficiency:** Advanced CEA systems use energy-efficient technologies such as LED lighting, which can provide specific light wavelengths beneficial for plant growth while consuming less energy than traditional lighting systems.

Digital and AI-driven Solutions

Digital and AI-driven solutions refer to the integration of digital technologies and artificial intelligence (AI) to enhance decision-making, optimize processes, and improve outcomes across various sectors, including agriculture, healthcare, finance, and more. These solutions leverage data analysis, machine learning, and automation to drive efficiency, innovation, and productivity.

Key Components of Digital and AI-Driven Solutions:

- 1. Data Analytics:** Digital solutions utilize data analytics to process and analyze vast amounts of information from various sources. This helps organizations make informed decisions based on real-time data, trends, and patterns (Provost, 2013).
- 2. Machine Learning:** AI-driven solutions often employ machine learning algorithms that enable systems to learn from data, improve over time, and make predictions or recommendations without being explicitly programmed.
- 3. Automation:** Automation technologies, powered by AI, streamline processes, reduce manual labor, and minimize errors. This can include robotic process automation (RPA) in business operations or autonomous systems in agriculture (Lacity and Willcocks, 2018).
- 4. Cloud Computing:** Cloud platforms facilitate data storage, processing, and collaboration, enabling organizations to access and share information seamlessly across geographic locations.

Future Directions in Enhancing Crop Productivity

- 1. Integration of Technology and Data Analytics:** The future of agriculture will heavily rely on advanced technologies, including artificial intelligence (AI), machine learning, and big data analytics. These technologies can optimize resource use, improve decision-making, and enhance crop management practices (Wolfert *et. al.*, 2017).
- 2. Adoption of Climate-Smart Agriculture (CSA):** CSA practices aim to increase productivity while enhancing resilience to climate change. These include crop diversification, improved soil management, and efficient water use, tailored to local conditions (Lipper *et. al.*, 2014).
- 3. Enhanced Genetic Improvement through Biotechnology:** Continued advancements in genetic engineering, including CRISPR and other gene-editing technologies, will enable the development of crop varieties that are more resilient to pests, diseases, and climate stressors (Kelley and Smith, 2016).
- 4. Expansion of Agroecological Practices:** Agroecology emphasizes the integration of ecological principles into farming. Future directions include the wider adoption of agroecological practices that enhance biodiversity, soil health, and ecosystem services (Altieri and Nicholls, 2017).
- 5. Policy Support and Farmer Education:** Future strategies must include strong policy frameworks that support sustainable practices and provide training for farmers on innovative techniques and technologies to improve crop productivity.

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Role of Forestry Practices in Sustainable Agriculture

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Ashish Kumar¹, Naval Kishore Meena², Suntilla Hajong³, Sridhar K⁴

^{1, 2}Department of Horticulture, Ph.D Scholar, RCA (MPUAT), Udaipur, Raj.

³M.Sc. scholar, Department of Horticulture, College - NEHU, Tura campus.

⁴M.Sc. scholar, Department of Vegetable science, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Iruvakki Shivamogga.

Sustainable Agriculture

Sustainable agriculture is a farming approach designed to meet food and fiber needs, protect the environment, use resources efficiently, support farm profitability, and improve life for farmers and society (1990 U.S. Farm Bill). A sustainable farm must produce sufficient high-quality food, conserve resources, be eco-friendly, and remain profitable, relying largely on natural processes and renewable resources from within the farm rather than on external inputs (Reganold *et al.*, 1990). Sustainable agriculture involves practices that align with natural processes to conserve resources, reduce waste, minimize environmental impact, and foster resilient, self-regulating ecosystems for long-term productivity and nourishment (MacRae *et al.*, 1989).

Roles of Sustainable Agriculture

Sustainable agriculture plays several key roles in promoting environmental health, economic viability, and social well-being. Here are some of the primary roles:

- 1. Environmental Conservation:** - Sustainable agriculture helps preserve natural resources by conserving water, improving soil health, and maintaining biodiversity (Altieri, 1999). It reduces dependency on chemical inputs, lowers pollution, and enhances ecosystem resilience.
- 2. Economic Viability for Farmers:** - By focusing on long-term productivity and reduced input costs, sustainable agriculture supports the economic stability of farms. It encourages practices that are cost-effective and resource-efficient, helping farmers achieve profitability without harming the environment (Pretty, 2008).
- 3. Food Security and Quality:** - It aims to produce sufficient, nutritious, and high-quality food to meet human needs. Sustainable farming practices can improve food safety and provide communities with reliable, locally sourced food (Putnam *et al.*, 2014).
- 4. Community and Social Well-being:** - Sustainable agriculture enhances quality of life for farmers and rural communities by promoting fair labor practices, fostering rural development, and supporting local economies. It also connects consumers to their food sources, fostering a stronger connection to and awareness of farming practices.
- 5. Climate Change Mitigation:** - By sequestering carbon in soil, reducing greenhouse gas emissions, and increasing climate resilience, sustainable agriculture plays a vital role in combating climate change. Practices like agroforestry, conservation tillage, and crop rotation help absorb carbon and reduce agriculture's carbon footprint (Kremen and Miles, 2012).
- 6. Preservation of Genetic Diversity:** - Sustainable agriculture promotes the use of diverse crop varieties and livestock breeds, helping to safeguard genetic diversity. This diversity improves resilience to pests, diseases, and climate fluctuations, ensuring more stable food systems.

Forestry

"Forestry is the science, art, and practice of managing, conserving, and sustainably using forests, woodlands, and related resources. It encompasses various activities, including planting and maintaining trees, protecting ecosystems, and managing forest resources for both timber and non-timber products while conserving biodiversity. The aim of forestry is to balance the ecological health of forest ecosystems with the economic and social needs of communities, ensuring that forests continue to provide essential

environmental benefits such as carbon sequestration, water regulation, soil protection, and habitat for wildlife (**Food and Agriculture Organization of the United Nations, 2022**).

King (1987): Forestry within agriculture is defined as the “integration of trees and farming practices to enhance both agricultural productivity and ecological stability.”

Young (1997): Forestry in sustainable agriculture, specifically agroforestry, is described as “a sustainable land use system that maintains or increases total yield by combining food crops (annuals) with tree crops (perennials) and/or livestock on the same unit of land, using management practices that take into account the interactions among them.”

Nair (1993): Forestry practices in sustainable agriculture are seen as “the inclusion of trees in farming systems to conserve soil, improve biodiversity, sequester carbon, and stabilize ecosystems, thereby contributing to long-term agricultural sustainability.”

Roles of Forestry in Sustainable Agriculture

Integrated Nutrient Management (INM) is a holistic approach to managing soil fertility and crop nutrition through the combined use of chemical fertilizers, organic manures, compost, green manures, and bio-fertilizers. INM aims to enhance soil health, optimize crop yields, and sustain productivity while minimizing environmental impacts.

Biological Crop Protection

1. Agroforestry Systems: - Agroforestry integrates trees and shrubs into agricultural landscapes, enhancing biodiversity and productivity. This practice can lead to improved crop yields and ecosystem services (**Nair, 2012**).

2. Soil Health Improvement: - Trees contribute organic matter and improve soil structure, enhancing soil fertility and preventing erosion. This results in healthier soils that support agricultural production (**Kumar *et al.*, 2004**).

3. Biodiversity Enhancement: - Forests and agroforestry systems can increase biodiversity on farms by providing habitats for various species, which can help with pest control and pollination (**Gomez-Baggethun *et al.*, 2010**).

4. Carbon Sequestration: - Forestry practices, especially agroforestry, contribute to carbon sequestration by storing carbon in biomass and soil, helping to mitigate climate change (**Change, I.C., 2014**).

5. Water Management: - Trees in agricultural landscapes help regulate water cycles by improving water infiltration, reducing runoff, and enhancing groundwater recharge (**Postel, 2000**).

6. Provision of Non-Timber Forest Products: - Forests provide valuable non-timber forest products (NTFPs) that can supplement farmers' incomes and enhance food security (**Ticktin, 2004**).

7. Resilience to Climate Change: - Agroforestry systems can enhance resilience to climate change by providing shade and wind protection, thus safeguarding crops from extreme weather (**Lin, 2010**).

8. Community Engagement and Sustainable Practices: - Community-based forestry and agroforestry initiatives promote local participation and stewardship, fostering sustainable land management practices (Pretty and Ward 2001).

Key Forestry Practices that Support Sustainable Agriculture

1. Alley Cropping: - In alley cropping, rows of trees are planted alongside crops to protect soil from erosion, enhance nutrient cycling, and provide shade. This practice benefits crop growth and supports soil fertility (**Garrett *et al.*, 2000**).

2. Silvopasture: - Silvopasture combines trees, forage, and livestock on the same land, enhancing biodiversity and providing shade and wind protection for animals. This practice improves animal welfare, productivity, and resilience to climate extremes (**Sharrow and Ismail, 2004**).

3. Riparian Buffers: - Riparian buffers involve planting trees and vegetation along water bodies to prevent soil erosion, reduces runoff, and filter nutrients. These buffers improve water quality and create wildlife habitat, benefiting both agriculture and surrounding ecosystems (**Lowrance *et al.*, 1984**).

4. Shelterbelts (Windbreaks): - Shelterbelts are rows of trees planted to reduce wind speed, protect crops from wind damage, and reduce soil erosion. Shelterbelts can also conserve moisture and create microclimates that benefit crop growth (**Brandle *et al.*, 2004**).

5. Cover Cropping with Trees: - Trees and cover crops are used together to improve soil organic matter, reduce erosion, and suppress weeds. This practice is particularly effective in enhancing soil fertility and improving soil structure (**Snapp and Borden, 2005**).

6. Forest Farming: - Forest farming involves cultivating high-value crops under a forest canopy, such as mushrooms, herbs, or shade-tolerant fruits. This practice diversifies farm income, enhances biodiversity, and promotes sustainable forest use (**Chamberlain and Predny, 2003**).

7. Tree planting and Reforestation: - Tree planting and reforestation improve soil fertility, increase biodiversity, and sequester carbon. These practices restore degraded lands and contribute to the resilience of agricultural systems (**Lal, 2004**).

8. Sustainable Forest Management: - Sustainable forest management involves maintaining forest resources for biodiversity conservation, timber, and non-timber forest products. When integrated with agriculture, it ensures a balance between land use and ecosystem preservation.

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Specialized Pheromone and Lure Application Technology (SPLAT)

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Gopu Sushma¹, Kota Sahithi Chowdary², Repaka Harika²

¹Ph. D Scholar, Professor Jayashankar Telangana Agricultural University, Hyderabad.

²Ph. D Scholar, Indira Gandhi Krishi Vishwavidyalaya, Raipur.

Abstract

SPLAT® (Specialized Pheromone and Lure Application Technology) is a versatile, controlled-release emulsion developed by ISCA Technologies for the targeted and sustained delivery of semiochemicals, pesticides, and other bioactive compounds. Unlike traditional dispensers, SPLAT® functions as a matrix-type diffusion system, capable of releasing active ingredients over periods ranging from two weeks to six months. Its rainfast, thixotropic formulation allows for easy application and strong substrate adhesion, supporting various pest management strategies including mating disruption, attract and kill, and repellent delivery. Proven effective in diverse agricultural systems, SPLAT® offers a flexible, eco-friendly alternative to conventional insecticides, with potential for broader adoption in integrated pest management (IPM) programs worldwide.

Introduction

SPLAT® (Specialized Pheromone and Lure Application Technology) emulsion is a unique controlled release technology that can be adapted to dispense and protect a wide variety of compounds from degradation, including semiochemicals, pesticides and phagostimulants in diverse environments. ISCA Technologies, Inc., in collaboration with colleagues in academia, government and industry has been developing SPLAT® based insect control products for close to a decade (UAS) (Panigrahi *et al.*, 2025).

Although most semiochemicals controlled release formulations have taken the form of devices, such as aerosol dispensers (Puffer®, Suterra, LLC), polyethylene tubes (Isomate®, Shin-Etsu Chemical Co., Ltd.) and laminated polymers (Disrupt®, Hercon Environmental). ISCA has taken an alternative approach and commercialized a chemical formulation in the form of a controlled-release emulsion, SPLAT®. Although adapting SPLAT® to release new compounds can pose technical challenges, the versatility of this flowable formulation provides many advantages.

SPLAT® emulsions can be created to hold a range of semiochemicals concentrations and additives to create a formulation that releases the optimal rate of semiochemicals for the desired amount of time, while protecting active ingredients from environmental, chemical and biological degradation (Pawar *et al.*, 2022). In addition, SPLAT®, unlike most other semiochemicals dispensers, is not restricted to a particular point source size. Any amount of SPLAT®, large or small, can constitute a point source.

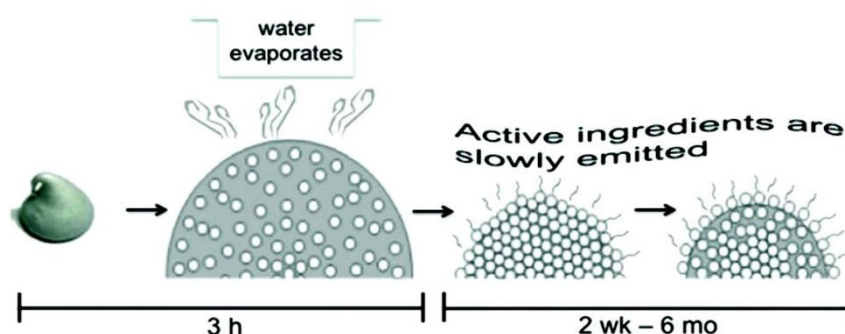
This provides yet another way to optimize the amount of volatile insect control compound released per point source for optimal efficacy. In addition, the rheological properties of SPLAT® can be adjusted to create emulsions with a wide range of physical properties. This has enabled SPLAT® products to be dispensed using a variety of manual and mechanical application techniques, allowing easy application to virtually any substrate or plot size.

Application: SPLAT® formulations typically have a paste or cream-like consistency. SPLAT® is a non-Newtonian, shear-thinning, thixotropic fluid, which means that SPLAT® viscosity decreases when the emulsion is placed under stress, such as when it is stirred or pumped, but increases again when the stress is removed.

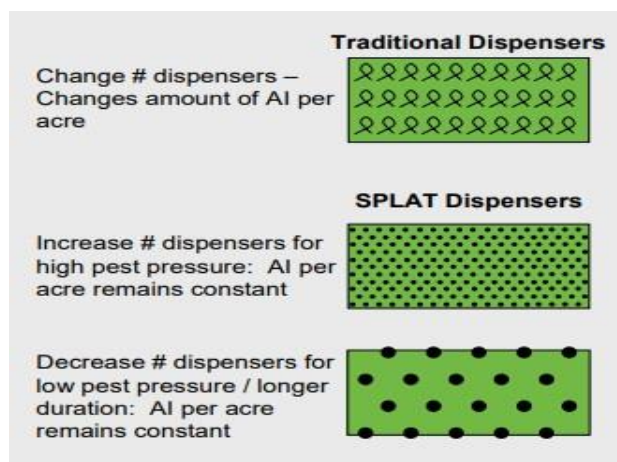
This property is advantageous in that the less viscous SPLAT® can easily be manipulated (e.g., stirred or pumped), but quickly thickens upon application to a surface, aiding in product adhesion. A wide variety of manual and mechanical applicators can be used to apply SPLAT®. The most basic SPLAT® applicator can be a stick, spatula, or knife.

Controlled Release Technology

The aqueous component of the SPLAT® emulsion gives the product its liquid character, allowing it to flow. The non-aqueous component of the emulsion is the controlled release device. It comprises the active ingredients (e.g., semiochemicals compounds or pesticides) and the additives that will protect these and fine-tune their release rates from the dispenser. Upon application, the aqueous component of SPLAT® evaporates from the dispenser within 3 hours, leaving the rain fast, nonaqueous component firmly affixed to the substrate, where it will release the active ingredients until all available molecules are dispensed (Gomez *et al.*, 2015).



After application, SPLAT® emulsion dries and becomes rainfast within 3 hours. It then gradually releases active ingredients over a period of 2 weeks to 6 months. The release duration depends on the specific formulation, how it's applied, and environmental conditions. SPLAT® functions as a *monolithic* or *matrix-type* diffusion controlled device, meaning the release of active ingredients is governed by their movement through the matrix material. These ingredients are typically dissolved in the matrix, enabling direct diffusion without needing to first break apart. Release occurs *via* diffusion, following Fick's First Law, where molecules move from areas of high concentration to low concentration at a rate proportional to the concentration gradient.



Advantages

- 1. Rain fast formulation:** Once cured, SPLAT will not wash off vegetation
- 2. Season long protection and more:** SPLAT can remain effective in managing pest populations up to a six-month duration.
- 3. Mixes with kairomones and feeding stimulants:** SPLAT can be mixed with a variety of feeding stimulants or attractants including liquids, solids and oils to enhance attraction or stimulate feeding.

SPLAT in Insect Pest Management

SPLAT has proven to be an effective and adaptable tool for managing insect pests, particularly through mating disruption. By releasing synthetic sex pheromones into the environment, SPLAT confuses male insects, preventing them from locating females and thereby reducing reproduction and pest populations. Products like SPLAT-PBW and SPLAT-BSFB have shown strong results in crops like Bt cotton and brinjal

(Sreenivas *et al.*, 2019; Sreenivas *et al.*, 2021). Field trials in Karnataka and Gujarat revealed lower male moth captures, less crop damage, and higher yields in SPLAT-treated areas compared to conventional farming methods.

Formulations

SPLAT products are offered in various categories, each designed to support specific pest control strategies to release a variety of compounds, including sex pheromones, kairomones, attractants, repellents, phagostimulants and insecticides.

SPLAT® Mating Disruption Formulations

Mating disruption consists of dispensing a synthetic form of one or more components of the natural pheromone blend of an insect, or biologically equivalent compounds, where host plant(s) are present. The presence of the species' sex pheromones in the environment delays or prevents mating of the insect, reducing fecundity and subsequent populations. It has proven to be a powerful technique for insect control and has become the most commonly used semiochemicals based insect control method.

Commercial SPLAT® Mating Disruption Products

Product	Pest	Availability
SPLAT® OFM	<i>Grapholita molesta</i>	U.S. & international
SPLAT® Cydia	<i>Cydia pomonella</i>	U.S. & international
SPLAT® LBAM	<i>Epiphyas postvittana</i>	U.S. & international
SPLAT® GM	<i>Lymantria dispar</i>	U.S. & international
SPLAT® Tuta	<i>Tuta absoluta</i>	U.S. & international
SPLAT® CLM	<i>Phyllocnistis citrella</i>	U.S. & international
SPLAT® PBW	<i>Pectinophora gossypiella</i>	International

SPLAT® Attract and Kill Formulations

They have proven to be effective and can provide an alternative control option for pests that may offer advantages over mating disruption, mass trapping, and the use of conventional insecticide sprays. Attract-and-kill products can also be used to lure and control pests out of areas that cannot be treated with conventional sprays. Depending on the attractant used, attract-and-kill products may be very selective (i.e., if insect sex pheromones are used). However, attractants with broad effects, such as plant kairomones, should be tested to determine their impact on non-target organisms. Another important difference between mating disruption and attract-and-kill products for manufacturers is that unlike mating disruption products, these insecticide-containing formulations cannot take advantage of legislation which has simplified and reduced the cost of EPA registration of arthropod pheromone-based insect control products that do not contain insecticides.

SPLAT® Repellents

Repellents are substances that discourage insects from locating, feeding, or laying eggs on host plants. While some repellent semiochemicals have been identified for agricultural and forest pests, their use remains limited. This is due to cheaper alternatives, challenges in effective delivery, and regulatory hurdles. Although repellents alone or in push-pull strategies can be effective, their success depends on a deeper understanding of insect behavior and ecology. SPLAT® is suitable for delivering volatile repellents, but high development and registration costs, along with small market demand, limit commercial adoption. Repellents are generally most effective for specific pests, crops and farmers willing to adopt specialized methods.

Conclusion

SPLAT® represents a significant advancement in sustainable pest management, offering a flexible, eco-friendly alternative to traditional chemical pesticides. Its controlled-release technology, broad applicability, and compatibility with integrated pest management (IPM) strategies make it a valuable tool for modern agriculture and forestry. As the demand for environmentally responsible solutions continues to grow,

SPLAT's proven effectiveness and potential for wider adoption position it as a key contributor to the future of global pest control.

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Bhagalpuri Zardalu Mango: A GI-Tagged Heritage Fruit with Nutraceutical Properties and Entrepreneurial Opportunities

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D.R. Singh¹, V. Shajeeda Banu¹, Amita Singh¹, A.K. Singh¹

¹Bihar Agricultural University, Sabour.

Introduction

Bihar, a state renowned for its fertile Gangetic plains, is home to several crops of national and international fame. Among these, the Zardalu mango of Bhagalpur occupies a unique place. Known for its distinctive aroma, delicate flavour and silky texture, this variety has been admired and enjoyed through generations. It is more than just a seasonal fruit, it represents Bihar's identity while reflecting the richness of its horticultural heritage. With its recognition under the Geographical Indication (GI) registry, Zardalu now enjoys global attention. Beyond its sensory qualities, it is also a fruit of health and opportunity, rich in nutrients and bioactive compounds like mangiferin and opening up new avenues for entrepreneurship. Zardalu mango is famed for its distinctive aroma, which is so intense that even a single fruit can perfume an entire room. This fragrance is not only a sensory quality but also a cultural symbol, as families in Bihar eagerly await its arrival every summer. The aroma has also played a significant role in shaping Zardalu's popularity in both domestic and international markets. In terms of flavour, Zardalu strikes a perfect balance. It is neither overwhelmingly sweet nor too tangy, making it palatable for all age groups. The pulp is buttery and fibre free, giving a smooth mouthfeel that distinguishes it from fibrous mangoes. Its thin golden-yellow skin enhances its appeal, making it visually as attractive as it is delicious. Culinary experts consider Zardalu versatile, it can be eaten fresh, blended into milkshakes and smoothies, prepared as aamras, or used in pickles, jams and chutneys. Its flavour has even inspired chefs to experiment with gourmet dishes, cocktails and desserts, giving Zardalu a premium status among mango varieties.



Fig: Bhagalpuri Zardalu Mango

Nutritional Wealth: Zardalu Mango as Nature's Health Booster

While its taste and aroma often capture immediate attention, the Zardalu mango is equally remarkable for its nutritional wealth. This golden fruit is a powerhouse of essential vitamins and minerals that make it much more than just a seasonal delight. It is an excellent source of Vitamin C, which strengthens the immune system, enhances iron absorption and promotes radiant, healthy skin. Zardalu also provides Vitamin A, vital for good eyesight, growth and immunity, as well as Vitamin E and B-complex vitamins, which support energy metabolism and maintain vital cellular functions. The fruit is also rich in dietary fibre, improving digestion, preventing constipation and aiding in weight management. Its mineral profile, especially potassium and magnesium, plays a significant role in regulating blood pressure and supporting cardiovascular health. Beyond these nutrients, Zardalu contains natural antioxidants that protect the body from oxidative stress. These bioactive compounds safeguard cells from damage and reduce the risk of

chronic conditions such as heart disease, cancer and premature aging. During the hot summer months, Zardalu also acts as a natural hydrating food, replenishing electrolytes and preventing dehydration. This makes it an ideal seasonal delight, that not only pleases the senses but also nourishes the body. Truly, the Zardalu mango is a wholesome gift of health from nature.

Mangiferin and Health Benefits

What makes the Zardalu mango truly stand out in the world of nutrition is its richness in mangiferin, a rare polyphenolic compound often hailed as a “super antioxidant.” Scientific research has revealed that mangiferin possesses a wide range of pharmacological properties, highlighting Zardalu not just as a fruit of flavour but as a potential functional food with significant health benefits. One of the most important roles of mangiferin is its anti-diabetic properties. It helps improve insulin sensitivity, lowers blood sugar levels and assists in managing complications related to diabetes. For diabetic patients, enjoying Zardalu in moderation provides a safe way to experience sweetness without causing harmful spikes in blood glucose. Mangiferin also exhibits strong anti-inflammatory and cardioprotective effects, reducing oxidative stress and safeguarding vital organs such as the heart, liver and kidneys from free radical damage. In addition to these benefits, mangiferin has been shown to exert antimicrobial and antiviral properties, inhibiting the growth of harmful microbes and strengthening the body’s natural defence mechanisms. Early studies also point to its role in cancer prevention. Taken together, these attributes make the Zardalu mango a fruit that delights the senses while supporting long term health and vitality.

Nutraceutical Value of Zardalu Mango

In recent years, the Zardalu mango has gained importance in the nutraceutical sector because of its unique composition of bioactive compounds. Nutraceuticals are food products that provide medical or health benefits beyond basic nutrition and Zardalu fits this category perfectly. The presence of mangiferin, combined with vitamins, minerals and natural antioxidants, place this fruit as a promising raw material for nutraceutical formulations. Powdered extracts of Zardalu pulp and peel can be developed into diabetic-friendly health supplements, antioxidant beverages, and functional foods. These products not only extend the fruit’s commercial value but also create opportunities for researchers, entrepreneurs and the wellness industry to utilize Zardalu as a natural solution for lifestyle-related disorders.

Startups and Entrepreneurship Opportunities

The Zardalu mango is not only a fruit of heritage but also a catalyst for startups and entrepreneurship in Bihar. With the right vision, this golden fruit can be transformed into multiple business opportunities:

- 1. Food Processing Startups:** Processing units can convert Zardalu into pulp, juice, jam, dried slices and confectionery products. These value-added products can be marketed throughout the year, creating demand beyond the seasonal supply.
- 2. Nutraceutical and Wellness Industry:** The high content of mangiferin provides a unique opportunity to develop nutraceutical products such as diabetic-friendly powders, capsules and herbal supplements. Entrepreneurs in the wellness industry can showcase Zardalu as a brand of natural remedies and holistic health.
- 3. Agri-Tourism and Mango Festivals:** Bhagalpur’s orchards can be developed into tourist hubs. Mango festivals, orchard visits and farm-stay experiences will promote both cultural heritage and rural economy. Tourists can enjoy mango picking, tasting sessions and learn about GI-tagged fruits.
- 4. Export-Oriented Ventures:** With proper branding, cold-chain logistics and certification, entrepreneurs can capture premium export markets. Zardalu can be promoted as India’s “Aromatic Golden Mango,” fetching higher returns abroad.
- 5. Women and Youth Enterprises:** Self-help groups (SHGs) and farmer producer organizations (FPOs) can establish micro-enterprises focused on mango based pickles, chutneys and ready to drink juices. This creates local employment and empowers women and rural youth.

Future Prospects

The Zardalu mango holds immense promise for the future. Bihar Agricultural University, Sabour is working on scientific cultivation practices, pest management and post-harvest technologies to ensure consistent quality. Government initiatives under schemes like One District One Product (ODOP) are helping promote Zardalu globally. With better infrastructure such as packhouses, cold storage and transport facilities, farmers and entrepreneurs can reduce post-harvest losses and maximize income. Moreover, the use of digital platforms and e-commerce can connect Bhagalpur's orchards directly to consumers across India and abroad.

Conclusion

The Bhagalpuri Zardalu mango is a rare blend of tradition, taste, health and opportunity. Its fragrance enchants, its flavour delights and its nutrients heal. For farmers, it is a crop of pride and livelihood; for consumers, it is a fruit of joy and wellness and for entrepreneurs, it is a gateway to innovation and prosperity. With sustained efforts in research, branding and entrepreneurship, Zardalu has the potential to become a global ambassador of Bihar's agriculture. Truly, it is a golden treasure, a fruit that carries the sweetness of heritage and the promise of a brighter future.

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Guar Gum: The Hidden Hero Behind Everyday Foods and Modern Medicine

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Rachamalla Ravi Teja¹

¹Sri Konda Laxman Telangana Horticultural University, Mulugu, Telangana, India.

Abstract

Guar gum, derived from the seeds of the cluster bean (*Cyamopsis tetragonoloba*), is emerging as one of the most versatile natural ingredients of our time. Widely recognized for its ability to thicken, stabilize, and bind, guar gum plays a hidden yet vital role in everyday foods from creamy ice creams to fresh breads and sauces. Beyond the kitchen, it has gained importance as a functional dietary fiber that supports digestive health, regulates blood sugar, lowers cholesterol, aids in weight management, and boosts immunity. In pharmaceuticals, modified guar gum is being explored for advanced drug delivery systems, wound healing, and tissue engineering, while in industries, it is indispensable in oil drilling, textiles, cosmetics, and paper production. Its plant-based, biodegradable nature also positions it as a sustainable material for the future. Truly, guar gum is a “hidden hero” linking agriculture, health, and modern technology.

Keywords: Guar gum, dietary fiber, food industry, pharmaceuticals, sustainability.

Introduction

If you’ve ever scooped into a creamy bowl of ice cream, bitten into fluffy bread fresh from the oven, or come across news about futuristic plant-based medicines, there’s a good chance guar gum was quietly working behind the scenes. This natural ingredient, extracted from the seeds of the cluster bean (*Cyamopsis tetragonoloba*), may look humble, but it packs a powerful punch. Known for its extraordinary ability to thicken, bind, and stabilize, guar gum is far more than a kitchen additive. It’s a multitasking marvel finding roles in our food, enhancing our health, supporting pharmaceutical breakthroughs, and even powering industries like oil, textiles, and cosmetics. Often described as a “hidden hero” of modern life, guar gum has journeyed from traditional Indian farms to becoming a global commodity, with India supplying nearly 80% of the world’s demand. What makes it so special is not just its versatility, but also its eco-friendly, plant-based origin, aligning perfectly with today’s push for sustainable, clean-label ingredients. Whether it’s helping regulate blood sugar, keeping your yogurt smooth, or enabling high-tech drug delivery systems, guar gum has a story worth telling.

What is Guar Gum?

Guar gum is a galactomannan polysaccharide a type of natural fiber made from two simple sugars, galactose and mannose. Found in the seeds of the cluster bean (*Cyamopsis tetragonoloba*), this gum is prized for its ability to form a gel-like consistency when mixed with water. Thanks to this property, guar gum works as a stabilizer, emulsifier, and binder, giving it a starring role in industries ranging from food and cosmetics to textiles, pharmaceuticals, and even oil drilling. What makes guar gum particularly fascinating is its versatility. In the kitchen, it helps ice creams stay creamy, breads remain soft, and sauces hold together without separating. In medicine, it is being developed into smart carriers for controlled drug delivery. In heavy industries, its thickening power is harnessed in processes like hydraulic fracturing (fracking), paper production, and textile finishing. Globally, India leads the guar gum market, supplying nearly 80% of the world’s production, with the majority grown in Rajasthan and Haryana. This not only supports global industries but also sustains the livelihoods of thousands of farmers in semi-arid regions, where guar is cultivated as a drought-tolerant crop. In short, guar gum is much more than a food additive it’s a hidden workhorse of modern life, quietly linking agriculture, nutrition, medicine, and technology (Amiri *et al.*, 2021; Ganiger *et al.*, 2023).

Health Benefits of Guar Gum

Beyond its industrial fame, guar gum is also earning recognition as a **functional food ingredient** a natural fiber that supports modern health challenges like digestive issues, diabetes, and heart disease. Here's how it contributes to wellness:

- 1. Digestive Health:** One of the most studied forms of guar gum is partially hydrolyzed guar gum (PHGG), a water-soluble fiber that's gentle on the stomach. Research shows PHGG can relieve constipation, ease symptoms of irritable bowel syndrome (IBS), and even encourage the growth of "good bacteria" in the gut making it a natural prebiotic
- 2. Diabetes Management:** For people with diabetes, guar gum can be a quiet ally. By slowing the absorption of glucose in the small intestine, it helps prevent sharp spikes in blood sugar after meals. Some studies have even shown improved long-term blood sugar control when guar gum is added to the diet (Alaeian *et al.*, 2023).
- 3. Heart Health:** Clinical trials reveal that guar gum lowers LDL cholesterol ("bad" cholesterol) and triglycerides, while maintaining or even boosting HDL ("good" cholesterol). This makes it a valuable dietary tool for reducing the risk of cardiovascular disease.
- 4. Weight Management:** Thanks to its gel-forming ability, guar gum **slows digestion** and promotes a feeling of fullness. This satiety effect helps reduce snacking and overall calorie intake supporting healthy weight management.
- 5. Immunity Boost:** The non-digestible carbohydrates in guar gum serve as food for beneficial gut microbes. As these microbes ferment guar gum, they produce compounds that strengthen the gut barrier and **stimulate immune responses**, helping the body defend itself against infections.

Food Industry Applications

When it comes to food, **guar gum is everywhere** though most of us never notice it on the label. The U.S. Food and Drug Administration (FDA) classifies it as **GRAS (Generally Recognized as Safe)**, which means it's approved for widespread use at safe levels. Its remarkable ability to thicken, stabilize, and bind makes it one of the food industry's favorite "behind-the-scenes" ingredients

Here's how guar gum quietly improves the foods we love:

- 1. Baked Goods:** In breads, biscuits, cakes, and pastries, guar gum **improves dough elasticity**, helping loaves rise higher and stay softer longer. By locking in moisture, it prevents staleness and extends shelf life so your bread stays fresh for days (Encina-Zelada *et al.*, 2019).
- 2. Dairy & Frozen Foods:** That smooth, creamy spoonful of ice cream? Guar gum helps make it happen. It **prevents ice crystals from forming**, ensuring frozen desserts stay velvety. In yogurt, milkshakes, and cheese, it acts as a stabilizer, maintaining texture and consistency (Demirci *et al.*, 2014).
- 3. Meat & Savory Sauces:** In sausages, burgers, and processed meats, guar gum improves **binding and juiciness**. In salad dressings, ketchups, and sauces, it keeps ingredients from separating, so your favorite condiments stay smooth and uniform.
- 4. Beverages:** In juices and low-calorie drinks, guar gum **prevents pulp separation** and gives a uniform texture. It also helps reduce calories while improving mouthfeel an important quality for today's "better-for-you" beverages.
- 5. Candies & Confectionery:** From chewy caramels to glossy jelly candies, guar gum maintains **shine, thickness, and chewiness**. It helps retain moisture, keeping sweets soft and fresh instead of sticky or dry.

Affordable, plant-based, and safe, guar gum has become an **indispensable kitchen tool for the global food industry**. Whether it's in your morning toast, your afternoon smoothie, or your evening dessert, this humble bean extract is hard at work ensuring taste, texture, and quality.

Pharmaceutical & Biomedical Uses

Guar gum isn't just a superstar in the kitchen it's also making waves in **modern medicine and biotechnology**. Thanks to its natural biocompatibility, biodegradability, and ability to form gels, guar gum and its derivatives are being harnessed for **innovative healthcare solutions**.

Here's where science is putting this humble bean to work:

1. Smarter Drug Delivery Systems: Guar gum is being engineered into **hydrogels, beads, and nanoparticles** that can carry drugs and release them in a controlled manner. This is especially valuable for **colon-specific therapies** like treatments for **colorectal cancer, tuberculosis, and hypertension** where medicines need to reach a specific site in the body without breaking down too early (Verma *et al.*, 2021).

2. Wound Healing & Tissue Engineering: Hydrogels made from guar gum are excellent at **retaining moisture** while allowing oxygen flow two key factors for faster healing. They also provide a supportive matrix for cell growth, making them promising materials in **tissue engineering and regenerative medicine**.

3. Prebiotics & Immunity: Beyond drug delivery, guar gum acts as a **prebiotic fiber**, feeding beneficial gut bacteria. This not only improves digestion but also strengthens the **gut-immune connection**, boosting overall immunity.

4. Eye & Gastrointestinal Treatments: In pharmaceuticals, guar gum derivatives are used in **eye drops** to keep the eyes lubricated and in therapies for **colitis, diarrhea, and constipation**, offering safe, plant-based solutions to common health problems.

5. A Futuristic Biomaterial: While guar gum is powerful in its natural form, scientists are also **chemically modifying** it to overcome challenges like variable viscosity and microbial growth. These modifications improve stability and precision, making guar gum a strong candidate for **next-generation biomedical applications**.

With each new discovery, guar gum is proving it can do far more than stabilize your yogurt—it may soon help stabilize your health.

Beyond Food and Medicine

While guar gum may be best known as a food ingredient, its impact stretches far beyond the dining table. Thanks to its **remarkable thickening, stabilizing, and binding properties**, guar gum has become a backbone material for several major industries.

1. Oil & Gas: In the energy sector, guar gum is indispensable for **hydraulic fracturing (fracking)**. Its viscosity allows it to carry sand and chemicals deep into underground rock formations, helping release trapped oil and natural gas.

2. Textiles & Paper: Guar gum improves the quality and efficiency of textile and paper production. It acts as a **sizing, printing, and finishing agent**, ensuring smoother fabrics, clearer prints, and stronger paper.

3. Cosmetics & Personal Care: From silky shampoos to creamy lotions, guar gum adds **smoothness, thickness, and stability** to beauty products. It also helps prevent separation, keeping products consistent and appealing on the shelf.

4. Explosives & Mining: In mining and explosives, guar gum works as a **stabilizer and binding agent**, ensuring safer handling and more effective performance.

What makes guar gum stand out in these heavy-duty sectors is its eco-friendly and biodegradable nature. As industries worldwide move toward sustainability, plant-based solutions like guar gum are becoming more valuable than ever. It's not just an industrial workhorse it's also a green ally for the future.

The Future of Guar Gum

The story of guar gum is far from over in fact, it's just beginning a new chapter. As the world faces a surge in lifestyle diseases like diabetes, obesity, and heart conditions, demand for natural, fiber-rich supplements is on the rise. At the same time, industries are under pressure to find eco-friendly, sustainable materials

that reduce dependence on synthetic chemicals and plastics. Guar gum, with its plant-based origin and wide-ranging uses, is uniquely positioned to meet both needs.

Cutting-edge research is already pushing guar gum beyond its traditional roles:

- 1. Advanced Drug Delivery:** Modified guar gum is being designed to release medicines with precision, targeting diseases such as **colon cancer, hypertension, and diabetes** while minimizing side effects.
- 2. Biodegradable Packaging:** Scientists are experimenting with guar gum blends to create **eco-friendly films and coatings**, offering sustainable alternatives to single-use plastics.
- 3. Smart Hydrogels:** New guar gum-based hydrogels that can **self-heal, respond to pH changes, or deliver drugs on demand** are opening possibilities in wound healing, tissue engineering, and medical devices.

With India already at the center of global guar gum production, the future could see this humble crop become a cornerstone of green technology and preventive healthcare. From your kitchen to the clinic, from energy fields to environmental solutions, guar gum is set to transform from a “silent helper” into a super-ingredient of the future.

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Speed Breeding: A Powerful Tool to Accelerate Crop Research and Breeding in Rice

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Dikshant Jangra¹, Deepanshu¹, Nidhi¹

¹Department of Genetics and Plant Breeding, Banaras Hindu University, Varanasi, U.P., India.

Abstract

The growing global population and climate change necessitate accelerated crop improvement strategies to meet future food demands. Conventional rice breeding is limited by long generation cycles, restricting the rate of genetic gain. To overcome this bottleneck, the International Rice Research Institute exploited Speed Breeding and developed **SpeedFlower**, a novel speed breeding protocol capable of achieving 4–5 rice generations annually. The protocol integrates optimized growth parameters, including light spectrum, intensity, photoperiod, temperature, humidity, and growth stage-specific foliar nutrient sprays, along with early germination techniques using GA₃ to shorten the maturity duration. Tested across diverse *indica* and *japonica* rice varieties, SpeedFlower demonstrated significant acceleration in flowering and seed development without compromising adaptability. This advancement provides a robust platform for rapid varietal development, offering an efficient pathway to enhance rice breeding and ensure global food security under changing climatic conditions.

Introduction

The current human population is around 7.8 billion and is estimated to reach nearly 9.7 billion by 2050. Climatic fluctuations involving rising temperature, more frequent floods, and drought are predicted to lead to novel diseases and more frequent pest outbreaks, requiring an agile plant breeding response. Lin et al. highlighted the urgent need for increasing the current rate of genetic gain of critical food crops to safeguard global food security. Breeding crops in a conventional way demands considerable time, space, inputs for selection, and the subsequent crossing of desirable plants.

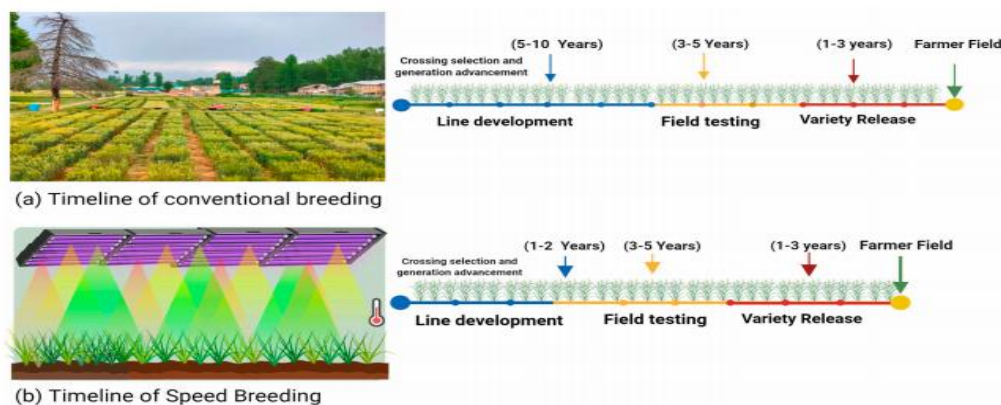


Figure: Timelines of varietal development with (a) conventional breeding and (b) Speed breeding

The duration of the seed-to-seed cycle is one of the crucial bottlenecks in the progress of plant research and breeding. The average estimated rate of genetic gain in rice drought breeding programs is 0.13% (2.29 kg/ha/year), while in irrigated breeding programs, it is 0.23% (8.75 kg/ha/year) (Juma et al., 2021; Khanna et al., 2022). However, these rates are insufficient to meet the increasing future demands for rice with a growing population. The first detailed results on Speed breeding, which accelerates flowering and generation time through controlled environmental conditions such as extended photoperiod, light intensity, temperature and early harvest of premature seeds in long-day crops, were jointly reported by Ghosh et al. (2018) and Watson et al. (2018). Watson et al. (2018) utilized a Speed breeding protocol to advance four generations of canola and six generations of spring and durum wheat, barley, peas, and chickpeas, achieving a faster rate compared to the two to three generations possible in a glasshouse. Additionally, it

allowed crossing and inbreeding (8–12 generations) to be completed within 2 years rather than 6–7 years in field conditions, as reported by Ghosh et al. (2018). Speed breeding also enabled the development of one of the world's first wheat varieties with high protein milling features, DS Faraday (Schwager, 2017).

Speed Breed Facility at International Rice Research Institute, South Asia Regional Centre (ISARC)

Scientists from the International Rice Research Institute (IRRI) developed a robust, first ever speed breeding protocol for rice that will achieve 4 to 5 crops of rice in one year - almost double of what has been possible in breeding programs until now. This protocol will be important to accelerate breeding new improved varieties of rice to cope with climate change and the needs of a growing world population. Called SpeedFlower, the protocol focuses on optimizing light spectrum, amount and intensity, along with temperature, humidity and other variables that expedite growth, flowering and maturity in rice. The protocol is suitable for the vast majority of rice grown globally, including for indica and japonica rice. The SpeedBreed facility is equipped with six optimization and two multiplication growth chambers that allow precise control of various growth parameters such as light spectrums, intensity, photoperiod, temperature, relative humidity, CO₂ levels, as well as an automated irrigation system. Temperature plays a crucial role in regulating plant growth, particularly during the flowering and grain-filling stages. The interaction between photoperiod signalling pathways and temperature has been well-documented (Halliday et al., 2003). For rice, the optimal temperature range for growth and maturation is typically around 30–32 °C. Heading date and yield traits in rice production are strongly influenced by temperature variations. Higher temperatures can lead to early heading and yield losses (Yoshida, 1981). Full-spectrum light contains four tuneable LED channels at 450 nm (blue), 660 nm (red), 735 nm (FR) and a white 5700 K LED channel, which are distributed uniformly using primary and secondary optic plates to achieve optimal light distribution over a growing area of 1.2 * 1.2 m.

Optimization of speed breeding protocol 'SpeedFlower' for indica and japonica rice.

Optimization of spectrum and intensity: Three spectrum ratios ($R > B$, $B > R$ and $R = B$) were optimized in conjunction with two light intensities (400 and 800 lux). In this experiment, in continuation of these three spectrum ratios, supplementary SAR and EOD far-red light spectrums were provided for the induction of early flowering in rice

Optimization of photoperiod: Three distinct photoperiods (20, 22 and 24 h) were implemented for 6, 9, 12 and 15 days to examine the impact of extended photoperiod on rice. Among these treatments, a 24 h photoperiod for the initial 15 days significantly accelerated the flowering duration.

Optimization of growth stage-specific foliar spray to accelerate flowering: At the different stages, foliar sprays containing urea, N:P:K, micronutrients, CaNO₃ and MgSO₄ were applied based on fertilizer deficiency symptoms.

Early germination experiment to reduce maturity duration: Immature seeds harvested at various days (9, 11, 13 and 15 days) after flowering were incubated at 38 °C to transition from the milky or dough stage to the maturation stage. Different concentrations of GA₃ (20, 40, 60 and 80 ppm) were employed to assess germination in the immature harvested seeds.

Conclusion

The development of the **SpeedFlower protocol** marks a significant breakthrough in accelerating rice breeding by enabling 4–5 generations per year, nearly doubling current capacities. Through optimized light spectrum, photoperiod, temperature, nutrient management, and early seed germination strategies, this protocol ensures faster flowering, maturity, and seed set across diverse indica and japonica varieties. By reducing the breeding cycle duration, it offers a practical solution to enhance the rate of genetic gain in rice. Ultimately, SpeedFlower provides a powerful tool to meet future food security challenges under climate change and growing population pressures.

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Merging Traditional Practices and Modern Technology through Computational Plant Breeding

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Anjali Yadav¹, Neeraj Parasar²

¹ M. Sc Student, Department of Genetics and Plant Breeding, Rani Laxmi Bai Central Agricultural University, Jhansi, UP.

² Senior Research fellow, Department of Genetics and Plant Breeding, Agriculture University, Kota, Rajasthan.

Introduction

Plant breeding has been a cornerstone of agricultural progress for millennia. Traditional practices—such as farmer-led selection, seed exchange, and crossbreeding—have fostered diverse, locally adapted crop varieties. These methods, grounded in phenotypic observation and farmer wisdom, played a vital role in shaping resilient cropping systems suited to regional environments. However, the challenges of the 21st century—climate change, population growth, shrinking arable land, and emerging pests and diseases—demand faster, more precise breeding strategies. Conventional approaches, though effective, are often slow and labor-intensive. To meet these demands, breeders now integrate advanced computational tools into crop improvement programs. Genomics, bioinformatics, artificial intelligence (AI), and high-throughput phenotyping (HTP) have revolutionized the selection process, enabling rapid and data-driven decisions. This convergence of traditional knowledge and digital innovation forms the foundation of computational plant breeding—a next-generation strategy that promises both speed and sustainability. Historically, trait selection relied solely on phenotypic evaluation and manual calculations. Today, biometrical genetics has streamlined this process through statistical models such as AMMI (Additive Main Effects and Multiplicative Interaction), BLUP (Best Linear Unbiased Prediction), and other genetic parameter tools. These methods enhance the accuracy of phenotypic selection across diverse environments. The current era of high-throughput phenotyping allows breeders to analyze plant traits throughout the entire growth cycle. Coupled with AI and machine learning (ML), this enables precise identification of desirable traits, prediction of genotype–phenotype interactions, and robust decision-making. As a result, computational plant breeding offers a more standardized, authentic, and scalable approach to crop improvement.

Traditional Breeding Practices: The Foundation

Traditional breeding has historically been based on **observation and selection**. Farmers selected plants with desirable traits such as:

1. **Grain size and yield** (larger grains, more productive plants).
2. **Resistance to local pests and diseases**.
3. **Adaptation to climate and soil type**.
4. **Quality attributes** like taste, cooking quality, or oil content.

Some key traditional methods include:

- a. **Mass Selection:** Choosing superior plants from a population and using their seeds for the next cycle.
- b. **Pure-Line Selection:** Isolating uniform lines from self-pollinated crops.
- c. **Crossbreeding:** Hybridizing two parent plants to combine desirable traits.
- d. **Farmer Seed Exchange:** Preserving genetic diversity by exchanging local landraces.

These methods not only produced improved varieties but also created a **vast gene pool** of diverse germplasm that modern breeders rely upon today.

Limitation: Despite their importance, traditional methods are **time-consuming** (10–12 years for a new variety), less precise, and vulnerable to environmental variation.

Differences Between Conventional and Modern Plant Breeding

Aspect	Conventional Plant Breeding	Modern Plant Breeding
Selection Basis	Based on phenotype; less reliable for identifying pure gene lines	Genotype-based; more accurate in determining pure gene lines
Time to Release Variety	More time-consuming	Comparatively faster
Source of Variability	Created through hybridization	Enhanced via genomic selection and high-throughput phenotyping (HTP)
Gene Selection	Dominant genes are typically selected; recessive allele selection is lengthy	Recessive alleles can be identified using markers and gene site mapping
Effectiveness	Depends on breeder's skill and subjective analysis; less reliable	Based on scientific research and data; more effective and trusted
Skill Requirement	Requires less technical and genetic science knowledge	Requires advanced technical skills and understanding of genetics
Cost	Less expensive; uses local tools and techniques	More expensive; involves high-tech machinery and methodologies

Modern Technology in Plant Breeding

The past three decades have witnessed **transformative advances** in genetics, information technology, and computational tools. Together, these innovations have accelerated breeding cycles and improved precision.

Biometrical Genetics in Plant Breeding

The development of crop varieties requires accurate estimation of heritability, genetic variability, correlation among traits, ammi and gge biplot – help in selection of stable traits after analysing the data from the multilocation trail and combining ability. Biometrics is the application of statistical and mathematical tools—plays a crucial role.

Major Biometrical Techniques

1. Analysis of Variance (ANOVA): Used to partition observed variation into genetic and environmental components in different designs. Help identify whether differences among genotypes /TREATMENT, block and error terms effects which are only for checks, are statistically significant.

2. Heritability and Genetic Advance Estimates: Broad-sense heritability (H^2): Proportion of total variance attributable to genetics. High heritability suggests that trait expression is largely controlled by genetic factors and can respond well to selection.

3. Genetic advance (GA): Expected progress of selected traits as compared to original population in the next generation under the selection.

Genetic Advance as Percent of Mean (GAM): Helps to understand the practical significance of GA relative to the trait mean.

4. Correlation and Path Analysis: Determines relationships between yield and its component traits., also help to measure the strength and direction of linear relationship between two traits.

Path analysis partitions correlation into **direct** and **indirect effects** for trait prioritization using a standardized multiple regression approach . Path analysis reveals the true contribution of each trait to yield:

a. Direct effect: The actual influence of a trait on yield.

b. Indirect effect: Influence through another correlated trait.

Correlation indicates associations among traits, while path analysis provides a clearer picture of causal relationships, aiding breeders in identifying key traits for yield improvement.

5. Diallel and Line × Tester Analysis: Used in hybrid breeding to estimate **general combining ability (GCA)** and **specific combining ability (SCA)** variance and effects and D and H components of variance,

Helps breeders choose parent lines effectively. Applicable in open pollinated species having male sterility and in line and tester analysis help in evaluation of large number of germplasm lines.

6. Stability Analysis (e.g., Eberhart & Russell Model): Measures genotype $\times$ environment ($G \times E$) interaction. Identifies stable varieties adaptable across diverse environments.

Comparison Stability Models:

Particulars	Eberhart and Russell	Perkins and Jinks	Freeman and Perkins
Parameters Used	3: Mean yield, regression coefficient, deviation from regression	Not specified	Not specified
Fractions of Variation	2: Genotype (G) and Genotype $\times$ Environment ($G \times E$)	3: Genotype (G), Environment (E), and $G \times E$	3: Genotype (G), Environment (E), and $G \times E$
Independent Calculation of Mean Performance & Environment Index	Not possible	Not possible	Possible
Degrees of Freedom for Environment Calculation	1	$e-2$	$e-2$
Calculation Complexity	Simple	Difficult	More difficult
Expenditure Involved	Less	Less	More

7. QTL Mapping and Association Analysis: Combines molecular markers with statistical models to locate genomic regions controlling traits.

For the association analysis there are two ways by correlation and path coefficient analysis.

Correlation coefficient – degree of relationship between two or more variables and determines the component characters on which selection can be relied upon for the genetic improvement of yield.

Path coefficient analysis is standardised partial regression coefficient which splits the correlation coefficient into the measures of direct and indirect effects means measures the direct and indirect effect of various independent characters on a dependent character.

8. Genomic Prediction Models (BLUP, RR-BLUP, GBLUP, Bayesian methods): Predict breeding values using dense molecular marker data. Widely used in computational plant breeding for **genomic selection (GS)**.

BLUP allows ranking of genotypes based on predicted genetic merit. And helps in selecting genotypes that perform well consistently across diverse environments.

Integration with Computational Tools

Traditional biometric methods (ANOVA, heritability) remain essential in **early stages** of evaluation. Advanced computational tools (machine learning, AI, Bayesian prediction) expand biometrical analysis to **big data from genomics and phenomics**. Together, they enable **precise, predictive, and rapid breeding decisions**.

1. Genomic Selection (GS): The most promising individuals for breeding are chosen based on their estimated breeding values, which reflect the genetic merit of an individual as inferred from the average performance of its progeny. Compared to traditional breeding methods, genomic selection (GS) offers a more efficient approach, enabling faster enhancement of grain yield through early and accurate prediction of genetic potential. Breeding Values can be predicted through methods like penalized regression method and Bayesian method. These estimated and actual breeding values are calculated through two types of data sets used in Genomic selections: training population and validation population. The already phenotyped and genotyped training population helps to predict breeding values in validation population.

2. Marker Assisted Selection: Markers are linked with trait or the sequence to which may or may not be expressed phenotypically for the selection of plant with specific qualities.

It is particularly useful for the traits that are controlled by multiple genes which are difficult to measure. Most importantly it helps in identification of genotype at early stage reduce the cost and extensive field trial.

Types of MAS are compared in table below:

Molecular Marker	Type	Benefits	Drawbacks
Polymorphism of Restriction Fragment Length (RFLP)	Co-dominant	highly reproducible and locus-specific. It requires high-quality DNA and is useful for comparative mapping. It can distinguish between homozygotes and heterozygotes.	Time-consuming and labor-intensive; rarely used in plant breeding
Random Amplified Polymorphic DNA, or RAPD	Dominant	Needs a very tiny quantity of DNA. Simple, quick, and inexpensive. Universal primers eliminate the requirement for blotting or hybridization.	Dominant marker (unable to differentiate between heterozygotes). Reproducibility is low in comparison to other
Amplified Fragment Length Polymorphism, or AFLP	primarily dominant with some co-dominant	High reproducibility; combines the benefits of PCR and restriction digestion. It requires pure, high-quality DNA and produces a large number of polymorphic loci each assay. It is also resistant to PCR fluctuations.	Requires high-quality DNA; is more time-consuming than RAPD/SSR; produces false findings if DNA is impure; Advanced technology needed
Microsatellites and Simple Sequence Repeats, or SSR	Co-dominant	Extremely varied and polymorphic. A tiny DNA sample is needed; primer development can be costly; sequence information is necessary; QTL mapping, MAS, and genomics all make extensive use of primers; and beginning costs are low.	
One Nucleotide Polymorphism, or SNP	Co-dominant	The most prevalent and straightforward marker; high resolution (single base alteration); useful in high-density genetic mapping; widely employed in contemporary breeding	high operating costs; requires high-quality DNA; requires advanced technology

Genome Editing

Crispr (clustered regulated interspaced palindromic repeats) is not only a gene editing tool but also genome editing tool as it is capable of modifying any DNA sequence, not just the protein coding region means they are multiplex multigene editing which means simultaneously, it can target many gene sequence or alter many coding (that form protein) or non-coding DNA any DNA sequence in many ways as it has many classes of endonuclease. These are some crops which are edited by the CRISPR-Cas9 tool (table below):

Year	Crop	Pathogen	Target gene	Gene Editing
2013	Rice	<i>Xanthomonas oryzae</i> (Bacterial Blight)	OsSWEET11, OsSWEET14	Disruption of OsSWEET genes reduced bacterial blight susceptibility.

2017	Rice	<i>Magnaporthe oryzae</i> (Blast Disease)	OsERF922	CRISPR/Cas9 knockout of OsERF922 improved blast resistance.
2020	Wheat	<i>Magnaporthe oryzae</i> (Wheat Blast)	Wheat orthologs of rice S-genes	Genome editing proposed as a strategy for wheat blast resistance.
2021	Papaya	Papaya ringspot virus (PRSV)	Susceptibility (S) genes	CRISPR/Cas9 used to develop PRSV-resistant papaya varieties
2025	Indian Rice (DRR Rice Dhan 100 – KAMALA)	Abiotic stress & climate resilience	SDN1 , SDN 2	Genome-edited rice variety with 25% higher yield, early harvesting, and water conservation.
2025	Indian Rice (Pusa DST Rice 1 – MTU1010)	Salinity stress tolerance	SDN1,SDN2	CRISPR-edited salt-resistant rice variety with 9.66% higher yield in saline conditions and 14.66% higher yield in alkaline conditions .
2022	Maize	Drought stress	ARGOS8	CRISPR-engineered maize with enhanced water-use efficiency and drought tolerance .
2023	Potato	Acrylamide formation (Food Safety Concern)	Vlnv gene	CRISPR/Cas9 used to reduce acrylamide levels for safer consumption.

Example: developing drought-tolerant rice or low-erucic acid mustard.

High-Throughput Phenotyping (HTP)

High-Throughput Phenotyping (HTP) leverages modern sensors, software, and remote sensing technologies to simplify the assessment of diverse phenotypic traits such as yield, disease resistance, and stress tolerance. This process encompasses phenotyping, data compilation, analysis, and plant selection, offering a non-destructive approach to examining complex plant characteristics. Throughout the crop's growth cycle, HTP continuously monitors development and environmental responses, enabling detailed analysis of collected data. One of its key advantages over traditional visual phenotyping is the ability to track dynamic changes in plant phenotypes and effectively link them to underlying genotypic variations.

Role of sensors:

- The sensors which help in capturing non visual traits like temperature, moisture, gas exchange or photosynthetic efficiency.
- Imaging are those sensors which take visual traits like leaf color, shape, disease, canopy structure etc.

Artificial Intelligence and Machine Learning

These are **data-driven computational tools** used to analyze large datasets (like DNA sequences, phenotypic traits, environmental data). They help breeders **predict traits, select parents, and optimize breeding schemes**. And The development of machine learning and artificial intelligence in plant breeding Originally, traditional breeding methods used AI and ML as data analysis tools. AI and ML have emerged as critical tools in contemporary breeding efforts due to the proliferation of genomic data and high-throughput sequencing technology. Statistical models and computational algorithms for genotype-phenotype prediction tasks were used in the early phases of AI and ML usage in plant breeding. It combines environmental, phenotypic, and genetic data and predicts the traits , select parents , and optimizing breeding schemes.

Speed Breeding

In order to shorten the time to floral initiation, accelerate embryo development, and seed maturity, speed breeding (SB) primarily uses adjustment of day/night temperature, available light spectrum and intensity, photoperiod duration, and humidity regime.

Bridging Tradition and Technology

Plant breeding's full potential is found in combining cutting-edge computational advancements with conventional agricultural methods. In order to make sure that crop varieties satisfy regional demands, such as those related to taste, cooking quality, and cultural preferences, farmers' practical expertise is essential. The breeding process is also made more accurate and efficient by the use of computer methods like high-throughput phenotyping, genomic selection, and machine learning, which speed up the discovery of the genes causing certain traits. Landraces and wild relatives make up traditional germplasm collections, which are important repositories of resilience traits like pest resistance and drought tolerance. This synergy is best demonstrated by Participatory Plant Breeding (PPB), in which scientists and farmers work together to co-develop varieties while using computational models to forecast performance and optimize trait selection. For example, in India's pulse breeding projects, genomic selection for disease resistance is combined with local farmer preferences for taste and cooking time to produce cultivars that are both socially and scientifically acceptable.

Future Prospects

The next generation of breeding - often termed *Breeding 4.0*, envisions a holistic integration of traditional practices with cutting-edge technologies. Traditional knowledge, including insights into local adaptability and cultural acceptance, will remain central, ensuring that improved varieties are farmer-friendly and socially inclusive. At the same time, the rapid progress in genomics and multiomics (genomics, transcriptomics, proteomics, metabolomics, and phenomics) will deepen our understanding of trait expression and plant-environment interactions. Artificial intelligence (AI) and machine learning are revolutionizing predictive breeding by enabling fast and accurate analysis of complex genomic, phenotypic, environmental, and management datasets. The creation of integrated, cloud-based databases will enhance data accessibility, strengthen global collaborations, and provide powerful platforms for informed decision-making. Advanced phenotyping tools such as drones, satellite imaging, and sensor networks will accelerate the study of genotype-environment interactions, while precision agriculture technologies will enable the development of crop varieties suited to local conditions. Together, these approaches will support the breeding of climate-smart crops resilient to heat, drought, and salinity stress, ensuring sustainability and resource efficiency. Equally important will be the education of future breeders, who must be skilled in both traditional plant breeding and modern data science, as well as active participants in farmer-scientist partnerships. Finally, transparent communication, ethical responsibility, and supportive regulatory frameworks will be essential to build public trust and ensure the safe, sustainable adoption of these innovations.

Conclusion

The journey from traditional plant breeding to modern computational approaches marks a transformative shift in agricultural science. While conventional methods laid the foundation through farmer wisdom, landrace selection, and generational observation, today's breeding strategies harness the power of data, sensors, and predictive algorithms to accelerate and refine trait selection.

Modern breeding leverages high-throughput phenotyping, imaging technologies, and artificial intelligence to analyze complex traits such as disease resistance, yield potential, and stress tolerance. Machine learning models now enable early-stage prediction of genotype performance, reducing unnecessary labor and input costs by identifying non-promising lines before field trials begin.

Importantly, participatory plant breeding acts as a bridge between tradition and technology. By involving farmers directly, scientists gain insights into locally relevant traits and real-world performance of improved varieties. This feedback loop ensures that breeding programs remain grounded in practical needs while advancing genetic potential.

The integration of wild relatives and landraces into breeding pipelines further enriches genetic diversity, offering novel alleles for resilience and adaptability. Together, these approaches form a holistic framework—where ancestral knowledge meets computational precision—to create crop varieties that are not only high-performing but also contextually meaningful and sustainable.

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Fruit Bagging in Horticultural Crops: A Sustainable Approach to Pest Management and Post-harvest Quality

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Gaurav Kant¹

¹Department of Horticulture, CCS Haryana Agricultural University, Hisar.

Abstract

Fruit bagging is an increasingly adopted pre-harvest practice in horticultural crops, offering a sustainable alternative to chemical-based pest and disease management. By enclosing developing fruits in protective bags, the technique creates a modified microenvironment that reduces insect infestation, disease incidence, and mechanical injuries while also influencing fruit physiology. Research has shown that bagging can enhance fruit appearance by minimizing blemishes, russetting, cracking, and sunburn, and improve postharvest performance by lowering microbial decay and chemical residues. The effectiveness of bagging depends on multiple factors including bag material, design, timing of application and removal, cultivar response, and orchard conditions. Although labor-intensive, it is particularly valuable in high-value and organic fruit production systems where reduced pesticide use is desirable. Future advancements in biodegradable materials, photo selective films, and mechanization could further enhance its applicability and cost-effectiveness. Overall, fruit bagging represents a promising eco-friendly practice for improving both marketability and consumer safety of fruits.

Keywords: Fruit bagging, Pre-harvest management, Fruit quality, Pest and disease control, Sustainable horticulture.

Introduction

Fruit bagging, also called on-tree or pre-harvest fruit bagging, is a horticultural technique in which developing fruits (or fruit clusters) are enclosed in protective bags while still attached to the plant. The method is increasingly adopted in fruit orchards worldwide as a tool to reduce pests, diseases, and physiological disorders; enhance fruit appearance; and reduce reliance on chemical sprays. The concept is simple but the outcomes are complex and depend strongly on bag material, timing, cultivar, environment, and bag removal practices.

Principles and Mechanisms

Bagging is essentially a physical barrier approach. By enclosing the fruit, it modifies the microenvironment around the fruit surface and blocks or reduces exposure to external stresses. The main mechanisms by which bagging influences fruit development and quality include:

- 1. Barrier to pests, pathogens, birds and mechanical injury** (Sharma *et al.*, 2014): The bag prevents insect pests (borers, fruit flies, mites, etc.) from directly attacking the fruit. It reduces incidence of diseases whose inocula land on fruit surface (e.g. photic spore deposition) or which require direct contact with fruit cuticle. The bag shields fruit from damage by birds, hail, wind abrasion, sunscald or physical scratches.
- 2. Modification of microclimate:** The interior of the bag has altered temperature, humidity, light intensity and spectral composition (David *et al.*, 2021). Such modifications can slow tissue dehydration, reduce transpiration stress, moderate thermal extremes, and buffer sudden environmental fluctuations. However, if poorly ventilated, humidity buildup may promote condensation or fungal growth, so bag design and material permeability are important.
- 3. Influence on light exposure and pigment biosynthesis:** Because the fruit is shaded during early growth, pigment (especially anthocyanin) synthesis is suppressed while bagged. When the bag is removed (or partially perforated), the sudden re-exposure to light stimulates pigment biosynthesis, often leading to more vivid coloration ("light shock effect"). The timing and duration of bagging (and when bag removal occurs) thus influence final peel coloration (Wang *et al.*, 2024).

4. Effects on internal fruit quality and physiology: Bagging may influence sugar accumulation, organic acids, phenolic compounds, antioxidant activity, firmness, and cell wall metabolism, via changes in light, gas exchange, and microclimate. In some cases, bagging reduces postharvest decay and fungal colonization by reducing initial infection and altering the microbial community on the fruit surface (Gao *et al.*, 2022).

5. Reduction of chemical residues: Because the fruit surface is shielded, pesticide, fungicide or other spray droplets are less likely to reach the fruit. This can reduce surface chemical residues.

Thus, bagging acts through a combination of exclusion, microenvironment alteration, and modulation of fruit physiology.

Key Factors Affecting Bagging Outcomes

Although conceptually simple, the success of fruit bagging depends on many interacting factors. Some of the most critical are:

1. Bag material and design

- Many types have been used: paper, polyethylene (plastic), nonwoven fabrics, mesh, double-layer combinations, photoselective inserts, biodegradable materials.
- The bag must allow gas exchange but block pests; resistance to tearing, UV exposure, and rain/humidity is important.
- Some studies have used photoselective inserts (filters for spectral wavelengths) to influence fruit coloration. Example: in peaches, colored inserts affected firmness and pigment metrics.

2. Timing of bagging (start) and duration

- Bagging is usually done in an early stage (fruit set or early growth) and maintained until a certain pre-harvest date.
- If bagging is too early or maintained too long, shading stress or reduced accumulation of sugars/volatiles may occur.
- Studies (e.g. on apple) show that delaying the bagging (within a window) can reduce peel browning risk and improve internal quality (Wang *et al.*, 2024).

3. Timing of bag removal (or partial exposure)

- Bag removal before harvest (or partial opening) is often needed to allow light-mediated pigmentation or final quality adjustments.
- The length of exposure to natural light after bag removal is critical: too short and pigment may not develop fully; too long and sunburn may occur.

4. Cultivar or fruit species

- Different cultivars respond differently to bagging in terms of color, sensitivity to shading, resistance to disorders, etc.
- Some fruit species are more amenable to bagging (apple, pear, peach, loquat, mango, guava) and bagging is more commonly practiced in regions with high pest or disease pressure.

5. Environmental conditions and orchard practices

- Climate (sunlight intensity, humidity, rainfall) interacts with bag microclimate. In humid climates, poor ventilation can backfire.
- Orchard spacing, leaf canopy, ventilation, and cultural practices (fertilization, pruning) influence microclimate and thus bag efficacy.

6. Labor and economic cost

- Bagging is labor-intensive: individual fruits must be enveloped, tied, monitored, and finally removed. For large-scale operations, labor cost is a major constraint.
- The cost–benefit balance (i.e. extra yield/fruit quality vs labor/material cost) must be evaluated for each system and region.

7. Interaction with postharvest effects

- The state of the fruit surface (microflora, cuticle, microcracks) at harvest influences how bagging will impact storage life, decay, and quality.

b. Thus, bagging is not a one-size-fits-all technique; optimization is required for each fruit-orchard-context.

Reported Benefits and Results

Multiple studies across fruit species have reported a variety of benefits from bagging. Some key findings and summary insights follow.

1. Enhanced external appearance and reduction of defects

- Bagging generally reduces blemishes, russetting, skin cracking, sunburn, and surface scarring.
- In pomegranate, bagging in white or brown bags reduced sunburn from ~90% (control) to ~25% in one treatment, and cracking from ~65% to ~5%.
- A recent study showed that bagging increased fruit size and reduced cuticle thickness, though did not change soluble solids or acidity.
- Bagging sometimes reduces fruit russetting, improving surface smoothness.

2. Pest, disease and decay control

- Fruit bagging often lowers incidence of insect pests and disease infections, by acting as a physical barrier.
- Bagging significantly reduced postharvest decay and altered fungal community composition on the fruit surface.
- In some cases, bagging allows reduced use of pesticide sprays for example, in peaches, bagging reduced fungal disease and insect incidence, improving yield in organic systems.

3. Improved internal quality:

- Many studies report that bagging can enhance fruit color (after bag removal), sugar:acid ratio, firmness and antioxidant levels although results are variable.
- In apples, bagging followed by removal often gives better color development.
- In guava (the Sharma *et al.* 2020 paper), on-tree bagging reduced biotic stresses and improved postharvest quality in rainy season crop of 'Allahabad Safeda'.

4. Trade-offs, limitations or negative effects

- Because bagging reduces light, over-shading may suppress photosynthesis of peel tissues, sometimes reducing sugar accumulation or volatile compounds.
- Poorly ventilated bags can lead to excessive humidity, condensation, or fungal growth if not well designed.
- Labor requirements and material costs can outweigh the benefits, particularly in large-scale fruit enterprises.
- In some fruits or cultivars, bagging may lead to peel browning or other physiological disorders if applied too early or removed too late. For instance, in apples, improper bagging timing led to browning of peel.

Practical Guidelines and Recommendations

Based on review of the literature, here are general guidelines for implementing fruit bagging in orchards:

1. Bag choice and design:

- Use breathable, pest-resistant bag materials (e.g. paper, nonwoven fabrics) rather than impermeable plastic.
- The bag should be durable (resist tearing, UV degradation) but economical (ideally recyclable or biodegradable).
- Ventilation holes or perforations may help reduce humidity buildup.
- In advanced systems, photo selective or spectral-filter inserts may help tune coloration responses (as seen in peach studies).

2. Optimal timing of bagging and removal:

- Begin bagging in a stage when the fruit is still small but past vulnerability of early fruit drop (e.g. shortly after fruit set).
- Avoid too early bagging which might suppress growth or physiological development.

- c. Remove (or partially open) the bags sufficiently in advance of harvest to allow light-driven coloration and to acclimate the fruit to ambient environment.
- d. The duration of exposure post-bag removal is critical; monitor local solar radiation, risk of sunburn, and color development.

3. Monitoring and maintenance:

- a. Regularly check bagged fruits for signs of moisture accumulation, mold, bag damage, or pests that may penetrate.
- b. Repair or replace damaged bags where possible.
- c. Consider partial ventilation or periodic airing if humidity is a risk.

4. Economic analysis:

- a. Evaluate whether the benefit (higher grade fruit, lower losses, reduced pesticides) outweighs labor and material costs.
- b. In regions with high pest pressure or premium markets (export, organic), bagging is more likely to be cost-effective.

5. Integration with other practices:

- a. Bagging works better when combined with good orchard sanitation, pruning (to allow airflow), monitoring, and timely spray applications (if needed).
- b. In organic or low-spray systems, bagging may substitute for or reduce chemical applications.
- c. For large-scale operations, mechanization (e.g. bagging machines or robotic bag application) may be explored (though research is limited).

6. Local adaptation and trials:

- a. Conduct small-scale trials to test bagging efficacy under your local climate, cultivar, and pest/disease pressures.
- b. Adjust bag type, timing, and removal schedule based on observed results.

Future Research Directions

Although fruit bagging has been studied for decades, there remain many promising areas for further research:

- 1. Material innovation:** Development of cost-effective, biodegradable, UV-resistant, fungistatic bag designs with optimal permeability.
- 2. Smart bagging:** Incorporation of sensors or responsive materials (e.g. color-changing, temperature-responsive vents) to better regulate the microclimate.
- 3. Mechanization and automation:** Devices or robots for bag application, removal, or re-adjustment to reduce labor demands.
- 4. Optimizing spectral effects:** Better understanding of how spectral filtering (via photo selective inserts) can enhance coloration, firmness or other quality traits.
- 5. Microbiome studies:** Exploring how bagging shapes the microbial communities on fruit surfaces and its effect on decay and shelf life.
- 6. Economics and life-cycle assessment:** More region-specific cost-benefit analyses, considering labor, bag life, quality premium, and environmental impact.
- 7. Cultivar-specific responses:** Systematic screening of how different cultivars (and fruit species) respond to bagging in various climates.
- 8. Combined stress scenarios:** Testing bagging under combined stresses (drought, heat, high humidity) to understand its limitations.

Conclusion

Fruit bagging is a promising and environmentally friendly technique for enhancing fruit quality, reducing pest and disease incidence, and limiting chemical residues. However, its success depends heavily on optimal bag material, timing, cultivar choice, microclimate, and labor economics. While many studies demonstrate positive outcomes across multiple fruit types, its adoption must be carefully tailored to local conditions.

Ongoing research in materials, automation, and integration with precision cropping will likely expand its utility in modern orchard systems.

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Ornamental and Confectionery Sunflowers Represent Emerging Frontiers in *Helianthus* utilization

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Dr. T. K. Nagarathna¹

¹Professor & Scheme Head, All India Coordinated Research Project on Sunflower, University of Agricultural Sciences, Bangalore-560065.

Summary

Sunflower (*Helianthus annuus* L.) is a versatile crop that plays significant roles in global agriculture from oilseed production and human nutrition to landscape aesthetics. Two lesser-discussed but economically valuable segments are ornamental sunflowers, bred for cut-flower, landscaping and decorative uses, and confectionary sunflowers, cultivated for their large seeds consumed directly as snacks or ingredients. This article presents a comprehensive overview of both categories, covering their botanical and agronomic distinctions, breeding priorities, market trends and production statistics at global and Indian levels. The analysis also highlights emerging opportunities, demand trajectories and value-chain considerations for enhancing farmer income and market diversification.

Introduction

Sunflower (*Helianthus annuus*) is one of the world's most important annual crops, widely cultivated for oil, edible seeds and ornamental purposes. While oilseed types dominate production, two niche but high-value categories; ornamental and confectionary types are gaining increasing attention due to their market potential and diversification benefits.

Confectionary types are characterized by large, striped seeds with thick shells, primarily consumed as roasted snacks, bakery ingredients, and health foods. Ornamental types are bred for diverse flower forms, colours, plant stature and extended vase life, meeting demand from landscaping, floriculture and urban horticulture sectors (FAO & Our World in Data, 2024; USDA-FAS, 2024).

Though often overshadowed by oilseed production, these specialized segments contribute significantly to value addition, market diversity and rural livelihoods.

Ornamental Sunflowers: Traits and Uses

Characteristics: Ornamental sunflower cultivars exhibit wide diversity in morphology:

- Growth habit:** dwarf, compact or tall single-headed types
- Inflorescence:** single or double flowered, pollen-free varieties for extended vase life
- Aesthetics:** wide colour range (yellow, cream, red, chocolate), multi-headed branching and decorative forms.

Applications

- Landscaping and urban beautification
- Cut-flower production and export
- Pollinator-friendly plantings in agroecological systems
- Educational and home gardening projects

Increasing urbanization and demand for decorative plantings have created new avenues for ornamental sunflower commercialization, especially in urban and peri-urban horticulture (Coherent Market Insights, 2025; Gardenia.net, 2023).

Confectionary Sunflowers: Traits and Uses

Key features: Confectionary sunflowers differ significantly from oilseed types:

- Seed morphology:** larger size, striped or patterned seed coats, thicker shells
- Kernel quality:** superior taste and texture for direct consumption
- Processing:** high importance of seed grading, mechanical handling and appearance preservation.

End uses

- Human consumption (roasted, salted, flavoured snacks)
- Bakery and confectionery products
- Bird feed and specialty oil applications

Grading and post-harvest handling are crucial in determining market value, with larger, intact seeds commanding premium prices (Prairie Californian, 2023; Grand View Research, 2024).

Global Production and Market Context

Global sunflower seed production has remained robust, ranging between 50–57 million metric tonnes (MMT) during 2022–2024. Russia (~16–17 MMT) and Ukraine (~12–15 MMT) are the largest producers (FAO & Our World in Data, 2024; Farm Progress, 2024), together contributing over 50% of global output. These countries' dominance makes global supply highly sensitive to geopolitical and climatic disruptions.

The global sunflower seed market, including oilseed, snack and ornamental segments, is valued at several billion USD. Demand for healthy, plant-based snacks is a major driver of growth in the confectionary segment, while floriculture and landscaping expansion fuel the ornamental market (Global Market Insights Inc., 2024).

India: Production, Market Trends, and Opportunities

Production and consumption: India's sunflower production is modest compared to global leaders, with 2023 - 24 estimates ranging between 1,67,000 and 3,60,000 tonnes (Tridge, 2024) depending on data source and reporting period. Despite this, India remains a major importer of crude sunflower oil due to high domestic demand for edible oils.

The market dynamics of sunflower utilization are undergoing significant transformation, with both confectionary and ornamental segments showing promising growth trajectories. Confectionary sunflower seeds are increasingly in demand, driven by their expanding use in snack foods, bakery products, and nutraceutical formulations owing to their high nutritional value and consumer preference for healthy, plant-based ingredients. The packaged confectionary sunflower seed market in India is projected to grow from USD 33.5 million in 2024 to approximately USD 52 million by 2030, registering a robust compound annual growth rate (CAGR) of 7.5–8%. Parallely, ornamental sunflowers are emerging as a niche yet rapidly expanding segment, fuelled by rising interest in floriculture, urban landscaping and agrotourism. Although relatively smaller in market size, this segment is expected to increase from USD 6.5 million to USD 9.5 million (Grand View Research, 2024; Coherent Market Insights, 2025) during the same period, reflecting its growing commercial and aesthetic significance in the horticulture sector.

Breeding and Agronomy: Contrasting Priorities

Trait	Ornamental Sunflowers	Confectionary Sunflowers
Selection focus	Flower colour, form, branching, vase life, disease resistance	Seed size, shell thickness, kernel yield, drying uniformity
Crop management	Visual quality, bloom scheduling, stem strength	Seed preservation, harvest timing, grading
Target markets	Landscaping, cut-flowers, floriculture exports	Snack foods, bakery, direct consumption

The value chain and processing pathways for confectionary and ornamental sunflower segments differ significantly but share opportunities for value addition. In the confectionary sector, post-harvest handling such as cleaning, grading, roasting, flavouring, and packaging is crucial for quality and consumer appeal (Prairie Californian, 2023; Grand View Research, 2024). Ornamental sunflower value chains centre around branded seed packets, nursery sales, cut-flower logistics, and export-oriented supply chains (Gardenia.net, 2023; Coherent Market Insights, 2025). Strategic investments in grading infrastructure, branding, and retail networks can boost profitability and competitiveness across both sectors.



Ornamental and confectionary sunflower varieties maintained at UAS, Bangalore

The University of Agricultural Sciences, Bangalore, maintains a collection of approximately 2,600 germplasm lines, including several identified for ornamental and confectionery purposes. However, further breeding efforts are required to select stable lines and develop high-performing hybrids.

Challenges and Opportunities

Challenges:

- Pest and disease pressure (e.g., *Sclerotia*, rust, downy mildew)
- Climatic variability affecting seed fill and flowering
- Supply chain disruptions in global trade

Opportunities:

- Rising demand for nutritious, plant-based snacks
- Urban horticulture and agrotourism boosting ornamental demand
- Dual-purpose cultivars combining ornamental appeal with edible seed production
- Value-added processing and product diversification (e.g., flavoured snacks, specialty cut flowers)

Conclusion

The growing global and national demand for both confectionary and ornamental sunflowers present a significant opportunity for agricultural scientists to innovate through targeted breeding and hybrid development. For confectionary sunflowers, emphasis on traits such as larger seed size, uniform kernel quality, shell thickness, and post-harvest resilience can help meet the rising demand in snack foods, bakery products, and nutraceutical applications. Similarly, ornamental sunflower breeding focuses on flower colour diversity, plant stature, branching patterns, extended vase life, and disease resistance to satisfy expanding urban horticulture, landscaping, and floriculture markets. By integrating modern breeding techniques, participatory varietal selection, and climate-resilient approaches, scientists can develop high-performing hybrids that not only enhance yield and quality but also cater to evolving market preferences. Strategic promotion of these varieties, along with support for processing infrastructure, branding, and value-chain development, can strengthen farmer incomes, diversify agricultural production, and position India as a competitive player in the global sunflower economy. Ultimately, proactive scientific interventions

in both confectionary and ornamental sunflower sectors will ensure sustainable production, market expansion, and greater adoption of high-value sunflower cultivars in response to domestic and international demand trends.

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Indigenous Barb (*Puntius spp*): A Potential Small Indigenous Fish Species for Aquaculture

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Prem Kumar¹, Jagruti Mote¹, Munilkumar Sukham¹, Kedar Nath Mohanta¹, Bijay Kumar Behera²

¹ICAR-Central Institute of Fisheries Education, Panch Marg, Off Yari Road, Versova, Andheri (W), Mumba, India- 400061

²National Fisheries Development Board, Department of Fisheries, Government of India, Hyderabad, 500052, India

Summary

The genus *Puntius* represents a taxonomically diverse group of freshwater cyprinid fishes widely distributed across India, inhabiting varied ecosystems from the Western Ghats to the Himalayan foothills. Nutritionally, these indigenous small fish serve as an important source of nutrients in rural population due to their rich protein, micronutrient, and essential fatty acids content. The most of the species of Puti are in danger due to habitat degradation, overexploitation, and invasive species. Therefore, it is important to conserve and promote the aquaculture of these species through targeted management and captive breeding.

Introduction

The genus *Puntius* (family Cyprinidae, order Cypriniformes) comprises a highly variable and taxonomically challenging group of freshwater fishes of South and Southeast Asia (Talwar and Jhingran, 1991). In India alone, more than sixty species have been recorded. Seven *Puntius* species: *P. chola* (Swamp or Chola barb), *P. sophore* (Pool barb / spot fin barb), *P. conchoni* (Rosy barb), *P. ticto* (two spot barb), *P. sarana* (Olive barb/ Cheni Puthi), *P. sarana orphoides* (new state record), and *P. javanicus* (Java puti / exotic species) have been documented, spread across diverse habitats from the Western and Eastern Ghats to the Brahmaputra Valley and the Himalayan foothills (Mogalekar & Jawahar, 2021).

Morphologically, *Puntius* species have short to moderately elongated, laterally compressed, body with more or less rounded abdomens. Their mouths are arched, lips thin and without horny covers. Presence or absence of barbels is species specific. The dorsal fin is usually short, positioned roughly opposite the pelvic fin, and its first ray may be bony and either strongly or smoothly serrated. The caudal fin is forked, and the lateral line, when present, may be complete or incomplete (Mogalekar & Jawahar, 2021). Colouration is markedly variable, with species showing spots, blotches, bands, or their combinations.

Taxonomy Characters of *Puntius Spp.*

Species	Specific Character	Dorsal Fin Position	Spot	Sexual Dimorphism Observed
<i>P. chola</i>	One pair of maxillary barbels; silvery body with olive green on back; breeding males develop red lateral stripe	Between 2nd–5th dorsal fin rays		Males: larger head, longer dorsal fin or caudal peduncle
<i>P. sophore</i> (<i>Systomus sarana</i>)	Barbels absent; back grey-green to brownish; dark round blotch at base of caudal fin	Between 4th–8th dorsal fin rays		Males: larger head, longer dorsal fin or caudal peduncle
<i>P. ticto</i> (<i>Pethia ticto</i>)	Barbels absent; dorsal fin with 1–2 rows of irregular dark spots; grey to grassy green back	Between 15th–19th lateral line scales		Females: longer snout, eye, or other metrics
<i>P. conchoni</i> (<i>Pethia conchoni</i>)	No barbels; black blotch near caudal peduncle; breeding males deep rosy red	Multiple black marks along dorsal fin rays		Males: larger head, longer dorsal fin or caudal peduncle

<i>P. sarana</i>	Two pairs of barbels (rostral and maxillary); olive dorsum, silvery flanks with golden reflections	No consistent dorsal fin spot; lateral blotch near tail	Females: longer snout, eye, etc.

Nutritional Importance

The pool barb is a nutrient-dense fish, particularly valued for its fat and calcium content. The lipid profile is favourable for human health, with a high proportion of polyunsaturated fatty acids (PUFAs) (Chakrabarty et al., 2018). *Puntius* species are highly nutritious, serving as excellent sources of protein, vitamins, and minerals in Northern and Eastern India. These small indigenous fish species (SIFS) are consumed fresh or as fermented products like "Shidol," which are rich in protein, lysine, and essential minerals such as calcium, zinc, and iron (Chakrabarty et al., 2018). Their nutritional profile includes essential amino acids, vitamins D, E, and K, and omega-3 fatty acids, making them a crucial dietary component for communities in the region and a valuable resource for public health.

Reproductive Biology and Captive Breeding

Among *Puntius* species, size at maturity differs significantly. Most common species reach maturity between 5-15 cm standard lengths. *P. sophore* typically matures at about 6–8 cm, whereas *P. sarana* matures at a size of 10–15 cm (Mahapatra et al., 2006)

Fecundity of *Puntius* varies between a few thousand to nearly one lakh, depends on size and condition (Mahapatra et al., 2006). Reproduction is external with scattering types of eggs deposition over substrate or vegetation. There is no parental care reported in these species. Eggs of *Puntius* species are generally sticky or adhesive in nature, which is a common characteristic of many cyprinid (carp family) species (Mahapatra et al., 2006). Like other carps, the spawning season lies in monsoon months. In many reports from India, peak spawning occurs during the southwest monsoon (June–September).

Conservation Implications and Future Directions

Puntius species are widely distributed small indigenous fish species and economically important for food, local consumption, and ornamental trade. Their conservation status is under pressure. Key threats include habitat alteration (pollution, river modification, siltation), overharvesting (especially during breeding), and competition from invasive or exotic species

Therefore, sustainable management strategies, habitat protection are captive breeding is important for its biodiversity conservation. ICAR-CIFE is presently engaged in developing hatchery seed production technology for SIFS (*Puntius sarana* and *Mystus cavasius*) (Figs. 1) with financial support from NFDB. Currently, successful captive breeding of closely related species, *Puntius sophore* has been reported by (Singha et al., 2024).

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Fig. *Puntius sarana*

Nutritional Immunity in Fruit Crops: Linking Mineral Homeostasis to Pathogen Defense and Quality Traits

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Shiv Kumar Ahirwar¹, Sachin Kumar Rathor²

¹PhD Research Scholar, Department of Horticulture (Fruit Science), College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh.

²M.Sc. (Ag.), Department of Plant Pathology, College of Agriculture, RVSKVV, Gwalior, Madhya Pradesh.

Abstract

A changing environment puts increasing pressure on fruit crops from oomycete, bacterial, and fungal infections. "Nutritional immunity," which goes beyond traditional resistance breeding and pesticide use, provides a systems viewpoint where mineral homeostasis is actively adjusted to restrict pathogen success while maintaining fruit quality. Current knowledge about how calcium, zinc, iron, potassium, and silicon influence the fruit host's structural barriers, perception and signaling (PTI/ETI), redox balance, phytohormone crosstalk, and postharvest integrity is summarized in this review. From calcium's pectin crosslinking and Ca²⁺ waves that stiffen tissues and prime defenses to zinc's function in antioxidant enzymes and zinc-finger transcriptional regulation, iron withholding at host-pathogen interfaces, potassium-mediated stomatal and osmotic control influencing infection courts, and silicon-enabled physical and biochemical fortification, we highlight element-specific mechanisms. We explain a translational framework that employs diagnostics, decision rules, and phenotyping to co-optimize disease suppression and fruit quality. We also integrate these with orchard and packhouse practices (pre-/postharvest calcium and silicon applications, targeted micronutrient fertigation, and bio-based coatings). We conclude with research goals that can speed implementation in both tropical and temperate orchards: quantitative nutrient-immunity models, genotype-by-nutrition-by-pathogen interactions, and interoperable field phenotyping.

Keywords: fruit pathology, mineral nutrition, calcium, zinc, iron, potassium, silicon, PTI/ETI, postharvest diseases, quality traits, microbiome.

Introduction: From “Feeding Plants” to Nutritional Immunity in Perennial Orchards

Redefining mineral nutrition as an active determinant of immune competence rather than a passive yield input, nutritional immunity—first conceptualized in animal systems as host-driven control of bioavailable metals—has quickly gained popularity in plants. Mineral content affects postharvest resilience against decay organisms as well as vulnerability during flowering and fruit set in fruit crops, where edible organs experience prolonged growth and ripening. The composition/function of rhizosphere and phyllosphere microbiomes, apoplastic chemistry, ROS generation/scavenging, receptor signaling, transcriptional regulation, and cell wall architecture are all influenced by mineral availability and homeostasis (Tripathi et al., 2022; Bai et al., 2021; Marles, 2017). For fruit science and pathology, this leads to two strategic questions: (i) how do certain factors influence immunity and quality, and (ii) how can orchards be managed to take advantage of these relationships without causing toxicity or environmental problems? Both can be addressed with the help of recent syntheses and mechanistic research from Nature Portfolio, Wiley, Elsevier, and T&F (Kim et al., 2022; Palmer & Allen, 2024; The Plant Journal, 2024; Bastakoti et al., 2023).

Plant Immune Architecture Meets Mineral Homeostasis

Pattern-triggered immunity (PTI) and effector-triggered immunity (ETI) are two types of plant immunity that depend on transcriptional reprogramming, ROS dynamics, receptor function, membrane integrity, Ca²⁺ signaling, and MAPK cascades (Jones & Dangl, 2006; Jones et al., 2024). Mineral ions are present everywhere: Si deposition alters the apoplast; Fe, Zn, and Cu function as redox cofactors; K⁺ establishes membrane potential and turgor; and Ca²⁺ transients decode PAMP signals. IRT/ZIP, NRAMP, YSL, coumarins, and phenolics are examples of metal transporters and chelators that establish local availability at infection sites, forming "withhold or deploy" tactics that either starve pathogens or strengthen defenses

(Herlihy et al., 2020; Krämer et al., 2024). These processes interact with storability and quality attributes (firmness, color, and scent) for fruit crops, creating trade-offs that need to be measured and controlled (Bai et al., 2021; Marles, 2017).

Element-By-Element: Mechanisms and Evidence in Fruit Systems

1. Calcium (Ca): Cell wall fortification, Ca^{2+} signaling, and postharvest defense: Homogalacturonan in middle lamellae is crosslinked by calcium, which stiffens tissues and constricts infection pathways. Early defense is coordinated by Ca^{2+} waves, while sufficient fruit Ca lessens rot-promoting cuticular microcracking and leakiness. Similar results have been reported for peaches and apples, where pre-/postharvest Ca increased apoplastic Ca and reduced bitter pit and rots; in melon and papaya, postharvest CaCl_2 slowed softening, suppressed microbial development, and decreased decay (Guo et al., 2023; Reitz et al., 2025; Shi et al., 2023). Pre-bagging Ca in mangos slowed down ripening and decreased the occurrence of illness, highlighting its benefits in tropical environments.

Quality linkage: Fruit Ca is a strong predictor of firmness retention and shelf-life; thus, Ca-driven resistance frequently coincides with better marketability

2. Zinc (Zn): Antioxidant defense, transcriptional control, and disease suppression: Zinc stabilizes membranes, promotes superoxide dismutase activity, and controls zinc-finger transcription factors that affect hormone crosstalk and PR gene expression. Supplementing with zinc is consistently linked to less severe illness in all crops (Cabot et al., 2019; Bastakoti et al., 2023). Zn nutrition enhances cuticle function and antioxidant capacity in fruit contexts, which has a positive impact on postharvest conditions and disease resistance. However, balanced dosage is still necessary to prevent toxicity (Ahmed et al., 2024; J Plant Nutr., 2025).

3. Iron (Fe): Withholding strategies and redox signaling: Plants use transporter control and the release of Fe-chelating coumarins to limit pathogen-accessible iron ("nutritional immunity" at infection sites); this inhibits pathogen growth and modifies ROS-dependent signaling that is crucial for PTI/ETI. In the field, Fe status affects fruit color development and oxidative stability, which in turn affect infection dynamics (Marles, 2017). Molecular syntheses also establish a strong link between Fe homeostasis and immunological readouts (Herlihy et al., 2020).

4. Potassium (K): Osmotic control, stomatal function, and tissue resilience: Potassium buffers oxidative stress, controls stomatal aperture, and maintains turgor—all of which affect pathogen infiltration and lesion growth. According to a 2024 Wiley review, K modifies susceptibility through a variety of pathways, such as cell wall reinforcement and phytohormone signaling modulation—mechanisms pertinent to fruit canopies vulnerable to foliar diseases (Wiley AGG2, 2024).

5. Silicon (Si): Physical-biochemical dual defense: Si deposition stimulates phenolics, phytoalexins, and PR proteins and creates micro-barriers against penetration, albeit it is not always necessary. Foliar Si (either by itself or in combination with sulfur) continuously decreased the severity of powdery mildew on leaves and bunches in viticulture, reducing inoculum pressure till harvest (Laane, 2018; Calzarano et al., 2024). Cucurbits and solanaceous hosts are also affected by silicon, indicating a wide range of applications for orchard crops with suitable absorption (Frontiers 2018; Agronomy 2024).

Climate Extremes, Microbiomes, and the Disease Triangle

By disrupting temperature-sensitive transcriptional hubs, warming reduces immunological margins; research at the nature level demonstrates conserved components that buffer immunity at high temperatures, which directly affects perennial fruit pathosystems (Kim et al., 2022). Full immunocompetence, on the other hand, depends on eubiotic leaf and root microbiota; defense maturation is compromised by dysbiosis, underscoring the necessity of coexisting mineral programs and microbiome care (Paasch et al., 2023).

Postharvest Interface: Minerals, Coatings, and Decay

By harvest, tissue mineral status and surface chemistry prefigure outcomes against *Colletotrichum*, *Botrytis*, *Penicillium* and others. Meta-evidence shows **postharvest Ca dips or sprays** strengthen cell walls, inhibit pathogen spread, and extend shelf-life in melons, papaya, peaches, apples, and mangoes (Guo

et al., 2023; BMC Plant Biology, 2024; Li et al., 2025). Bio-based coatings (e.g., chitosan, alginate) can be co-formulated with Ca to further restrict decay while maintaining quality in berries and tropical fruit (Duana et al., 2011; multiple Elsevier reports).

Translational Framework for Orchards and Packhouses

1. Diagnostics and thresholds: Adjustments are guided by tissue testing (leaf/fruit Ca, Zn, Fe, and K) at phenological checkpoints (fruit set, fast cell expansion, and color break). 2) Firmness/SSC tracking and portable spectroscopy offer stand-ins for quality and degradation risk. Preharvest optimization is encouraged by reviews that increasingly associate mineral profiles with robustness metrics (Secretaria et al., 2025).

2. Decision rules for interventions:

a. Calcium: Preharvest CaCl_2 sprays (late fruit expansion) combined with postharvest dips can improve firmness and reduce decay in fruit where calcium levels are below ideal and rot risk is high (Guo et al., 2023; Shi et al., 2023; Li et al., 2025).

b. Zinc: To enhance antioxidant capacity and defense gene regulation, apply soil or foliar zinc; however, stay within safe ranges to prevent phytotoxicity and residue issues (Bastakoti et al., 2023; Ahmed et al., 2024).

c. Silicon: Apply foliar Si (or Si + S) during initial infection windows to mildew-prone canopies (grapes, cucurbits); there is consistent evidence of decreased severity and inoculum carryover (Laane, 2018; Calzarano et al., 2024).

d. Iron and Potassium: Prevent excess and deficiency; for Fe, control chelation and pH to maintain host ROS signaling without feeding pathogens; and for K, preserve membrane potential and canopy water status to lessen infection risk (Herlihy et al., 2020; Wiley AGG2, 2024).

3. Integration with microbiome stewardship: Eubiotic communities that gate full immunity are supported by a moderate, balanced mineral supply; when verified, combine with organic mulches and composts, reduced phyllosphere disinfectants, and PGPR/endophyte inoculants (Paasch et al., 2023; Tripathi et al., 2022).

Methods Frontiers and Research Gaps

1. Quantitative nutrient-immunity models: Under climate variability, there are no prediction models that link tissue mineral status to PTI/ETI thresholds and postharvest decay risk.

2. Fertilization guidelines should incorporate cultivar-specific nutrient baselines and transporter alleles (ZIP/IRT/NRAMP) as part of $G \times E \times M \times P$ (genotype $\times$ environment $\times$ management $\times$ pathogen) (Krämer et al., 2024).

3. High-throughput phenotyping: Ca/Zn/Fe-linked firmness and decay risk during harvest might be non-destructively indexed using hyperspectral and textural sensing (Secretaria et al., 2025).

4. Safe intensification: Studies should incorporate runoff and residue monitoring; reviews warn that excessive use of micronutrients can result in toxicity and environmental load (Chrysargyris et al., 2022; Palmer & Allen, 2024).

Practical Checklist for Growers and Postharvest Managers

1. Profile leaf + fruit minerals at set and pre-harvest.

2. Correct Ca and Zn first where decay pressure/history is high; adjust Fe/K with pH and water status.

3. Layer Si foliar sprays in mildew-prone systems; monitor efficacy across seasons.

4. Finish with Ca dips or sprays postharvest for high-risk cultivars; consider bio-coatings when logistics allow.

5. Track firmness/SSC and early decay in cold storage; close the loop into next season's nutrition plan.

Conclusion

Mineral management is reframed by nutritional immunity as a protective tool that also improves fruit quality. Zinc supports antioxidant and transcriptional networks, calcium fortifies walls and synchronizes

signaling, potassium stabilizes osmotic and electrical states, silicon creates physical-biochemical barriers, and iron starves pathogens while regulating ROS. The best programs respect toxicity limits, coordinate pre- and postharvest therapies with phenology and risk, and support microbiome stewardship. Measurable disease reductions can be achieved while preserving the structural and sensory characteristics that characterize premium fruit by combining diagnostics, orchard nutrition, and packhouse therapies.

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Mixed Models in Plant Breeding: BLUES, BLUPs and Breeding Values – A Transformative Pathway for Genomic Selection

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Neeraj Parasar¹, Anjali Yadav²

¹Senior Research fellow, Department of Genetics and Plant Breeding, Agriculture University, Kota, Rajasthan.

²M. Sc Student, Department of Genetics and Plant Breeding, Rani Laxmi Bai Central Agricultural University, Jhansi, UP.

Introduction

For over a century, plant breeding has been the engine driving agricultural productivity. Traditional breeding approaches were largely **phenotypic**, relying on direct observations of plant traits across environments. While effective in generating improved cultivars, phenotypic selection faced significant limitations:

1. **Environmental noise** often masked genetic potential.
2. **Low selection accuracy** reduced genetic gain per cycle.
3. **Long breeding cycles** delayed cultivar release.

The development of **mixed models** introduced a powerful statistical framework capable of separating **genetic signals from environmental noise**. Unlike simple linear models, mixed models can simultaneously incorporate **fixed effects** (such as treatments, replications, and locations) and **random effects** (such as genotypes, families, or environments).

Today, mixed models are applied extensively in:

- a. **Multi-environment trials (METs)**: to estimate genotype performance across diverse locations.
- b. **Genomic selection (GS)**: to predict genetic merit using DNA marker information.
- c. **Breeding value estimation**: to accelerate parent selection and shorten breeding cycles.

This shift towards **data-driven, statistically robust breeding** marks a paradigm shift in crop improvement programs worldwide.

BLUES: Best Linear Unbiased Estimators

Definition and Role: BLUEs are statistical estimates of **fixed effects** in mixed models. In plant breeding, fixed effects often include **replications, blocks, or treatments** applied in a trial. BLUEs are designed to provide **unbiased, minimum-variance estimates** of these effects.

Mathematical Expression:

$BLUE_i = y_i - \mu$
where y_i is the observed mean and μ is the overall mean.

Applications in Breeding:

- a. Used when **genotypes are considered fixed**, such as in early evaluation trials where specific lines are tested for advancement.
- b. Provide **adjusted means** that account for environmental and design-related variation.
- c. Allow fair comparisons across genotypes by removing noise introduced by experimental design.

Example: In an early-generation wheat yield trial with multiple replications, BLUEs help estimate **genotype means adjusted for replication effects**, ensuring that superior lines are not mistakenly rejected due to uneven field conditions.

In simple terms, **BLUEs provide clean averages**, serving as the foundation for comparing treatments or genotypes in controlled experiments.

BLUPs: Best Linear Unbiased Predictions

Definition: BLUPs extend beyond BLUEs by estimating **random effects**, often genotypes, while incorporating both **variance components and heritability**. Unlike BLUEs, BLUPs are influenced by **genetic relationships among individuals**.

Mathematical Expression:

$$BLUP_i = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_e^2}{n}} (y_i - \mu)$$

where:

σ_g^2 = genetic variance

σ_e^2 = error variance

n = number of replications

Key Concept: The Shrinkage Effect: A unique feature of BLUPs is **shrinkage**—estimates are pulled towards the mean depending on error variance and heritability (h^2). Genotypes with fewer observations or higher error variance will have stronger shrinkage, preventing overestimation.

Advantages

- Stable under unbalanced data:** ideal for real-world breeding trials where not all genotypes are equally replicated.
- Robust in noisy environments:** reduces the risk of selecting genotypes based on inflated means.
- Scalable:** can handle large-scale datasets with thousands of genotypes and environments.

Example in Practice: At CIMMYT (International Maize and Wheat Improvement Center), BLUPs have been widely used to **rank maize lines across multi-location trials**, allowing breeders to identify stable, high-yielding varieties even under environmental variability.

Thus, BLUPs are more reliable than BLUEs for **predicting true genetic potential** in practical breeding programs.

Breeding Values: The Genomic Revolution

Definition: The **Breeding Value (BV)** of an individual represents the **additive genetic worth**, i.e., the expected average performance of its progeny.

Expression in Mixed Models:

$$BV_i = h^2 \times (\text{Adjusted Mean})$$

Here, **heritability (h^2)** determines how much of the observed performance is attributable to genetics rather than environment.

Covariance Matrices: A and G:

A matrix = pedigree-based relationship matrix.

G matrix = genomic relationship matrix, derived from DNA marker data.

By replacing pedigree information with dense genomic markers, the **GBLUP (Genomic BLUP)** approach was developed (Meuwissen et al., 2001), which revolutionized plant and animal breeding.

Impact on Breeding

- Genomic Selection (GS):** Breeding values can now be predicted even before phenotyping, drastically shortening breeding cycles.
- Increased Accuracy:** Related genotypes provide more reliable estimates through shared covariance.
- Higher Genetic Gain:** By accelerating parent selection, GS achieves faster progress per unit time.

Real-World Success

- Rice at IRRI (Philippines):** GBLUP has been integrated into rice breeding pipelines, improving resistance to blast and bacterial blight.
- Maize at CIMMYT (Mexico):** GS using BLUP-based breeding values has increased yield under drought stress by **up to 15% over conventional methods**.

3. Wheat in India: BLUPs and BVs are helping identify rust-resistant lines more efficiently.

Breeding values, when combined with genomics, are therefore **game changers**, transforming crop improvement into a **predictive science** rather than trial-and-error selection.

Practical Implications in Plant Breeding

1. Multi -Environment Trials (METs): BLUPs allow breeders to derive stable genotype rankings across diverse environments, improving selection for adaptability and stability.

2. Genomic selection (GS): BLUP of genomic breeding values enables selection before field evaluation, drastically reducing breeding cycle time.

3. Improved Heritability Estimates: By accounting for genetic relationships, BLUPs and BVs provide more accurate heritability, which is critical for predicting long-term selection gain.

4. Efficient Resource Utilization: Shrinkage prevents overestimation of poorly tested genotypes, ensuring resources are allocated efficiently to the most promising candidates.

Challenges and Future Prospects

Despite their strengths, BLUEs, BLUPs, and BVs face certain limitations:

1. High-Throughput Phenotyping (HTP): BLUPs depend on accurate phenotypic data. Investment in drone-based imaging, remote sensing, and AI-driven phenotyping is necessary.

2. Computational Demands: Genomic BLUP requires handling massive datasets with millions of markers. Efficient algorithms such as GBLUP, Bayesian approaches, and machine learning models are being integrated.

3. Integration with New Breeding Tools: BLUP predictions can be combined with CRISPR/Cas9 gene editing and speed breeding to target specific alleles and accelerate cultivar release.

4. Multi-trait and G×E Models: Future models will account for multiple traits simultaneously and predict genotype performance under climate change scenarios.

The future of breeding lies in combining statistical models, genomics, digital agriculture, and AI-driven predictions—creating a holistic system of predictive breeding.

Conclusion

The evolution from **BLUEs to BLUPs to Breeding Values** reflects the broader transition of plant breeding from observational science to a **quantitative, data-driven discipline**. By integrating **genomic information, covariance structures, and robust statistical models**, breeders are now able to:

1. Predict future performance with higher accuracy.
2. Maximize **genetic gain per unit time**.
3. Develop **climate-resilient and nutritionally improved crops** more efficiently.

As global agriculture faces unprecedented challenges of **climate change, population growth, and food security**, mixed models are no longer just statistical tools—they are **strategic pillars for sustainable agriculture in the 21st century**.

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Advanced and Modern Techniques for Orchard Management in Fruit Production

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Gaurav Kant¹

¹Department of Horticulture, CCS Haryana Agricultural University, Hisar.

Abstract

Orchard management has undergone a rapid transformation with the integration of advanced technologies such as virtual modeling, hyperspectral imaging, spectroscopy, machine vision, and robotics. These innovations enable precise, data-driven decision-making for improved fruit yield, quality, and sustainability. Virtual models like VCHERRY allow growers to simulate tree physiology, canopy development, and management practices, offering valuable predictive insights. Spectral imaging and spectroscopy support early disease detection, pesticide residue analysis, and nutrient monitoring, while hyperspectral tools and portable optical sensors provide accurate, non-destructive assessments of leaf health and chlorophyll content. Advances in machine vision and 3D imaging enhance fruit detection, yield estimation, and automation of labor-intensive tasks. Together, these technologies reduce resource use, optimize orchard performance, and support environmentally sustainable production systems. As accessibility and affordability improve, these modern techniques are expected to revolutionize fruit production and orchard management globally.

Keywords: Precision orchard management, hyperspectral imaging, spectroscopy, virtual modeling, machine vision.

Introduction

Orchard management has experienced a revolutionary transformation over the past two decades, driven by rapid advancements in agricultural technologies and digital tools. Where once orchard practices relied heavily on manual labor, visual assessments, and generalized crop care routines, modern fruit production systems now incorporate precision agriculture, sensor-based monitoring, remote sensing, artificial intelligence (AI), machine learning (ML), robotics, and computer vision technologies. These innovations enable growers to monitor and manage orchards with greater accuracy, efficiency, and sustainability than ever before. For instance, smart sensors can now measure real-time changes in plant physiology, soil moisture, and microclimate conditions, allowing for site-specific interventions such as targeted irrigation or nutrient applications. AI-driven models can predict pest outbreaks, optimize harvest timing, or even make pruning decisions based on data from drones and ground-based imagery. Robotic systems are also being developed and deployed for labor-intensive tasks like fruit picking and pruning, offering solutions to the growing labor shortages in agriculture. At the heart of this technological transformation is the concept of data-driven decision-making, where orchard managers base their practices on actionable insights derived from big data, machine learning, and advanced modeling. This not only improves fruit yield and quality but also ensures sustainable use of resources such as water, fertilizers, and agrochemicals, thereby reducing environmental impact. Furthermore, simulation models like VCHERRY allow researchers and growers to visualize tree growth, predict yield outcomes, and explore the long-term effects of different management practices. These models bridge the gap between field experimentation and real-world application, offering a virtual platform for testing and refining orchard strategies.

Virtual Orchard Modeling: VCHERRY

A groundbreaking advancement in orchard decision-support systems is the ‘VCHERRY’ model, a virtual simulation tool developed by Lang (2005) to assist in the management of sweet cherry orchards. This interactive computer-based model enables growers and researchers to predict and analyze various aspects of cherry tree growth, fruit yield, and quality under different environmental and management scenarios.

Key Features of VCHERRY

- 1. Predictive Capabilities:** The model forecasts essential physiological parameters such as leaf area, light interception, fruit yield, and fruit quality. These predictions provide valuable insights into how the tree responds to changing conditions throughout the growing season.
- 2. Canopy Architecture Simulation:** Using advanced computer animations, VCHERRY visually simulates the development and structure of the tree canopy over time. This helps in understanding how light distribution and canopy growth influence overall productivity.
- 3. Management Practice Evaluation:** The model allows for the assessment of various rootstock genotypes, pruning techniques, and other cultural practices, enabling users to examine how these factors impact tree growth and fruit outcomes.
- 4. Scenario Analysis:** VCHERRY supports semi-permanent scenario evaluations, allowing orchard managers to experiment with different management decisions annually and predict their long-term effects. This facilitates informed decision-making and optimization of orchard performance.

Spectral Imaging & Detection Technologies

Recent advancements in spectral imaging and spectroscopy have provided powerful tools for disease diagnosis, pesticide residue detection, and nutrient monitoring in fruit orchards. These non-invasive technologies offer early and accurate assessments, enabling better orchard management and ensuring crop health and safety.

1. Hyperspectral Imaging for Disease Detection: Guo *et al.* (2015) demonstrated the use of hyperspectral imaging to differentiate between healthy citrus leaves and those infected with Citrus Tristeza Virus (CTV). By analyzing reflectance spectra within the 400–1000 nm wavelength range, the study successfully distinguished between different virus isolates, including TRL514, CT30, CT32, and CT11A.

- a. Application:** Enables early detection of viral infection before symptoms become visually apparent.
- b. Benefit:** Facilitates timely intervention, reducing the spread of disease within orchards and minimizing crop loss.

2. Raman Spectroscopy for Pesticide Residue Analysis: Liu et al. (2015) utilized Surface-Enhanced Raman Spectroscopy (SERS) to detect residues of the pesticide phosmet on the surface of navel oranges. The method involved the use of silver colloids to amplify Raman signals, allowing detection over a concentration range of 5 to 30 mg/L.

- a. Methodology:** Silver colloids were employed to enhance spectral signals, providing high sensitivity.
- b. Outcome:** The technique achieved a Root Mean Square Error of Prediction (RMSEP) of 6.424 mg/L, demonstrating strong accuracy in pesticide residue quantification.
- c. Significance:** This approach offers a **non-destructive and highly sensitive** method to monitor pesticide residues, ensuring food safety and regulatory compliance.

3. Spectroscopic Nitrogen Sensing in Jujube Orchards: In a novel approach to nutrient monitoring, Wu et al. (2015) developed a nitrogen parameter detector designed for in-situ measurement of nitrogen content in **jujube trees**. The system utilized reflectance data at selected wavelengths of 550, 650, 766, and 850 nm, collected through multiple sensor nodes coordinated by a central control unit.

- a. Design:** Distributed sensor nodes provide spatially resolved measurements across the orchard canopy.
- b. Function:** Enables real-time, non-destructive assessment of nitrogen levels, allowing for precise nutrient management and timely fertilization.

Monitoring Leaf Health Using Hyperspectral Tools

Maintaining optimal leaf health is critical for maximizing photosynthesis and fruit production. Hyperspectral sensing technologies have emerged as precise and non-invasive tools to assess key physiological parameters such as chlorophyll and nitrogen content, which are indicators of plant health and nutritional status.

1. Chlorophyll Estimation in Apple Leaves: Wang et al. (2015) developed advanced hyperspectral models, particularly using Partial Least Squares Regression (PLSR), to accurately estimate the chlorophyll content of young apple tree leaves. Their approach involved analyzing reflectance data across sensitive wavelengths to establish a predictive model that correlates spectral signatures with chlorophyll concentration.

a. Outcomes: The model demonstrated high predictive accuracy with low error rates, making it a reliable tool for monitoring photosynthetic pigment levels.

b. Significance: Early detection of chlorophyll changes enables orchard managers to identify stress factors and optimize fertilization strategies for healthier trees and improved fruit quality.

2. Portable Optical Detectors for Chlorophyll & Nitrogen: To facilitate practical, in-field assessments, Zhang *et al.* (2015) developed a portable optical sensor capable of estimating chlorophyll and nitrogen content based on reflectance measurements at specific wavelengths: 550 nm, 640 nm, 680 nm, and 780 nm.

a. Advantage: This lightweight, user-friendly device allows for rapid, non-destructive, and real-time monitoring directly in the orchard.

b. Utility: The portability and ease of use make it highly suitable for routine health checks and precision nutrient management, enabling growers to make informed decisions promptly.

Prediction of Soluble Solids Content in Oranges

The **soluble solids content (SSC)** is a key indicator of fruit sweetness and overall quality, playing a crucial role in harvest decisions and market grading. Accurate and non-destructive methods to estimate SSC are invaluable for orchard management and post-harvest handling. Spectroscopic techniques combined with Partial Least Squares (PLS) regression modeling to predict the SSC of Newhall navel oranges sourced from seven different regions across China. The study analyzed the spectral data of orange samples and developed predictive models tailored to each region.

1. Finding: The use of region-specific models significantly improved the accuracy of SSC predictions, accounting for the variability caused by differing climatic and soil conditions across origins.

2. Implication: These predictive models assist growers and marketers in determining the optimal harvest timing, ensuring fruits reach consumers at peak sweetness and quality. Moreover, they facilitate quality grading processes and support strategic market decisions.

By integrating spectroscopy and modeling, this approach offers a rapid, non-destructive, and reliable solution for monitoring fruit maturity and quality in diverse production areas.

Machine Vision and 3D Imaging for Fruit Detection

Recent advancements in machine vision and 3D imaging have significantly enhanced the ability to automatically detect and locate fruits within orchards, supporting automation in harvesting and precise yield estimation.

One such innovation is the Time of Flight (ToF) 3D imaging system, which has been applied to citrus orchards for automatic fruit recognition and spatial localization. This system integrates advanced image acquisition techniques with sophisticated noise-filtering and edge-detection algorithms to improve accuracy.

1. Process: The system captures three-dimensional images and applies a combination of partial differential equation filters and shock filters to reduce noise and sharpen fruit edges within the images.

2. Benefit: This technology is critical for enabling automated harvesting systems and providing reliable yield estimation, contributing to more efficient and precise orchard management.

Table: Advanced Techniques in Orchard Management:

Technique	Key Features / Benefits
Virtual Orchard Modeling	Simulates tree growth, yield, and canopy development for decision support
Hyperspectral Imaging	Early detection of diseases and stress through leaf reflectance analysis

Raman Spectroscopy	Sensitive, non-destructive detection of pesticide residues
Spectroscopic Nutrient Sensing	Real-time monitoring of nutrient levels such as nitrogen in trees
Chlorophyll Estimation Models	Accurate prediction of chlorophyll content using spectral data
Portable Optical Sensors	In-field, rapid assessment of leaf chlorophyll and nutrient status
Spectroscopic Quality Prediction	Non-destructive estimation of fruit quality parameters (e.g., sweetness)

Conclusion

Advanced and modern technologies in orchard management have become indispensable for precision agriculture. Innovations such as virtual modeling (VCHERRY), hyperspectral imaging, machine vision, smart sprayers, and robotic pruning systems are enhancing productivity, sustainability, and profitability in fruit production. These tools provide valuable support for real-time decision-making, ensuring optimized use of resources and improved fruit quality. As these technologies become more accessible and refined, they are set to revolutionize the future of horticulture and orchard systems worldwide.

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Advances in Packaging Materials for Maintaining Quality of Horticultural Crops

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Lalthan Tluanga¹, Naval Kishore Meena², Mohit Pal³, Kana Ram Sodh⁴

¹Ph.D. Scholar, Plant Physiology, Indian Agricultural Research Institute, New Delhi.

²Ph.D. Scholar, Department of Horticulture (Fruit Science), Maharana Pratap University of Agriculture & Technology, Udaipur Rajasthan.

³Ph.D. Scholar, Department of Fruit Science, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur.

⁴Farm Manager, Krishi Vigyan Kendra Sardarshahar, Churu-1, Rajasthan.

The journey of horticultural crops from harvest to consumer is fraught with challenges. Once detached from the plant, fruits and vegetables remain alive-continuing to respire, transpire and respond to stress-while being highly susceptible to mechanical damage and microbial spoilage. Without adequate intervention, postharvest losses worldwide can range between 30% and 50%, leading to economic losses and significant food waste (Kader, 2013). Packaging, therefore, represents more than mere containment, it has evolved into a vital technology for creating a controlled microenvironment that preserves quality and extends shelf life (Caleb *et al.*, 2013).

The Physiological Imperatives for Packaging Innovation

The underlying biology of fresh produce dictates the functional requirements of effective packaging. At the core lies respiration-the process converting sugars and other substrates into energy, releasing carbon dioxide and heat.

Since respiration continues robustly postharvest, particularly in highly perishable crops like leafy greens and berries, reducing its rate is critical to maintaining quality (Kader, 2013). Packaging materials designed to modify internal O₂ and CO₂ levels-a principle known as Modified Atmosphere Packaging (MAP)-are thus inherently tied to preserving freshness.

Concurrently, transpiration-driven water loss compromises turgidity, appearance, and texture. Leafy vegetables can become unattractive and unmarketable with as little as 3-5% weight loss (Liu *et al.*, 2020). Packaging that reduces moisture loss while avoiding condensation is therefore essential.

Ethylene, a plant hormone governing ripening and senescence in climacteric crops (like bananas, tomatoes, and mangoes), further complicates shelf life because even slight ethylene accumulation speeds up quality decline (Sadeghi *et al.*, 2019). Lastly, warm humid conditions promote microbial growth, and any mechanical damage sustained during handling accelerates both microbial decay and physiological breakdown (FAO, 2012).

Given this, modern packaging must address at least four physiological parameters: gas composition (especially O₂, CO₂, ethylene), moisture balance, microbial load and mechanical protection.

From Passive Barriers to Active Microenvironment Regulators

Historically, packaging for horticultural produce involved rudimentary solutions-wooden crates, jute sacks, and corrugated cartons. These protected against compression but lacked functionality in controlling ripening, respiration or water loss (FAO, 2012). The mid-20th century introduction of plastic films (e.g., polyethylene, polypropylene) improved moisture retention and visibility, but often resulted in harmful condensation, anaerobiosis, or off-flavors when improperly matched with produce respiration (Caleb *et al.*, 2013).

The realization that packaging could do more than encase produce sparked a shift toward advanced systems that regulate internal microenvironments. Over the last two decades, research has culminated in several major innovations.

Modified Atmosphere Packaging (MAP): Balancing Respiration, Gaseous Exchange and Quality

The theoretical foundation of MAP lies in establishing a beneficial equilibrium of reduced O₂ and elevated CO₂ within packaging, thereby slowing respiration and inhibiting microbial activity. For produce like fresh-cut lettuce, maintaining 2-5% O₂ and 3-8% CO₂ substantially preserves firmness and color compared to air-stored controls (Liu *et al.*, 2020).

Passive MAP leverages the produce's natural respiration and packaging film permeability to reach a desirable gas balance. Films with carefully specified O₂ and CO₂ transmission rates (ideally matched to the commodity's respiration profile) enable this equilibrium. However, passive MAP is constrained by environmental variability and produce heterogeneity.

Active MAP circumvents such limitations by prefilling packages with controlled atmosphere gas mixtures using external flushing systems. In both passive and active systems, the advent of microperforated films, precisely perforated (often via laser) with controlled pore size and density, has allowed dynamic fine-tuning of gas exchange in response to both respiration and environmental conditions (Qu *et al.*, 2021).

The theoretical advantage is clear: dynamic gas regulation tailored to respiration rates enables longer shelf life-often two to threefold-while preserving flavor, texture, and visual quality (Habiba *et al.*, 2022). However, mismatches between film permeability and produce respiration-especially under fluctuating temperatures-can cause excessive CO₂ buildup, triggering physiological disorders or conversely permit O₂ depletion, causing off-odors from fermentation. This underscores the importance of respiration modeling that forecasts behavior across temperature ranges, informing film selection and packaging design (Sonawane *et al.*, 2020).

Active Packaging: Sensing, Scavenging and Selectively Interacting with the Environment

While MAP seeks to alter the headspace composition indirectly, active packaging systems incorporate materials that directly interact with and modulate ethylene, oxygen, moisture and microbial populations.

Ethylene scavengers - common agents like potassium permanganate-oxidize ethylene into inert compounds, reducing its concentration and slowing the ripening of climacteric produce. Emerging substrates, such as activated carbon or zeolite-based materials, offer biodegradable and safer alternatives (Sadeghi *et al.*, 2019; Mariah *et al.*, 2020). The delivery forms vary from sachets to film-integrated layers.

Oxygen absorbers – It is typically iron-based systems, systematically remove residual O₂ within sealed packaging, suppressing oxidative reactions and aerobic microbial growth-particularly beneficial for fresh-cut product where oxidation-related browning is a concern. CO₂ emitters or absorbers further modulate the gas environment to discourage decay without triggering physiological issues (Vermeiren *et al.*, 2019).

Active packaging also includes antimicrobial releases, using natural compounds (essential oils, organic acids) or inorganic nanomaterials (e.g., silver, ZnO, TiO₂). These inhibit microbial growth on contact or via controlled release, offering extended protection against spoilage and pathogens (Priya *et al.*, 2021).

Collectively, active packaging strategies represent a proactive rather than reactive approach-intercepting specific physiological pathways to slow deterioration.

Edible Coatings and Films: A Direct Interface Between Produce and Preservation

Edible coatings and films, composed of polysaccharides, proteins, lipids or combinations thereof, create a thin, semi-permeable barrier on the surface of produce. This barrier modifies gas diffusion, reduces respiration rates, slows moisture loss and may also serve as a vector for delivering antioxidants, antimicrobials or ethylene inhibitors.

Polysaccharide-based coatings-such as those derived from alginate, starch, or pectin-can be manipulated to achieve targeted O₂/CO₂ permeability and mechanical properties. Protein-based coatings (e.g., whey, soy, zein) provide effective gas barriers and film-forming ability, while lipid-rich coatings (like waxes or glycerolipids) excel at reducing water vapor transmission (Blancas-Benitez *et al.*, 2022).

Empirical studies show that these coatings can double the shelf life of delicate fruits by mitigating water loss and surface discoloration without compromising sensory attributes-provided formulations are

optimized for transparency, flavor and safety (Blancas-Benitez *et al.*, 2022; Priya *et al.*, 2021). Although commercial adoption exists (e.g., amphiphilic plant-based coatings applied via spray or dip), successful deployment requires validated safety, organoleptic neutrality and logistical feasibility.

Sustainable Packaging: Bio-Based, Biodegradable, and Compostable Alternatives

The environmental toll of conventional plastics has created a pressing demand for packaging derived from renewable sources and designed for circularity. Bio-based polymers such as polylactic acid (PLA), polyhydroxyalkanoates (PHA) and starch- or cellulose-blended materials offer compostable or biodegradable alternatives suitable for tray liners, film wraps and clamshells (Olawade *et al.*, 2023).

Paperboard composites coated with functional biopolymers combine structural integrity with improved barrier properties-offering an eco-conscious compromise between strength and performance (Adak *et al.*, 2025). However, the intrinsic gas and moisture barrier properties of these biopolymers often lag behind petrochemical polymers, leading to functional limitations that may impair preservation unless enhanced via coatings or multilayer constructions (Olawade *et al.*, 2023).

When these systems can achieve composability or effective recyclability without sacrificing performance, they represent a key advance in aligning postharvest quality with environmental responsibility.

Nanocomposites and Functional Fillers: The Power of the Nanoscale

Integrating nanoscale fillers into packaging matrices has unlocked significant performance improvements. Nano clays and nanocellulose reinforcement markedly improve mechanical strength and reduce gas and water permeability by inducing tortuous diffusion paths at the molecular level. When paired with biopolymer matrices, nanocomposites may offer durability comparable to traditional polymers while retaining compostability (Chen *et al.*, 2021).

Importantly, incorporation of nano silver, zinc oxide, or titanium dioxide imparts antimicrobial properties to packaging surfaces, suppressing pathogen colonization and prolonging shelf life (Priya *et al.*, 2021). The theoretical benefit is clear-dual-function packaging that is both physically robust and biologically active.

Nevertheless, concerns about nanoparticle migration into produce and associated toxicological risks require rigorous safety evaluations and regulatory frameworks to ensure consumer safety (Priya *et al.*, 2021).

Intelligent Packaging: Indicators, Sensors and Digital Integration

Intelligent packaging leverages technological capabilities to monitor and communicate produce quality in real time:

1. Time-Temperature Indicators (TTIs): Visual markers that track cumulative temperature exposure-helping detect cold chain failures or exposure to abuse conditions that accelerate respiration and spoilage (Biji *et al.*, 2015).

2. Gas/Freshness Indicators: Colorimetric or electronic sensors that detect O₂, CO₂, ethylene and volatile metabolites of spoilage (e.g., ethanol, aldehydes), providing consumers and handlers with signals of produce status (He *et al.*, 2021).

3. RFID/IoT Platforms: Embedding data capture and sharing capability into packaging facilitates traceability, allows shelf-life predictions and enables dynamic routing or pricing based on real-time quality metrics.

These systems add transparency, reduce waste through informed decisions and enhance food safety by alerting stakeholders to compromised conditions (Du *et al.*, 2022).

Sustainability and Regulatory Considerations

Advanced packaging must balance functional efficacy with environmental and health considerations. Life cycle assessments must compare raw materials, manufacturing energy, end-of-life scenarios (composting, recycling) and postharvest waste reductions to determine net environmental benefit (Olawade *et al.*, 2023).

Use of active compounds and nanoparticles in contact with produce raises regulatory questions. Materials must meet food-grade safety criteria and migration limits. Edible coatings require adherence to labeling

laws and antimicrobial additives may fall under regulatory scrutiny depending on jurisdiction (He *et al.*, 2021; Priya *et al.*, 2021).

Thus, stewardship demands not just technological innovation, but integration with sustainability frameworks and rigorous safety standards.

Future Prospects: Smart, Sustainable, and Predictive Packaging Ecosystems

The evolving frontier in packaging for horticultural crops is one where materials science, environmental responsibility and digital intelligence intersect.

1. Model-driven packaging: Using crop-specific respiration and quality models coupled with predictive temperature data will inform dynamic packaging designs that adapt permeability or active loading to anticipated conditions (Sonawane *et al.*, 2020).

2. Hybrid biopolymer-nanocomposites: Combining biopolymers with nanoscale fillers for performance equivalence to conventional plastics, while retaining environmental credentials (Olawade *et al.*, 2023; Adak *et al.*, 2025).

3. Controlled-release functional coatings: Packaging surfaces that release antioxidants, ethylene inhibitors or antimicrobials in response to triggers such as moisture or ripening signals.

4. Integrated sensor-platforms: Packaging that tracks time, temperature, gas composition and freshness indicators, feeding data to IoT platforms for real-time shelf-life prediction, logistics optimization, and dynamic pricing.

5. Regulatory and standard harmonization: Development of unified standards for composability, bioplastic certification and nanomaterial safety in food packaging to facilitate adoption and consumer trust.

Conclusion

Packaging for horticultural crops has undergone a profound evolution from simple containers to dynamic systems that actively preserve life, quality and safety. Key theoretical advances-including MAP, active packaging, edible films, bio-based substrates, nanocomposites and intelligent sensors-have extended shelf-life, improved quality consistency and enabled better decision-making in supply chains. The greatest future gains lie not in isolated technologies but in integrated systems.

Packaging must align with crop physiology, cold-chain realities, environmental goals, safety regulations and digital information flows. By merging scientific understanding with materials development and data analytics, packaging can become a responsive steward of freshness-bridging field, storage, retail and table in a sustainable and intelligent way.

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How Nanomaterials like Quantum Dots can Improve Storage, Packaging, and Shelf Life of Fruits and Flowers?

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Manasa V¹, Mohit Pal², Saurabh Kumar Singh³, Nikhil Thakur⁴, Nisha Yadav⁵

¹M. Sc. Scholar, Department of Horticulture (Fruit Science), University of Agricultural Sciences, Raichur.

^{2&3}Ph.D. Scholar, Department of Fruit Science, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur.

⁴Ph.D. Scholar, Department of Horticulture (Floriculture and Landscaping), School of Agricultural Sciences (Nagaland University), Medziphema Campus.

⁵Ph.D. Scholar, Department of Agricultural Extension Education, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut.

Abstract

Postharvest losses remain one of the most pressing challenges in horticulture, accounting for 30–50% of fruits and vegetables worldwide. Cut flowers, likewise, suffer rapid deterioration and short vase life due to senescence, microbial growth, and oxidative damage. Traditional preservation techniques such as cold storage and chemical preservatives, while useful, fall short of meeting modern sustainability standards and consumer demand for chemical-free alternatives. Nanotechnology has emerged as a transformative approach, and within this field, quantum dots (QDs)-nanoscale semiconductor particles-offer novel opportunities. Their unique fluorescence, antioxidant-modulating capacity and photodynamic antimicrobial activity position them as multifunctional tools for extending shelf life. This article reviews how QDs can be applied in fruit storage, cut flower preservation and intelligent packaging. Mechanisms of action are explained, including oxidative stress regulation, microbial inhibition and packaging barrier enhancement. Challenges such as scalability, safety, and consumer acceptance are also discussed. The review concludes that QDs represent a promising, eco-friendly innovation for sustainable postharvest management.

Introduction

The global demand for fresh horticultural produce continues to rise in parallel with consumer expectations for safety, sustainability and longer shelf life. However, postharvest deterioration remains a significant barrier to achieving these goals.

Fruits are highly perishable due to their high-water content, metabolic activity and susceptibility to microbial infections, while cut flowers are extremely sensitive to water stress, microbial growth in vase solutions, and ethylene-induced senescence. Traditional preservation strategies-including refrigeration, controlled atmosphere storage and chemical preservatives-offer partial solutions but often come with trade-offs related to cost, environmental sustainability or consumer health concerns.

The emergence of nanotechnology has opened new avenues for addressing these limitations. Among various nanomaterials, quantum dots (QDs) have attracted growing attention due to their unique physicochemical properties.

QDs are nanocrystalline semiconductor materials typically ranging from 2 to 10 nanometres in diameter, exhibiting size-dependent fluorescence and high surface-to-volume ratios (Bera *et al.*, 2010). Originally explored for biomedical imaging and photovoltaic applications, QDs are now being investigated in food preservation for their ability to act as antioxidants, antimicrobials, and nano sensors.

Recent studies confirm that QDs-especially carbon quantum dots (CQDs)-can delay senescence, reduce decay, and enhance quality retention in fruits and vegetables (Ni *et al.*, 2024; Du *et al.*, 2024). Similarly, QDs can be used in flower vase solutions or embedded in edible coatings and packaging films, combining preservation with real-time quality monitoring (Priyadarshi *et al.*, 2024; Dodero *et al.*, 2021). Given the urgent need to reduce postharvest losses, QDs offer a next-generation technology for sustainable storage and packaging systems.

Nanomaterials and Quantum Dots in Postharvest Biology

Nanomaterials have been applied to the postharvest sector for over two decades, with silver nanoparticles, chitosan nanoparticles, and nano-clays among the earliest examples. However, QDs represent a distinct category, offering multifunctionality beyond simple antimicrobial activity. Their tunable fluorescence, photodynamic action and biocompatibility (particularly in carbon-based forms) set them apart (Xu *et al.*, 2004).

QDs can be synthesized via top-down or bottom-up methods, often using organic precursors. Notably, agricultural and food-processing wastes provide a sustainable feedstock for CQD synthesis. Onion peels, lemon peels or apple pomace can be converted into CQDs with strong luminescence and antioxidant potential (Aksu & Güzdemir, 2025). This “green synthesis” approach not only reduces waste but also enhances circularity in the food system.

From a biological perspective, QDs contribute to shelf-life extension through four main mechanisms:

- 1. Antioxidant defense activation** – QDs stimulate endogenous antioxidant enzymes such as catalase and superoxide dismutase, mitigating oxidative stress in plant tissues (Ni *et al.*, 2024).
- 2. Photodynamic antimicrobial activity** – Under light exposure, QDs generate singlet oxygen and hydroxyl radicals, which damage microbial membranes and nucleic acids (Du *et al.*, 2024).
- 3. Barrier enhancement in films and coatings** – Incorporated into polymers, QDs improve mechanical strength, block UV radiation, and regulate gas permeability (Priyadarshi *et al.*, 2024).
- 4. Real-time sensing** – Owing to their fluorescence, QDs function as indicators of spoilage or ripening in intelligent packaging (Doderio *et al.*, 2021).

Together, these mechanisms allow QDs to simultaneously delay senescence, suppress pathogens, and inform stakeholders about quality changes in perishable commodities.

Mechanisms of Action in Shelf-Life Extension

Postharvest deterioration in fruits and flowers is driven primarily by oxidative stress, microbial growth, and moisture loss. QDs intervene in these processes at multiple levels.

Oxidative Stress Regulation

Reactive oxygen species (ROS) such as hydrogen peroxide and superoxide radicals accumulate during ripening and senescence, accelerating chlorophyll degradation, membrane lipid peroxidation, and protein denaturation. QDs can modulate ROS metabolism by enhancing antioxidant enzyme activity. Ni *et al.* (2024) demonstrated that carbon dots delayed senescence in grapes by stimulating the activity of catalase and peroxidase, thereby reducing oxidative damage.

Microbial Suppression

Fungal pathogens such as *Botrytis cinerea* in grapes and bacterial contamination in vase water are major contributors to postharvest losses. Du *et al.* (2024) showed that carbon dots significantly reduced microbial spoilage in goji berries by generating singlet oxygen under light activation. This photodynamic effect offers a promising alternative to chemical fungicides, aligning with consumer demand for chemical-free preservation methods.

Structural and Barrier Enhancements

When integrated into edible coatings or packaging films, QDs improve mechanical strength, reduce water vapor transmission and create UV barriers. This not only slows down physiological processes such as respiration and transpiration but also shields products from photooxidative damage (Priyadarshi *et al.*, 2024).

Sensing Capabilities

The fluorescence of QDs allows them to act as spoilage indicators. In smart packaging systems, QDs embedded in films can provide visual cues when metabolic gases such as CO₂ accumulate, enabling real-time monitoring of fruit ripening or spoilage (Doderio *et al.*, 2021).

Applications in Fruits

Several studies highlight the successful application of QDs in fruit preservation. Ni *et al.* (2024) reported that grape berries treated with carbon dots exhibited delayed senescence, lower decay rates and improved antioxidant capacity compared to untreated controls. Similarly, Du *et al.* (2024) observed that goji berries exposed to carbon dot treatments maintained higher firmness, colour and nutritional quality during storage.

Edible coatings enhanced with QDs represent another application. Priyadarshi *et al.* (2024) reviewed studies on strawberries, mangoes and apples where QD-based coatings formed semipermeable barriers, reducing respiration and transpiration while simultaneously inhibiting microbial contamination. Importantly, these coatings provided an additional fluorescence-based quality indicator, setting them apart from conventional edible films.

Aksu and Güzdemir (2025) discussed how food waste-derived QDs can be integrated into fruit packaging systems. For example, onion-skin-derived QDs incorporated into polymer films not only improved mechanical and barrier properties but also exhibited antimicrobial activity. This approach valorizes agricultural waste while enhancing fruit preservation.

Applications in Flowers

Cut flowers such as roses, tulips, and chrysanthemums are highly valued for their ornamental appeal but face rapid deterioration after harvest. Vase life is influenced by water uptake, microbial growth in vase solutions and oxidative stress. Nanomaterials offer innovative approaches to mitigate these challenges.

El-Sayed *et al.* (2025) demonstrated that chitosan and copper nanoparticles in vase solutions significantly extended tulip vase life by reducing microbial proliferation and enhancing antioxidant activity. Although this study did not directly use QDs, it underscores the capacity of nanoscale materials to enhance flower longevity. Given their photodynamic antimicrobial action, QDs have strong potential for similar applications.

The introduction of QDs into vase solutions could prevent microbial biofilm formation inside xylem vessels, maintaining water uptake and flower turgidity. Additionally, their antioxidant-modulating properties may delay petal senescence, thereby prolonging aesthetic appeal. Compared to traditional silver-based preservatives, carbon-based QDs offer reduced environmental toxicity and greater sustainability.

Role in Smart and Intelligent Packaging

One of the most exciting applications of QDs is in intelligent packaging systems. These systems combine preservation with real-time monitoring, enabling consumers and retailers to assess freshness directly.

Dodero *et al.* (2021) emphasized that QDs, when embedded in packaging films, can act as nano sensors that respond to changes in gas composition, humidity, or microbial metabolites. For instance, QDs functionalized with specific ligands may exhibit fluorescence changes when exposed to elevated CO₂ or volatile organic compounds, serving as indicators of ripening or spoilage.

By integrating both barrier functions (enhanced UV blocking and gas regulation) and sensing capabilities, QD-based films provide a dual benefit, reducing food waste and improving consumer trust in product quality.

Safety, Toxicity, and Consumer Acceptance

Despite their promise, QD applications in horticulture must address safety and consumer acceptance concerns. Conventional cadmium- or lead-based QDs are unsuitable for food applications due to their toxicity. However, carbon-based and silicon QDs are emerging as safer alternatives, with studies confirming their biocompatibility and low cytotoxicity (Xu *et al.*, 2004).

Priyadarshi *et al.* (2024) highlighted the importance of regulatory compliance and consumer education in promoting acceptance of QD-enhanced preservation systems. Edible coatings and packaging films must demonstrate not only efficacy but also safety through rigorous testing. Furthermore, transparent labelling and green synthesis approaches-such as producing QDs from fruit wastes-can improve public trust.

Challenges and Future Prospects

While promising, several challenges remain before QDs can be widely adopted in horticultural preservation:

- 1. Scalability** – Industrial-scale production of QDs with consistent quality is still expensive.
- 2. Standardization** – Protocols for applying QDs in edible coatings or vase solutions are not yet standardized.
- 3. Toxicity Studies** – Long-term studies are needed to confirm safety in diverse applications.
- 4. Integration into Supply Chains** – Effective adoption requires collaboration across nanotechnology, horticulture and packaging industries.

Future prospects include the green synthesis of QDs from agro-wastes, multifunctional packaging systems with integrated QDs and hybrid preservation approaches combining QDs with natural antimicrobials or plant-derived coatings. As research progresses, QDs could become an integral part of sustainable postharvest management.

Conclusion

Quantum dots represent a frontier in postharvest technology, offering multifunctional roles in extending the shelf life of fruits and flowers. Their antioxidant-regulating capacity, antimicrobial photodynamic action and integration into smart packaging systems set them apart from traditional preservation methods. While challenges remain regarding scalability, safety and consumer acceptance, ongoing innovations in carbon-based and green-synthesized QDs provide encouraging prospects. With continued research and cross-sector collaboration, QDs could play a transformative role in reducing horticultural losses, improving sustainability and meeting consumer expectations for fresh, high-quality produce and flowers.

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Harvesting the Sun Twice: The Rise of Agrivoltaics

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Kesoju Ravali¹, Irayya Hiremath²

¹M.Sc. (Agriculture) in Genetics and Plant Breeding, Junior Executive (Agri.), National Seeds Corporation Ltd. (NSCL), Warangal, Telangana.

²M.Sc. (Agriculture) in Agronomy, Assistant Manager (Production), National Seeds Corporation Ltd. (NSCL), Warangal, Telangana.

Abstract

As the global demand for both food security and renewable energy intensifies, **agrivoltaics** emerges as a transformative solution to the competition for arable land. This practice involves the co-location of solar photovoltaics and agriculture, placing solar arrays at heights and intervals that allow for the cultivation of crops beneath them.

This article explores the **sybiotic relationship** inherent in these systems: solar panels provide essential shade that reduces thermal stress and water evaporation for heat-sensitive crops—such as leafy greens and berries—while the natural transpiration from plants cools the panels, enhancing their photovoltaic efficiency. By analyzing recent research from institutions like **NREL** and **Fraunhofer ISE**, the text highlights the environmental benefits of reduced water consumption and the economic advantages of diversified revenue streams for farmers. Ultimately, the article positions agrivoltaics not merely as a technical innovation, but as a critical strategy for sustainable land management in a climate-stressed world.

The Symbiosis of Power and Plants

Traditionally, solar farms and agriculture have been competitors for land. Agrivoltaics flips this script by elevating solar panels several feet off the ground, allowing crops to grow underneath. This creates a “win-win” microclimate:

Cooling the Crops: For heat-sensitive plants like leafy greens, berries, and peppers, the partial shade from panels prevents “sunburn” and reduces heat stress.

Saving Water: The shade reduces evaporation from the soil. In some studies, agrivoltaic systems have reduced water usage by up to 30%, a lifesaver in drought-prone regions.

Boosting Panel Efficiency: Interestingly, plants help the solar panels, too. As plants breathe (transpiration), they release moisture that cools the panels from below. Since solar panels are more efficient when they aren’t overheating, the crops actually help generate more power.

What Grows Best Under the Panels?

While sun-loving crops like corn might struggle in total shade, many high-value crops are perfect candidates for this “dual-use” farming:

Crop Category	Examples	Benefit
Leafy Greens	Lettuce, Spinach, Kale	Prevents bolting and keeps leaves tender.
Fruits	Strawberries, Raspberries	Protects delicate fruit from intense midday heat.
Root Veggies	Potatoes, Carrots	Maintains consistent soil moisture.
Forage	Pasture grass for sheep	Provides shade for livestock while maintaining grazing land.

The Economic Edge

For the modern farmer, agrivoltaics offers a diversified income stream. Agriculture is notoriously vulnerable to weather and market fluctuations. By “farming the sun,” a landowner gains a steady, predictable check from energy production that can offset a bad harvest year.

Furthermore, as global populations rise and the demand for renewable energy hits record highs, agrivoltaics provides a solution to the “land grab” debate, proving we don’t have to choose between food security and a green grid.

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The Virtual Harvest: How Digital Twins are Revolutionizing the Future of Food

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Irayya Hiremath¹, Kesoju Ravali²

¹M.Sc. (Agriculture) in Agronomy, Assistant Manager (Production), National Seeds Corporation Ltd. (NSCL), Warangal, Telangana.

²M.Sc. (Agriculture) in Genetics and Plant Breeding, Junior Executive (Agri.), National Seeds Corporation Ltd. (NSCL), Warangal, Telangana.

Abstract

As the global food system faces the dual pressures of a burgeoning population and climate instability, traditional agricultural methodologies are reaching their efficiency limits. This paper explores the emergence of Digital Twin (DT) technology as a transformative paradigm shift in the agrifood sector. By creating high-fidelity, real-time virtual replicas of physical biological assets—ranging from individual crops to entire regional ecosystems—Digital Twins enable a level of predictive precision previously unattainable.

We examine the multi-layered architecture of the “Virtual Harvest,” analyzing how the integration of IoT sensors, satellite imagery, and AI-driven simulation allows farmers to conduct “what-if” scenarios in a risk-free digital environment. The study highlights three critical areas of impact:

Resource Optimization: Significant reductions in water, fertilizer, and pesticide use through hyper-localized application.

Yield Resilience: The use of climate modeling to stress-test crop varieties against extreme weather events.

Supply Chain Transparency: Real-time monitoring from seed to shelf to minimize post-harvest loss.

Finally, the paper addresses the socio-economic barriers to adoption, including data sovereignty and the digital divide. We conclude that Digital Twins are not merely a tool for precision farming, but the foundational infrastructure for a resilient, transparent, and sustainable global food future.

Keywords: Digital Twins, Precision Agriculture, AgTech, Sustainable Food Systems, IoT, Predictive Analytics.

Digital Twin?



At its core, a digital twin is a high-fidelity, virtual 3D replica of a physical farm. It's not just a static map; it is a living, breathing model fueled by real-time data.

To create this "Matrix" for crops, scientists and farmers use a combination of:

1. **Satellite Imagery:** To track land use and vegetation health.
2. **IoT Sensors:** Buried in the soil to monitor moisture, pH levels, and nutrients.
3. **Drones:** To map the topography and identify specific plant stress.
4. **Weather Stations:** To feed local atmospheric conditions into the model.

Moving from "Reactive" to "Predictive"

Historically, farming has been **reactive**. If a pest outbreak occurred, the farmer sprayed the field. If a drought hit, they increased irrigation. The damage, however, often began before it was visible to the naked eye.

Digital twins allow for **predictive farming**. By running "what-if" scenarios in the virtual world, scientists can see the future before it happens:

1. **Simulating Weather Impacts:** Before a heatwave or a cold snap arrives, a digital twin can simulate how different crop varieties on a specific plot will respond. If the model shows the soil will dry out too fast, the farmer can adjust irrigation schedules *before* the plants enter a state of permanent wilt.
2. **Hunting Pests Virtually:** Pest outbreaks often follow specific patterns of humidity and temperature. A digital twin can highlight "hot zones" where conditions are perfect for an infestation. This allows farmers to apply targeted treatments to a small area rather than blanket-spraying an entire field with chemicals.

Why it Matters: Sustainability and Security

The implications of this technology go far beyond just saving a single crop. Digital twins help:

1. **Reduce Waste:** By applying water and fertilizer only where the model says it's needed, we reduce runoff into local waterways.
2. **Boost Yields:** Optimization means more food produced on less land.
3. **Climate Resilience:** As weather patterns become more volatile, these simulations provide a roadmap for adapting to a changing planet.

"The digital twin is the ultimate 'undo' button for agriculture. It lets us make the mistakes in the virtual world so we don't have to make them in the real one."

The Path Ahead

While the technology is currently being used by large-scale research institutions and high-tech agricultural firms, the goal is to make these virtual mirrors accessible to every farmer. As sensor costs drop and AI processing power increases, the farm of the future will be managed as much from a keyboard as it is from a tractor.

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Cold Chain – The Backbone of Modern Horticulture

Article ID: 72310

Jonnada Archana¹

¹Ph.D. Scholar, Department of Floriculture and Landscape Architecture, College of Horticulture, Rajendranagar, Hyderabad, SKLTGHU, Telangana, India.

Abstract

The cold chain is a temperature-controlled system essential for preserving the quality, safety, and market value of horticultural commodities from harvest to consumption. Given the highly perishable nature of fruits, vegetables, flowers, and ornamentals, effective cold chain management is vital for reducing postharvest losses, maintaining nutritional and sensory quality, and enabling domestic and international trade. This chapter discusses the principles, components, technologies, challenges, sustainability aspects, and future prospects of cold chain systems in modern horticulture, with examples from major horticultural crops.

Introduction

Horticultural crops such as fruits, vegetables, cut flowers, and ornamentals are living tissues that continue physiological and biochemical processes even after harvest. Crops like tomato, strawberry, spinach, rose, and gladiolus have high respiration and transpiration rates, making them extremely sensitive to temperature fluctuations. Exposure to unfavorable temperatures results in rapid softening, wilting, discoloration, and microbial spoilage.

The cold chain refers to an uninterrupted series of temperature-controlled operations starting immediately after harvest and extending through storage, transportation, distribution, and retail. In crops like grapes, apples, bananas, and cut roses, even short breaks in the cold chain can lead to quality deterioration and reduced market value. Hence, cold chain systems form the backbone of modern horticulture.

Role and Significance of Cold Chain in Horticulture

Cold chain systems significantly reduce postharvest losses in highly perishable crops. For example, leafy vegetables such as lettuce, coriander, and spinach lose water rapidly under ambient conditions, leading to wilting and loss of freshness. Cold storage at 0–4°C with high relative humidity helps retain turgidity and green color.

In fruits such as apple, pear, and kiwi, low-temperature storage slows respiration and delays senescence, enabling long-term storage and export. Banana and mango, being climacteric fruits, require controlled temperature management to regulate ripening during transport.

In floriculture, crops like rose, carnation, gerbera, and chrysanthemum depend heavily on cold chain management. Immediate pre-cooling and refrigerated transport are essential to maintain flower freshness, color, and vase life, particularly for export markets.

Principles of Cold Chain Management

Temperature management is commodity-specific. While apple, grape, and cabbage can be safely stored near 0°C, tropical crops such as banana, papaya, and pineapple are susceptible to chilling injury below 10–13°C, resulting in peel browning, pitting, and off-flavors.

Relative humidity plays a vital role in maintaining freshness. Carrot, radish, cucumber, and capsicum require high humidity (90–95%) to prevent shriveling, whereas lower humidity is preferred for crops like onion and garlic to reduce sprouting and decay.

Rapid removal of field heat is particularly important in crops harvested under hot conditions, such as tomato, okra, and marigold flowers. Delays in pre-cooling significantly reduce storage life and market quality.

Components of the Horticultural Cold Chain

Pre-cooling is the first critical step in cold chain management. Hydro-cooling is commonly used for crops such as sweet corn, carrot, and broccoli, while forced-air cooling is effective for apple, grape, strawberry, and cut flowers. Vacuum cooling is particularly suitable for leafy vegetables like lettuce and spinach.

Cold storage facilities maintain optimal conditions for various crops. Controlled atmosphere (CA) storage is widely used for apple and pear, allowing storage for several months by reducing oxygen and increasing carbon dioxide concentrations.

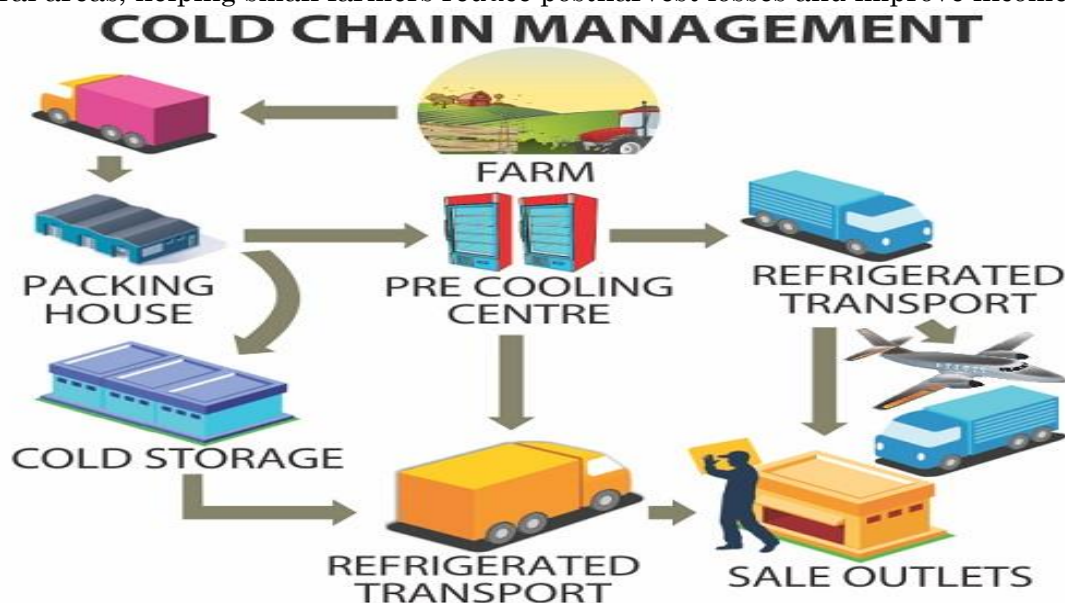
Refrigerated transportation is essential for long-distance movement of mango, citrus, grape, tomato, and cut flowers. In floriculture, temperature-controlled logistics from harvest to retail are crucial for maintaining vase life, especially for export-oriented crops such as rose and lily.

Modern cold chains rely on continuous monitoring using sensors and data loggers. For high-value crops like strawberry, cherry, and orchids, real-time monitoring helps prevent temperature abuse and quality loss.

Technologies Supporting Modern Cold Chains

Advanced refrigeration technologies and natural refrigerants are increasingly used to store crops such as apple, grape, potato, and onion with reduced energy consumption. Modified atmosphere packaging (MAP) has proven effective for extending shelf life of fresh-cut vegetables, berries, and minimally processed fruits.

Solar-powered cold storage units are gaining popularity for crops like tomato, brinjal, banana, and marigold flowers in rural areas, helping small farmers reduce postharvest losses and improve income.



Challenges in Cold Chain Development

Despite technological advancements, cold chain adoption remains limited for crops such as okra, leafy greens, and local flowers, especially in developing regions. High infrastructure costs, lack of cold storage near farms, unreliable electricity, and limited awareness among farmers result in significant losses of fruits, vegetables, and floricultural crops. Smallholder farmers growing crops like mango, tomato, and flowers often depend on traditional markets, where inadequate cold chain facilities lead to distress sales and wastage.

Sustainability and Environmental Considerations

Cold chains reduce wastage of resource-intensive crops such as banana, apple, grape, and cut flowers, thereby improving sustainability. Adoption of energy-efficient refrigeration systems and renewable energy sources reduces the environmental footprint of storing crops like potato and apple, which require long-term storage.

Emerging Trends and Future Prospects

Artificial intelligence and predictive analytics are increasingly being used to manage cold chains for high-value crops such as berries, grapes, and flowers. Blockchain technology enhances traceability and quality assurance for export-oriented crops including mango, grape, apple, and cut roses.

Community-level cold storage hubs are emerging as effective solutions for small-scale producers of vegetables, fruits, and flowers, enabling better market access and reduced losses.

Conclusion

The cold chain is central to the success of modern horticulture, ensuring quality preservation and market competitiveness of fruits, vegetables, and floricultural crops. From apple and grape to tomato, banana, rose, and gerbera, every horticultural commodity benefits from uninterrupted temperature control. Strengthening cold chain infrastructure, supported by technology and sustainable practices, is essential for reducing postharvest losses, improving farmer income, and meeting the growing demand for fresh horticultural produce.

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Smart Farming: When Technology Meets Horticulture

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Jonnada Archana¹

¹Ph.D. Scholar, Department of Floriculture and Landscape Architecture, College of Horticulture, Rajendranagar, Hyderabad, SKLTGHU, Telangana, India.

Abstract

Smart farming represents the convergence of advanced digital technologies with horticultural science to enhance productivity, resource-use efficiency, sustainability, and profitability. In horticulture, where crops are often high-value, sensitive, and input-intensive, smart farming tools such as sensors, Internet of Things (IoT), artificial intelligence (AI), robotics, automation, and data analytics are transforming traditional practices. This chapter provides a comprehensive overview of smart farming concepts, technologies, and applications in horticulture. It discusses system components, precision management of water, nutrients, pests, and climate, and presents crop-specific examples from fruits, vegetables, flowers, and plantation horticulture. The chapter also examines economic, environmental, and social impacts, challenges to adoption, and future prospects of smart horticulture.

Introduction

Horticulture plays a vital role in nutritional security, income generation, employment, and export earnings, especially in developing countries. However, the sector faces major challenges such as climate change, labor shortages, rising input costs, pest and disease pressures, water scarcity, and the need for consistent quality produce. Smart farming, also referred to as digital, precision, or intelligent farming, offers solutions by integrating information and communication technologies (ICT) with crop production systems.

Smart farming enables real-time monitoring, precise input application, predictive decision-making, and automation of horticultural operations. Unlike broad-acre field crops, horticultural crops require crop- and site-specific management due to their diversity, perishability, and quality sensitivity. Therefore, the adoption of smart technologies is particularly impactful in horticulture.

Concept and Principles of Smart Farming

1. Definition of Smart Farming: Smart farming is the application of modern digital technologies to agricultural production systems to increase efficiency, accuracy, sustainability, and profitability through data-driven decision-making.

2. Core Principles:

Precision: Applying the right input, at the right time, in the right amount, and at the right place.

i. Connectivity: Linking sensors, machines, and platforms through IoT and cloud computing.

ii. Automation: Reducing human intervention through automated systems and robotics.

iii. Intelligence: Using AI and machine learning for prediction, diagnosis, and optimization.

iv. Sustainability: Minimizing environmental impact while maintaining high productivity.

Components of Smart Farming Systems in Horticulture

1. Sensors and Data Acquisition: Sensors form the backbone of smart horticulture by collecting real-time data on:

- Soil moisture, temperature, pH, and electrical conductivity
- Weather parameters (temperature, humidity, rainfall, wind, solar radiation)
- Plant parameters (canopy temperature, chlorophyll content, growth rate)

Example: Soil moisture sensors in tomato fields help schedule irrigation precisely, reducing water use and preventing blossom end rot.

2. Internet of Things (IoT): IoT enables interconnection of sensors, controllers, and devices through wireless networks. Data are transmitted to cloud platforms for storage and analysis.

Example: IoT-based drip irrigation systems in capsicum and cucumber greenhouses allow farmers to control irrigation remotely using smartphones.

3. Data Analytics and Cloud Computing: Large volumes of data generated from farms are processed using cloud computing. Decision support systems (DSS) convert raw data into actionable insights.

4. Artificial Intelligence and Machine Learning: AI algorithms analyze historical and real-time data to:

- a. Predict yield and harvest time
- b. Detect diseases and nutrient deficiencies
- c. Optimize irrigation and fertigation schedules.

Example: Machine learning models are used in apple orchards to predict fruit size and yield based on weather and canopy data.

5. Automation and Control Systems: Automation includes climate control, irrigation, fertigation, and postharvest handling systems that operate with minimal human input.

6. Robotics and Drones: Robots and unmanned aerial vehicles (UAVs) perform tasks such as:

- a. Crop scouting and mapping
- b. Precision spraying
- c. Harvesting and pruning.

Smart Irrigation and Water Management

Water is a critical and limiting resource in horticulture. Smart irrigation systems integrate sensors, weather data, and control units to optimize water use.

1. Technologies Used:

- a. Soil moisture sensors
- b. Automated drip and micro-sprinkler systems
- c. Weather-based irrigation controllers.

2. Crop Examples:

- a. Grapes:** Smart drip irrigation reduces water stress and improves berry size and sugar content.
- b. Banana:** Sensor-based irrigation scheduling improves water-use efficiency and bunch weight.
- c. Strawberry:** Automated irrigation in protected cultivation prevents overwatering and root diseases.

Smart Nutrient and Fertigation Management

Precision nutrient management ensures optimal plant nutrition while reducing fertilizer losses and environmental pollution.

1. Technologies:

- a. EC and pH sensors
- b. Automated fertigation units
- c. AI-based nutrient recommendation systems.

2. Crop Examples:

- a. Tomato:** AI-driven fertigation improves yield and fruit quality in greenhouse tomatoes.
- b. Rose:** Precise nutrient control enhances flower size, color, and vase life.
- c. Lettuce:** Hydroponic systems with smart nutrient dosing ensure uniform growth and quality.

Smart Pest and Disease Management

Early detection and precise control of pests and diseases are essential in horticulture.

1. Digital Tools:

- a. Image-based disease detection using smart phones
- b. AI-powered pest identification
- c. Smart traps with sensors and cameras.

2. Crop Examples:

- a. Mango:** AI models detect powdery mildew and anthracnose at early stages.

- b. Chilli:** Smart pheromone traps help monitor and manage fruit borer populations.
- c. Orchid:** Sensor-based microclimate control reduces fungal diseases in greenhouses.

Smart Greenhouses and Protected Cultivation

Protected cultivation systems are ideal platforms for smart farming technologies.

- 1. Climate Control:** Automated systems regulate temperature, humidity, CO₂ concentration, and light intensity.
- 2. Crop Examples:**
 - a. Capsicum:** Smart greenhouses improve yield and uniformity.
 - b. Cucumber:** Automated climate and fertigation systems enhance productivity.
 - c. Gerbera:** Precise environmental control improves flower quality and year-round production.

Robotics and Automation in Horticulture

- 1. Harvesting Robots:** Robots equipped with vision systems are used for selective harvesting.

Example: Strawberry harvesting robots reduce labor dependency and postharvest losses.

- 2. Weeding and Pruning Robots:** Autonomous robots perform mechanical weeding and pruning with high precision.
- 3. Nursery and Postharvest Automation:** Automation in nurseries ensures uniform seedlings, while smart grading and packing systems improve postharvest efficiency.

Crop-Specific Applications of Smart Farming



- 1. Fruit Crops:**
 - a. Apple:** Yield prediction, precision pruning, and disease forecasting
 - b. Citrus:** Smart irrigation and nutrient management
 - c. Grapes:** Canopy management and quality monitoring
- 2. Vegetable Crops:**
 - a. Tomato:** Smart greenhouses and disease detection
 - b. Onion:** Precision irrigation and storage monitoring
 - c. Leafy greens:** Hydroponics and vertical farming with smart control systems

3. Floriculture Crops:

- a. **Rose:** Precision fertigation and climate control
- b. **Chrysanthemum:** Automated lighting and growth regulation
- c. **Gerbera:** Smart greenhouse management for export quality flowers

4. Plantation and Spice Crops:

- a. **Tea:** Drone-based monitoring and yield estimation
- b. **Coffee:** Smart irrigation and pest surveillance
- c. **Black pepper:** Microclimate monitoring for disease management

Economic and Environmental Impacts

Economically Increases yield and quality, Reduced input and labor costs, Higher profitability and market competitiveness, whereas environmentally impacts the efficient use of water and fertilizers, Reduced pesticide application, Lower carbon footprint.

Challenges and Constraints

- 1. High initial investment
- 2. Limited digital literacy among farmers
- 3. Connectivity and infrastructure issues
- 4. Data privacy and ownership concerns
- 5. Need for crop-specific customization.

Adoption of Smart Farming in Developing Countries

In countries like India, smart horticulture is gaining momentum through government initiatives, startups, and public-private partnerships. Mobile-based advisory services, low-cost sensors, and customized solutions are improving accessibility for small and marginal farmers.

Future Prospects of Smart Horticulture

In countries like India, smart horticulture is gaining momentum through government initiatives, startups, and public-private partnerships. Mobile-based advisory services, low-cost sensors, and customized solutions are improving accessibility for small and marginal farmers.

Future Prospects of Smart Horticulture

- 1. Integration of AI, blockchain, and big data
- 2. Expansion of vertical farming and urban horticulture
- 3. Climate-resilient and autonomous production systems
- 4. Digital twins and predictive farming model.

Conclusion

Smart farming is redefining horticulture by enabling precise, efficient, and sustainable crop production. The integration of digital technologies with horticultural practices enhances productivity, quality, and resilience against climatic and market uncertainties. With continued innovation, capacity building, and supportive policies, smart farming will play a crucial role in the future of horticulture.

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