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Fall Armyworm in Maize: From Invasion to Integrated Management in India

Article ID: 74600

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Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops cultivated in India and has emerged as a strategically important crop for the country's food, feed and industrial sectors. In 2024–25, India recorded the maize production of 43.41 million tonnes, according to the final estimates of the Department of Agriculture & Farmers Welfare, Government of India. Globally, India ranked as the fifth-largest maize producer in 2024, contributing approximately 3.3% of global maize production. The sustained increase in maize area and production over the years reflects its growing importance in the Indian agricultural economy.

The significance of maize extends far beyond its use as a food grain. It serves as an important source of poultry feed, livestock feed, fish feed, green and dry fodder, and is widely used as a raw material in the starch, food-processing and other industrial sectors. In recent years, the increasing utilization of maize as a feedstock for bioethanol production has further strengthened its economic importance. Consequently, maize has become an important link connecting crop production with the livestock and poultry sectors, food and industrial processing, feed industries and the emerging biofuel sector. With this expanding demand and growing economic significance, maintaining stable maize production and protecting the crop from biotic and abiotic stresses have become essential for sustaining farmer income and meeting the country's diverse maize requirements.

Journey of Fall Armyworm

The expanding maize production in India has been challenged by the emergence of fall armyworm (FAW), *Spodoptera frugiperda* J.E. Smith, an invasive and highly destructive lepidopteran pest. Native to the America, fall armyworm has long been recognized as a major pest of maize. Its high reproductive potential, rapid larval development, strong dispersal capacity, wide host range and ability to adapt to diverse agro-ecological conditions have contributed to its successful establishment and rapid spread into new geographical regions.

The global expansion of fall armyworm began with its detection in Africa in 2016, marking a significant change in the pest's distribution. From Africa, the pest rapidly expanded into several countries in Asia. India recorded its first official occurrence in 2018, when fall armyworm was detected on maize in Karnataka. Subsequent field surveys confirmed significant infestation in maize-growing areas, particularly during the kharif season, and the pest subsequently spread to several other maize-producing states.

The rapid establishment of FAW in India highlighted the exceptional dispersal ability of this invasive pest. Within a relatively short period, it expanded from its initial location in Karnataka to several maize-growing regions across the country. By June 2019, FAW infestation had been reported from 20 states, with approximately 3.76 lakh hectares affected during 2018–19. Maize was the principal crop affected, although the pest was also reported on other crops, including sorghum, millets and sugarcane.

Impact of Fall Armyworm on Maize Yield: Indian and Global Perspectives

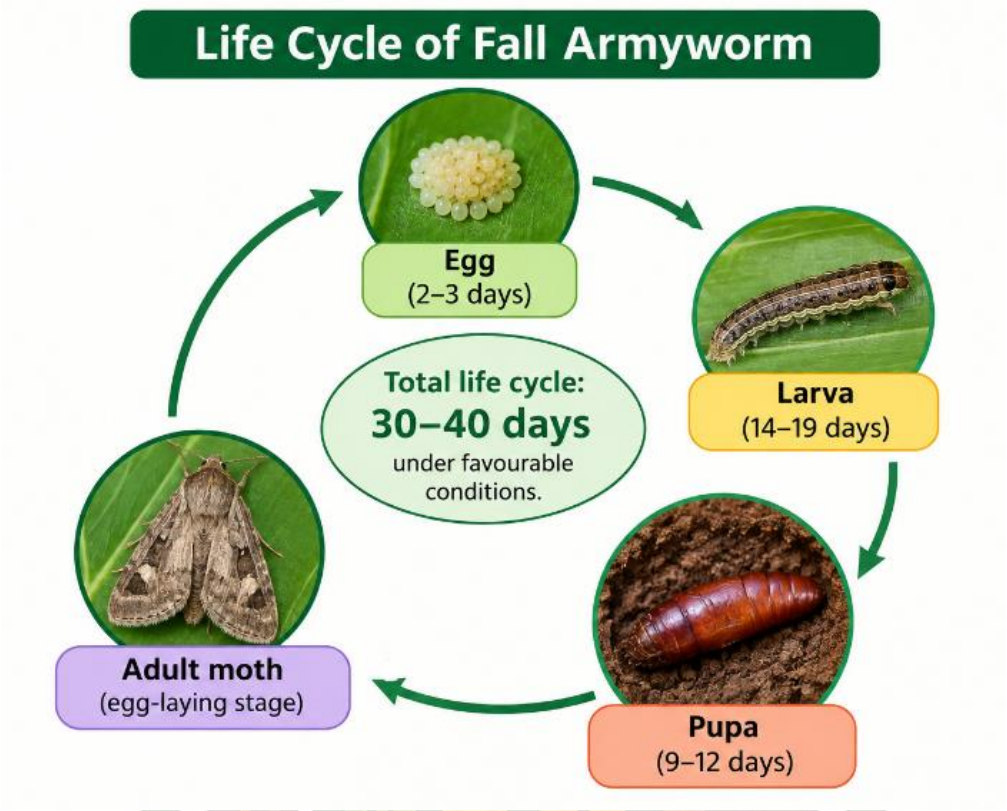
Globally, FAO reported that FAW can cause substantial maize production losses, with an estimated 8.3–20.6 million tonnes of maize lost annually in 12 African countries, while an FAO pilot study across affected countries recorded an average yield loss of 10.8% due to FAW; in countries where the pest was newly detected, annual yield losses were often reported in the range of 10–20%. FAO also reported that, in the absence of effective control, some estimates in Africa suggested potential maize production losses of up to 53%, although most field trials reported yield losses below 20%, demonstrating the strong influence of pest pressure and management on actual yield loss.

In India, field evidence from Tamil Nadu has demonstrated the substantial yield benefit of effective management, with 8,920 kg/ha under an IPM programme compared with 4,750 kg/ha under non-IPM conditions, highlighting the potential production loss when effective management is absent.

Therefore, the Indian and global evidence clearly demonstrates that FAW can cause economically significant yield losses, particularly under severe and unmanaged infestations, emphasizing the need for integrated pest and disease management (IPDM) involving regular surveillance, timely detection, cultural and mechanical practices, biological and botanical control, conservation of natural enemies and need-based, judicious use of insecticides to minimize yield losses and sustain maize productivity.

Life Cycle of Fall Armyworm

Fall armyworm undergoes complete metamorphosis, comprising four distinct stages: egg, larva, pupa and adult moth. The female moth lays eggs in masses, usually containing about 120–150 eggs, which are covered with scales and hatch within approximately 2–3 days under favourable conditions. The newly emerged larvae pass around 6 instars over a period of about 14–19 days; this is the most destructive stage, with young larvae initially scraping the leaf surface and older larvae feeding extensively within the maize whorl, tassels and cobs. Mature larvae generally pupate in the soil, where the pupal stage lasts approximately 9–12 days. Adult moths emerge from the pupae, mate and the females' lay eggs, thereby completing the life cycle. The relatively short developmental period, high fecundity and strong dispersal ability of the adult moths enable FAW populations to build up rapidly under favourable conditions. Therefore, early detection and management of young larvae are critical for preventing severe crop damage and reducing subsequent population build-up.



Symptoms of Fall Armyworm at Different Crop Stages

Fall armyworm can infest maize from the seedling stage to cob development. The nature and severity of damage vary with the crop growth stage and larval age. Early detection of characteristic symptoms is therefore essential for timely implementation of appropriate management measures.

1. Seedling Stage: During the early seedling stage, young larvae feed mainly by scraping the surface of tender leaves. This results in characteristic translucent or window-pane-like patches on the leaves. As the damaged leaves expand, small holes and irregular feeding marks become visible.

2. Early Whorl Stage: FAW larvae move towards the central whorl and feed on the developing leaves. Symptoms include fresh feeding holes, elongated feeding scars and irregular damage on emerging leaves. A characteristic indication of infestation is the presence of frass or faecal pellets inside the whorl, confirming active larval feeding.

3. Mid and Late Whorl Stage: During the mid and late whorl stages, larger larvae cause extensive feeding damage to developing leaves within the whorl. When the damaged leaves unfold, they appear ragged, shredded and irregularly perforated. Severe infestation may result in substantial defoliation, with large quantities of frass accumulating inside the whorl.

4. Tasseling and Silking Stage: During the reproductive phase, FAW larvae may move from the whorl to the tassels and silks, causing feeding injury to these structures. Damage at this stage can affect normal reproductive development, particularly when infestation is severe.

5. Cob Development Stage: Larvae may feed directly on the developing ear or cob and kernels, causing visible injury to the reproductive parts. Such direct damage can reduce marketable yield and may also expose the damaged tissues to secondary infections.



Economic Threshold Level (ETL)

The Economic Threshold Level (ETL) provides a practical benchmark for determining when pest incidence has reached a level at which management intervention is justified to prevent further economic loss. Therefore, farmers should regularly scout maize fields and assess the extent of fresh damage, particularly in the whorl and reproductive stages, and initiate appropriate management measures when the recommended threshold level is reached.

Crop stage	ETL
Seedling to early whorl (3–4 weeks after emergence)	5% plants damaged
Mid-whorl (5–7 weeks after emergence)	10% freshly damaged whorls
Late-whorl (5–7 weeks after emergence)	20% whorl damage
Fruiting/reproductive parts	10% infested fruiting parts or 1 egg or 1 larva/plant

Integrated Management of Fall Armyworm

Preventive Measures and Cultural Management

1. Timely and uniform sowing – Follow the recommended sowing period and avoid delayed or staggered sowing to minimize prolonged availability of maize.

2. Deep summer ploughing – Undertake deep ploughing before sowing to expose FAW pupae in the soil to sunlight, predators and adverse environmental conditions.

3. Crop rotation and intercropping – Avoid continuous maize cultivation and adopt crop rotation with non-host crops and suitable pulse intercrops such as redgram, blackgram and greengram.

4. Border/trap crops – Establish three rows of cowpea, gingelly, redgram or sunflower in garden land and fodder sorghum in dryland around maize fields.

5. Field sanitation – Remove volunteer maize plants, crop residues and severely infested plants wherever feasible to reduce alternate host availability and pest carry-over.

6. Balanced crop management – Maintain healthy crop growth through recommended spacing, irrigation and nutrient management to improve the crop's ability to withstand pest damage.

7. Regular field scouting – Begin surveillance soon after crop emergence and continue throughout the crop period, particularly during the seedling and whorl stages.

8. Pheromone traps – FAW-specific pheromone traps @ 12 traps/ha for monitoring adult male activity and early warning.

Mechanical Management

Mechanical management is particularly effective when fall armyworm infestation is detected at an early stage or remains localized. Egg masses and young larvae should be regularly hand-picked and destroyed, while dry sand or ash may be applied into infested maize whorls soon after FAW incidence is observed. During the first 30 days after sowing, sand mixed with lime in a 9:1 ratio can also be applied into affected whorls. Bird perches @ 10/acre may be installed during

the early crop stage, up to 30 days, to encourage natural predation. These measures, combined with regular field scouting, help suppress FAW populations at the early stage and reduce the need for chemical intervention.

Biological Management

1. Neem-Based Management: Neem-based formulations Azadirachtin 1500 ppm @ 2.5 L/ha, 5% NSKE and neem formulations @ 4 ml/L at 15–20 days after emergence (DAE) for early infestation. Neem-based treatments should be incorporated with regular scouting and other IPDM practices for effective suppression of young larvae.

2. Entomopathogenic fungi: The entomopathogenic fungus *Metarhizium anisopliae* is an effective biological control agent for managing fall armyworm, particularly during the late-whorl stage (35–40 DAE). It can be applied at 2.5 kg/ha to suppress larval populations and reduce pest pressure.

3. Conservation of Natural Enemies: Conservation of naturally occurring predators and parasitoids is an important component of sustainable fall armyworm management. Predators such as earwigs, ground beetles, ladybird beetles, flower bugs, spiders and ants feed on different stages of FAW and contribute to its natural suppression. Important parasitoids associated with FAW include Trichogramma spp., which parasitize FAW eggs, and other parasitoid wasps and flies that attack larval stages.

Chemical Management

Chemical management of fall armyworm should be adopted only when infestation reaches the locally recommended action threshold and should be integrated with cultural, mechanical, biological and botanical measures rather than used routinely. During the early-whorl stage (15–20 DAE), chemicals such as chlorantraniliprole 18.5 SC @ 200 ml/ha or flubendiamide 480 SC @ 250 ml/ha. During the late-whorl stage (35–40 DAE), emamectin benzoate 5 SG @ 200 g/ha, novaluron 10 EC @ 750 ml/ha or spinetoram 11.7 SC @ 250 ml/ha may recommended. At cob formation, further insecticide application should be considered only when necessary, and repetition of the same insecticide should be avoided.

Insecticide Resistance: A Major Challenge

Fall armyworm has a high potential to develop insecticide resistance because of its rapid reproduction, high mobility and repeated exposure to insecticides. Insecticide Resistance Management (IRM) should therefore be an integral part of FAW management. Farmers should monitor the crop regularly and apply insecticides only when the recommended action threshold is reached, use the correct label dose and application method, and avoid unnecessary or repeated sprays. Most importantly, insecticides with different modes of action should be rotated rather than repeatedly using the same insecticide or chemical class. Chemical control should be integrated with cultural, mechanical, biological and botanical measures, while unnecessary use of broad-spectrum insecticides should be avoided to conserve natural enemies. These practices help delay resistance development, maintain the effectiveness of available insecticides and reduce unnecessary pesticide expenditure.

Conclusion

Fall armyworm has established itself as an important and recurring pest of maize in India, with its rapid spread since its first detection in 2018 demonstrating its ability to adapt and persist across maize-growing regions. The magnitude of the problem is evident from the 3.76 lakh hectares affected across 20 states during 2018–19, while FAO assessments have reported an average FAW-associated maize yield loss of 10.8% globally, with losses of 10–20% commonly reported in newly affected areas. Evidence from Tamil Nadu further demonstrates the economic value of integrated management, where maize under IPM recorded a benefit–cost ratio of 4.05 compared with 1.29 under non-IPM practices. These figures emphasize that sustainable FAW management should focus on regular surveillance and early detection, threshold-based intervention, preventive and cultural practices, mechanical control, biological and botanical measures, conservation of natural enemies, and judicious rotation of insecticides with different modes of action. An effective Integrated Pest and Disease Management (IPDM) approach can therefore reduce pest pressure and crop losses, conserve beneficial organisms, delay insecticide resistance, reduce unnecessary pesticide expenditure and ultimately contribute to stable maize productivity and improved farmer profitability.

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The Himalayan Diamond Flower: Nature's Living Glasshouse

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High above the tree line, where icy winds sweep across rocky-mountains and the sun's ultraviolet rays are exceptionally intense, grows one of the world's most extraordinary plants, ***Rheum nobile***, popularly known as the **Himalayan Diamond Flower**, **Noble Rhubarb**, or **Sikkim Rhubarb**, belonging to Polygonaceae which is native to the alpine Himalayas of Nepal, Bhutan, Tibet, Sikkim, and adjoining regions, this remarkable species flourishes at elevations between 4,000 and 4,800 metres, where only a few plants can survive.

At first glance, *Rheum nobile* appears unlike any ordinary herb. During flowering, it develops into a spectacular pagoda-shaped tower reaching up to two metres in height. Its most striking feature is a series of large, overlapping, pale golden translucent bracts that completely surround the flowering spike. When sunlight shines through these delicate structures, the plant glows like a **crystal lantern**, earning it the popular name **'Himalayan Diamond Flower.'**

However, this breathtaking appearance is not merely ornamental, it is an ingenious survival strategy evolved over thousands of years.



Nature's Own Greenhouse

Scientists often describe *Rheum nobile* as a "glasshouse plant." Its translucent bracts function like the glass panels of a greenhouse. They allow most visible sunlight to enter while blocking more than 95 % of harmful ultraviolet radiation. As sunlight passes through the bracts, warmth is trapped around the flowers, creating a protected microclimate that is considerably warmer than the surrounding alpine environment. This natural greenhouse safeguards delicate floral organs from freezing temperatures, intense UV radiation, rain and strong mountain winds, ensuring successful flowering and seed production. Recent studies have shown that these specialized bracts warm the reproductive organs while simultaneously acting as efficient UV filters.



The Science Behind the Glow

The secret behind this natural marvel lies in its unique anatomy and chemistry. Unlike ordinary green leaves, the bracts contain very little chlorophyll and have a simplified internal structure, allowing light to pass through them almost like frosted glass. Instead of investing heavily in photosynthesis, the plant fills these bracts with flavonoids particularly quercetin-derived compounds that absorb harmful ultraviolet radiation while permitting visible light to enter. This elegant balance protects the flowers without preventing them from receiving the light and warmth needed for development.

The translucent bracts of *Rheum nobile* are remarkably thin, measuring only **110–170 µm** in thickness. Unlike ordinary leaves, they lack the typical differentiation into palisade and spongy mesophyll tissues, enabling them to transmit most visible sunlight while effectively filtering harmful ultraviolet (UV) radiation. This unique structural adaptation protects the developing flowers and the apical meristem from the intense UV exposure encountered at high elevations.



The UV-filtering ability of the bracts is primarily attributed to a group of **quercetin-based flavonoids**, including **rutin (quercetin 3-*O*-rutinoside), guaijaverin (quercetin 3-*O*-arabinoside), hyperin (quercetin 3-*O*-galactoside), isoquercitrin (quercetin 3-*O*-glucoside),** and the rare **quercetin 3-*O*-[6″-(3-hydroxy-3-methylglutaroyl)-glucoside]**. In addition, smaller amounts of **quercetin 7-*O*-glycoside, free quercetin, kaempferol glycosides,** and **feruloyl esters** further contribute to UV protection. Together, these compounds function as a natural sunscreen, allowing sufficient visible light to reach the reproductive organs while minimizing cellular damage caused by ultraviolet radiation.

Modern multi-omics research has revealed that the bracts exhibit reduced photosynthetic activity but enhanced flavonoid production, highlighting their specialization for protection rather than food production.

A Masterpiece of Alpine Evolution

The survival of *Rheum nobile* is supported not only by its remarkable structure but also by its genetics. Recent genome studies have shown that the species possesses expanded gene families associated with DNA repair, cold tolerance, UV protection and stress resistance. Its overwintering roots accumulate protective proteins and metabolites that help the plant endure freezing Himalayan winters. These discoveries demonstrate how evolution has equipped this species with multiple layers of defence, enabling it to thrive where environmental conditions are among the harshest on Earth.



More Than a Beautiful Plant

Despite its scientific importance, *Rheum nobile* also has value for local Himalayan communities. The thick stems possess a pleasantly sour taste and are traditionally eaten, while the hollow stem contains clear drinking water that can provide refreshment during mountain journeys. Such traditional knowledge reflects the close relationship between people and the unique alpine flora of the Himalayas.

Separating Fact from Fiction

Images of the Himalayan Diamond Flower frequently circulate on social media, often accompanied by sensational claims that it blooms only once every 400 years. These stories are entirely false. *Rheum nobile* flowers every year during **June and July**, although each individual plant flowers only once before completing its life cycle. Its rarity arises from its restricted high-altitude habitat rather than any mythical flowering cycle.

A Living Wonder of the Himalayas

The Himalayan Diamond Flower perfectly illustrates how evolution transforms adversity into beauty. Its glowing translucent bracts, greenhouse-like architecture, remarkable chemical defences, and sophisticated genetic adaptations make *Rheum nobile*, one of the finest examples of plant survival under extreme environmental conditions. More than a botanical curiosity, it is a living testament to the ingenuity of nature a crystal tower that silently endures freezing winds, brilliant sunlight and the challenges of life on the roof of the world.



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Microgreens – A New Generation of Superfoods

Article ID: 74602

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Introduction

Microgreens are new generation smart food products whose popularity is increasing with time. Microgreens are tiny edible greens obtained from different kinds of vegetables, herbs, and plants. Microgreens are popularizing as new culinary ingredients. Microgreens have a higher content of vitamins, minerals, and many bioactive compounds and more nutritious than their mature plant parts. Microgreens do not require specific nutrients for growth and can be grown throughout the year.

The lifestyle changes associated with the improved standard of living in terms of social, economic, and cultural standards have led to the major lifestyle associated problems including diseases and nutritional deficiencies. The non-availability of fresh and pesticide residue-free vegetables for consumption is a big problem in the future. The urban populations are mainly dependent on long food chains that begin in distant rural areas limits the availability of produce that has short shelf-life and poor shipping ability. As a result of that, many urban populations reside in areas classified as 'food deserts', where people do not have ready access to fresh agricultural products like fruits and vegetables and also lacking complete package of essential nutrients and depend mainly on processed and packaged foods. Increased health consciousness associated with lifestyle changes has created a vast demand for functional food globally.

Microgreens are considered 'practical nourishments' which are food items that have explicit wellbeing advancing and infection forestalling properties, that are extra to their typical healthy benefits. These are additionally named a decent wellspring of minerals in the human eating regimen. Microgreens are an arising class that can tackle practically all the medical conditions identified with wholesome lack. The culinary value of microgreens rose high in the past decades owing to its high nutrient content, versatility, flavor profile, and crisp texture imparted to the dish.

What are Microgreens?

Microgreens are young and tiny seedlings of vegetables and herbs, harvested when cotyledons (seed leaves) are fully expanded and the first pair of true leaves are emerging or partially expanded. The size of these microgreens is ranges from 1-3 inches (2.5–7.6 cm) in height which usually occurs within 7–14 days after germination, which varies from crop to crop and variety to variety and other environmental conditions. It has three basic parts; a central stem, two cotyledon leaves, and typically the first pair of very young true leaves. The commonly cultivated microgreens are spinach, Mustard, buckwheat, arugula, bull's blood beet, celery, cilantro, amaranth, golden pea, basil, spinach, mizuna, pepper cress, popcorn shoots, red mustard, red beet, red cabbage, red orach, sorrel, red sorrel, wasabi, cabbage, broccoli, radish, lettuce, kale, rapini, etc.

Microgreens are cut along with the stem and attached cotyledons/ seed leaves with the help of scissors. If left for a longer time, they will begin to rapidly elongate and lose color and flavor. It is different from sprouts in the sense that sprouts are the germinated seeds that are consumed with the embryonic root and the seeds. Microgreens are different from baby greens in their size and much smaller than baby greens. Their status remains in between sprouting and baby greens. It is also known as vegetable confetti.

Nutritional Composition Microgreens

Microgreens are richer sources of several micronutrients particularly vitamins and minerals. Microgreens are higher in nutritional content than their mature parts. The composition of vitamin A, C, E, K, enzymes, and carotenoid differs according to types of microgreens, growing medium, amount of sunlight and temperature, and the time of harvesting. Bright colored microgreens are found to be more nourishing than light ones. Microgreens have a higher content of a-carotene, ß-carotene, violaxanthin, lutein, and neoxanthin in comparison to sprouts. They have more protein, iron, and Zn content than sprouts. It is interesting to know that antinutritional factors like nitrate (NO_3^-) and nitrite (NO_2^-) content are also very low in microgreens.

	Microgreen common name	Nutrient composition (approx.)	Chemical compound	Days to harvest	Benefits
1	Wheatgrass	2mg Na, 431mg K, 71g carbs	Saponins, flavonoids	7-10	boosts immunity, cancer prevention
2	Radish	75mg Mg, 990mg K, 0.05mg Se	Carotenoids, Anthocyanin, niacin	8-10	Promotes Cellular repair
3	Broccoli	33mg Na,316mg k, 7g carb	Sulforaphane, glucosinolates	10-14	Promotes gut health
4	Beetroot	78mg Na, 325mg K, 10g carb	Betalains, carotenoids Ascorbic acid	10-20	Fights cancer, Controls blood sugar level
5	Amaranthus	2.75mg Ca, 2.9mg Mg	Lysine, niacin	8-12	Bone health and Blood clotting
6	sunflower	10 mg Na, 270mg K, 4g carb	Carotenoids, ascorbic Acid	8-9	Anti-inflamma tory
7	Cumin	168mg Na, 1788mg K	Cuminaldehyde	8-12	Promotes gut health and digestion

How to Grow Microgreens?

Microgreens can be grown in different mediums like soil, tissue paper, hydroponics, etc. But generally, a mixture of Coco-peat, vermiculite, and perlite can be used for growing microgreens in a 5:2:1 ratio respectively. The release of macro-and micronutrients present in this medium is very slow; hence, a farmer can reuse the same media several times for the growth of their young greens. Microgreens seeds generally do not require extra nutrition for germination but require only ideal conditions (environmental and proper water moisture conditions for imbibition) for germination up to the microgreen stage which makes the production of microgreens easy and cost-effective. Treatment of seeds by various chemicals is also not suitable for farming of microgreens and the use of hybrid seeds may not be economical for you.

Sowing Time

Seeds can be sown around the year as per the consumer's requirement. During the reuse of previous sowing media, roots and other remaining parts of preceding crops should be completely removed from the trays/container. Dry the media properly by exposing it to sunlight and then fill the trays/container. Any living place like rooms or any type of mini-greenhouse can be used to keep your greens to maintain optimum temperature, humidity, and light intensity. Microgreens grown in an environment with high light conditions, low humidity and good air circulation will result in a better harvest.

Harvesting and Packaging

Microgreens can be harvested at 7–14 days after germination (tropical climate) and somewhat longer (14-28 days) in cold weather (temperate climate) that depends on the crop, and other environmental conditions. Microgreens along with the stem and attached seed leaves can be cut with the help of scissors. Microgreens have a short time span of usability and require better strategies for storage and transport. Business microgreens are frequently put away in plastic clamshell containers. Biodegradable clamshell containers are also available in the markets.



Benefits of Growing Microgreens as a Business

The benefits of integrating leafy greens and microgreens into their diet are gradually being understood by people worldwide, ensuring that demand continues to grow. And we are also seeing more and more problems and crop failure of vegetables grown outdoors, so there is an indoor future for agriculture.

Low start-up costs - Farmers may start their business with very low investment by simply supplying one restaurant with their greens or producing enough microgreens to sell at a farmer's market once a week and rising production according to customer demand.

Quick turnaround time - Microgreens from seed to harvest take around 7-14 days. A farmer doesn't have to wait for a whole season or more to harvest.

Year-round growing - Microgreens can be grown round the year and a farmer can use microgreens to earn extra money and diversify their business for more profit.

Higher nutrition - Microgreens are 'functional foods'. They are a complete pack of different vitamins and nutrients

High-value crop - A farmer can sell their microgreens to top restaurants and food stores to get higher prices and as a local producer they can also charge a premium for their microgreens.

Conclusion

Microgreens may be small in size, but they offer remarkable nutritional value and promising opportunities for healthy living and entrepreneurship. Their short production cycle, minimal space requirement and relatively simple cultivation practices make them suitable for farmers, urban households, women entrepreneurs, SHGs and FPOs. Beyond their nutritional benefits, microgreens can be incorporated into salads, sandwiches, soups, smoothies and other food products, adding colour, flavour and valuable nutrients to everyday meals.

With increasing awareness of healthy diets and functional foods, the demand for fresh and nutritious microgreens is expected to grow. By adopting good production practices, hygienic handling, attractive packaging and effective marketing, microgreens can become both a valuable addition to the diet and a viable small-scale enterprise. Thus, microgreens truly represent a promising combination of nutrition, sustainability and entrepreneurship proving that sometimes, the smallest greens can make the biggest difference.

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Biostimulants and Biofertilizers in Sustainable Vegetable Production

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Abstract

Biostimulants and biofertilizers: a promising method to improve production and sustainability of onion (Allium cepa L.) Biostimulants are non-nutrient chemicals or microorganisms that promote natural plant processes, enhancing nutrient absorption, stress tolerance or quality, irrespective of their nutritional content. Biofertilisers are live microorganisms (e.g. Azotobacter, Azospirillum, phosphate-solubilizing bacteria, mycorrhizae) which fix nitrogen or mobilise nutrients for the plant. The prominent biostimulants in onion include seaweed extracts, humic/fulvic acids, protein hydrolysates and helpful microorganisms (plant growth boosting rhizobacteria, mycorrhizal fungi). They are administered at important phases by seed or seedling inoculation, soil soaking, transplant dips or foliar sprays. e.g. seaweed 0.5–3% (v/v) sprays, humic ~50–75 kg/ha soil drench, amino acids 1–2 cm3/L foliar, product variety. Reported rates are broad, Biostimulant treatments usually enhance onion growth, production, and bulb quality. Foliar seaweed at 0.5% increased bulb weight, total soluble solids and NPK Protein hydrolysate sprays increased yield by ~15% Serendipita indica (endophytic fungus) + complete NPK increased yield ~16% above fertiliser alone Organic additions using microbial inoculants like Azotobacter have increased the yields and enhanced soil fertility. Biostimulants typically decrease chemical fertiliser use: e.g. 75% N with Azospirillum equalled full N control (literature). These products also boost nutrient absorption (N, P, K) and stress tolerance (e.g. salinity tolerance with Pseudomonas+mycorrhizae, and may increase post-harvest bulb dry matter and storability (qualitative findings). But it varies with cultivar, soil and climate, and there are advantages. Active research ongoing on integration of biostimulants with nutrition management (e.g. biostimulants plus decreased NPK). This study analyses the state-of-the-art information on the definitions, methods and practical usage of biostimulants and biofertilisers in onion production based on recent peer-reviewed research. The tables compare the kinds of biostimulants, application techniques and effects on yield. A typical biostimulant program during an onion season is shown in a mermaid flowchart. Finally, gaps and research requirements (e.g., standardised dose, long-term studies) are identified.

Biostimulants vs Biofertilisers: Definitions and Distinctions

Biostimulants are often characterised as chemicals or microorganisms that stimulate plant processes to enhance nutrient absorption, usage efficiency, stress tolerance and/or crop quality, independently of supplying nutrients (du Jardin, 2015). According to this definition, humic acids, seaweed extracts, protein hydrolysates, plant oils, chitosan and even certain helpful bacteria are biostimulants. They frequently work by stimulating root development, photosynthesis or by activating physiological pathways (hormone-like actions, antioxidants). Crucially, biostimulants do not substitute nutrients but may enhance nutrient availability or efficiency.

Biofertilizers are live, microbial inoculants that are applied to seeds, soil or plant surfaces to boost the nutrient availability. Typical examples include nitrogen fixing bacteria (e.g. Azotobacter, Azospirillum), mycorrhizal fungi (e.g. Glomus mosseae) and phosphate solubilising bacteria (e.g. Bacillus spp. These organisms are known to enhance soil fertility by fixing atmospheric N, solubilising soil P, mobilising K/Mg or generating growth hormones . In fact, all biofertilizers are biostimulants but not all biostimulants are biofertilizers. Seaweed extracts, for instance, are biostimulants (rich in hormones, osmoprotectants) not biofertilisers since they do not contain any active bacteria. In contrast, Azospirillum inoculant is a biofertiliser and a biostimulant (fixes N and creates phytohormones).

Modes of Action

Biostimulants and biofertilisers influence onion plants via multiple **physiological, biochemical and microbial** mechanisms:

1. Physiological effects: Many biostimulants act as plant hormones or stimulate plant hormone production. For example seaweed extracts include natural cytokinins, auxins and betaines which encourage cell division and root development. Protein hydrolysates provide amino acids and peptides that may function as signalling molecules, inducing root branching or transpiration efficiency. Humic compounds are able to affect the membrane permeability and cation exchange capacity of the root zone. These impacts improve root length, leaf area and general vigour.

2. Biochemical effects: Biostimulants often activate biochemical pathways associated with stress resistance. They may enhance antioxidant enzymes (SOD, CAT, peroxidase) and osmolytes (proline, glycine betaine) in response to dehydration or salt. Some strains of Pseudomonas spp. generating ACC deaminase have been shown to reduce ethylene levels in stressed plants and hence reduce salt damage [41]. Humic acids may chelate micronutrients (Fe, Zn) and enhance their absorption. Many of them include phenolics or vitamins that are antioxidants in plant tissues. Studies reveal enhanced

phenolic and flavonoid content in inoculation onions, greater chlorophyll levels and photosynthetic rates using biostimulant sprays.

3. Microbial interactions: Biofertiliser bacteria colonise the rhizosphere/roots. Nitrogen-fixers (eg Azotobacter, Rhizobium) fix N2 to forms accessible to plants, lowering need for inorganic N. Phosphate-solubilizing bacteria (Bacillus polymyxa, Pseudomonas, etc.) release organic acids or phosphatases that solubilise phosphorus bound in the soil, enhancing P absorption. AMF enhance root absorption with hyphal networks and greatly improve P (and micronutrient) uptake. Inoculation with Glomus mosseae improved P absorption and bulb output by ~ 14 % in onion. In addition, several rhizobacteria synthesise phytohormones (IAA, gibberellins) and siderophores that stimulate root development and disease resistance. So biofertiliser bacteria are live biostimulants, while artificial biostimulants (seaweed, humates) function via direct plant biochemical pathways.

Types and Examples of Biostimulants in Onion

Key biostimulant categories used in onion include:

1. Seaweed extracts (SWE) : Usually from brown algae (Ascophyllum nodosum, Ecklonia maxima, etc. Rich in cytokinins, auxins, betaines and minerals. In onions, ~0.5–3% SWE is often used as foliar spray. For example, foliar spray with 0.5% extract of Ascophyllum considerably enhanced the bulb production, leaf length and nutritional content (N, P, K). Sometimes higher rates (e.g. 3%) increased bulb ascorbic acid, but with no effect to yield. Studies have most consistently shown that modest amounts of SWE (0.5–1%) boost the development and total soluble solids of onions.

2. Humic and fulvic acids – Organic molecules from peat, leonardite or compost Usually applied to soil (drench) or as a foliar (liquid). They chelate nutrients and encourage root development. For example, humic acid soil drench of 50-75 kg/ha enhanced onion bulb weight, neck diameter and N absorption. Foliar humic sprays (eg 1000 mg/L applied 2–3 times) have also increased onion growth metrics (leaf number, bulb size). Fulvic acids (lower molecular weight) are more soluble and are typically employed in foliar sprays at 0.5 to 1% for fast mobilisation of nutrients. Several studies reported that several humic administrations (21, 35, and 45 days after transplant) maximised vegetative and yield growth.

3. Protein hydrolysates and amino acids: These are derived from animal or plant protein (e.g. legume or fish hydrolysates, yeast extracts) and offer amino acids, peptides and small proteins. Foliar sprays are used (1-2% or 1-2 cm3/L solutions), notably in nurseries or early development stages. Protein hydrolysates are organic nitrogen sources and bioregulators. Onions : Vegetal protein hydrolysate treatment raised marketable production by ~15.5% and bulb antioxidant content . Some investigations also indicate that such biostimulants help increase bulb stiffness and shelf-life. A recent research demonstrated the maximum onion yields in sandy soil with amino-acid foliar at 2 cm3/L and soil drench of humic (75 kg/ha).

4. Seaweed vs. Protein (case study): An Italian research sprayed typical storage onions with a protein hydrolysate or microalgae (Spirulina) and saw production increases of 15.5% and 12.4%, respectively, compared to untreated plants. Both treatments also increased the antioxidants in bulbs. Thus, diverse organic biostimulants (non-microbial) may also increase yield equally.

5. Plant Growth-Promoting Rhizobacteria (PGPR): Beneficial soil bacteria (e.g. Bacillus subtilis, B. megaterium, Pseudomonas fluorescens, Azotobacter chroococcum, Azospirillum brasilense. They may be used as seed coatings, soil inoculants or root dips for transplants. They improve the availability of nitrogen, solubilise phosphates, generate phytohormones and promote systemic tolerance . For instance, onion shoot height, bulb weight and yield (up to ~66 t ha−1) were considerably improved by Azotobacter inoculation (with organic compost) over fertiliser alone. PGPR treated onions frequently exhibited increased leaf chlorophyll and NPK content.

6. Mycorrhizal fungus: Onion roots create symbiotic connections with arbuscular mycorrhizal fungus (AMF) such as Glomus mosseae. Usually applied by combining inoculum with soil or dipping seedlings (average rate ~60 kg/ha @ 250 spores/g). AMF boost P absorption (particularly in P-deficient soils) and enhance resistance to drought/salinity significantly. In one research, inoculation of onion with G. mosseae increased bulb output by ~14.4% and bulb diameter by ~40.8% compared with controls. Inoculation with combined AMF and PGPR usually results in additive advantages.

7. Nitrogen fixing inoculants: Apart from the aforesaid Azotobacter, seed may be infected with legume-rhizobia (though onion is non-legume, thus less frequent), Azospirillum and associative N-fixers. These are commonly combined in trials with decreased fertiliser e.g. 75% recommended N + Azotobacter obtained equivalent yield to 100% N treatments (literature reports).

8. Phosphate-solubilizing bacteria (PSB): Microbes (e.g. Bacillus polymyxa, Paenibacillus) that liberate phosphorus. Field experiments with onions inoculated with a PSB consortium (with full fertiliser) showed enhanced P absorption and yield, with a small rise in yield (7–9% when combined with 100% NPK). Only PSB alone can have a moderate influence unless P is restricting.

Table 1 compares key biostimulant categories for onion:

Biostimulant Type	Source/Example	Key Components/Function	Example Onion Effect
Seaweed Extracts	Brown algae (Ascophyllum, Ecklonia etc)	Hormones (auxins, cytokinins), minerals, betaines	+Bulb weight, yield, TSS; increased leaf length
Humic/Fulvic Acids	Leonardite, compost-derived humates	Chelation of nutrients; root growth promotion	+Leaf no., bulb diameter, NPK uptake
Protein Hydrolysates	Plant/animal protein sources (soy, fish)	Amino acids, peptides; organic N	+Yield (+15.5%), antioxidants
PGPR (N-fixers)	*Azotobacter*, *Azospirillum*	Atmospheric N fixation; hormone production	+Plant height, bulb weight; replaced ~20-25% N
PGPR (PSB)	*Bacillus*, *Paenibacillus* spp.	P-solubilization via acids/enzymes	+P uptake; +yield (~7–9% with full NPK)
Mycorrhizae (AMF)	*Glomus mosseae*, *Gigaspora* spp.	Extended root network; P, micronutrient uptake	+Yield (+14.4%), bulb size
Others (PGPB)	*Bacillus subtilis*, *Pseudomonas fluorescens*	Hormones, ACC-deaminase, siderophores	+Stress tolerance; growth (e.g. salinity resilience

Application Methods and Timing

Biostimulants can be applied at various crop stages for maximum effect (see flowchart below). Common methods:

1. Seed/seedling treatment: At planting, seeds or transplants are typically coated or soaked with microbial inoculants (PGPR, AMF). Seedlings of onion may be dipped into rhizobacterial or mycorrhizal solutions before transplanting for early root colonisation. Some rhizobacteria formulations (Azotobacter, Bacillus) are recommended for seed slurry application.

2. Soil application (drench or dissemination): Many biostimulants are applied by watering into the soil. Humic/fulvic acids Can be co-applied with soluble fertilisers (such NPK). In a field experiment humic acid was given at 50–75 kg/ha as a soil drench to increase vegetative growth and production. Onion biomass greatly increased with organic amendments (vermicompost, rabbit manure) + inoculant Azotobacter broadcast pre-plant. Biochar or compost tea (microbial broth) is also added to the soil.

3. Transplant dip: When transplanting onion seedlings may be dipped in suspensions of biostimulants (mycorrhizal inoculum, PGPR solution) to provide a boost to colonisation. For example, onion sets soaked in a mycorrhizal spore slurry increased root development and subsequent bulb production (typically done 24h before planting).

4. Foliar Spray: The most frequent foliar biostimulants for onions are seaweed extracts, protein hydrolysates, amino acids and humic solutions . These are sprayed on the leaves during vegetative and early bulbing phases. For instance, spraying seaweed extract 0.5% every 2–3 weeks during leaf development improved bulb weight. Foliar humic at 1000 mg/L applied thrice (days 21, 35, 45 after transplant) improved fresh weight and bulb size. Foliar protein/amino acid combinations (e.g. 1–2 cm3 L–1) are commonly given weekly to nurseries to encourage strong seedlings.

5. Scheduling: Applications are typically timed to critical growth phases. Common schedule:

- **a. Pre-sowing/Seeding:** Apply seed inoculants (biofertilisers) or prime seeds.
- **b. Early growth (2-3 leaf stage):** First foliar spray of seaweed or humic.
- **c. Mid vegetative:** Additional foliar sprays (seaweed, protein) every 2–3 weeks. Soil drench of humic at least once.
- **d. Bulb initiation:** Final foliar applications (to enhance bulb set) with low-rate seaweed or micronutrients.
- **e. Pre-harvest:** Occasionally, amino-acid sprays may be used to boost sugar content.

Doses and Rates

Reported application rates vary widely with formulation and local practices:

1. Seaweed extracts: Often 0.5–3% (v/v) solutions. In one study, 0.5% gave optimal yield responses while 3% mainly boosted ascorbic acid. Other reports suggest 2–5 L/ha (liquid extract) or 2–3 kg/ha (powder) every 15–21 days.

2. Humic/fulvic acids: Foliar: 0.5–2 g/L (0.05–0.2%) or 500–1000 mg/L. Soil drench: 50–150 kg/ha. In, 50 kg/fed (≈120 kg/ha) and 75 kg/fed had the strongest effects.

3. Protein hydrolysates: 0.5–2% foliar sprays. For liquid products, 1–2 cm^3/L or 1–2% dilution is common. Concentrated amino acid packets used at ~50–100 mL per 10 L water.

4. PGPR and biofertilisers: Typically applied at ~10^8–10^9 CFU per seed or per plant. Seed/soil inoculant granules (3–5 g per kg seed). For composts/vermicompost: 10–20 t/ha. *Azotobacter* is sometimes applied at ~100 g (10^8 cells/g) per 10 kg seed. Rates are often experimental; e.g. one trial used 50 kg/ha rabbit manure + Azotobacter.

5. Mycorrhizae: Field rate ~60 kg/ha of inoculum (containing ~250 spores/g). For transplant dip, a small pinch per seedling tray suffices.

Effects on Onion Growth, Yield and Quality

Numerous studies report positive growth and yield responses from biostimulant use in onion. Key findings include:

1. Vegetative growth: Biostimulants often enhance leaf quantity, length and biomass. For example, humic acid soil drenching (75 kg/fed) resulted in maximum plant height, leaf area and fresh weight. Foliar seaweed and protein sprays usually make the leaves greener and thicker. Microbial inoculants usually result in higher plants with more leaves (e.g. Azotobacter with manure generated the tallest plants in one study.

2. Yield of bulb: Biostimulant treatments have shown yield improvements ranging from 10–50% over controls. In two-year studies, application of a PGPR consortia to seedlings enhanced total bulb output 23% above complete NPK control. ~15% yield increase with foliar protein or algae. Azotobacter + organic treatments generated yields of ~64-66 t/ha, quite a little more than the unfertilised plots. Serendipita indica dry matter yield was improved by ~11–16 % with fertiliser. A complete research using Azotobacter and Bacillus subtilis inoculants shown up to 80% greater yield (34.7 versus 17.6 t/ha) compared to uninoculated controls.

3. Bulb quality: Many biostimulants increase quality parameters. Treatments with seaweed and humic typically increase total soluble solids (°Brix), sugar content and dry matter. For example, seaweed spray 0.5% greatly improved bulb °Brix and mineral content. (e.g. high-rate SWE enhanced vitamin C; Azotobacter increased bulb phenolics). enhanced ascorbic acid and phenolics levels were found. Biostimulants may help minimise the proportion of culls (bulbs that don't grow) by improving uniformity. One investigation found reductions in culls, with greater marketable yields and bigger average bulb size for seaweed treated onions. Some PGPR treatments have been demonstrated to boost onion pungency (THN – total pyruvic acid) - a quality attribute , however results vary . Earlier topping along with biostimulants inhibited sprouting of stored onions.

4. Nutrient absorption and soil fertility: An often seen result is increased nutrient acquisition. Foliar and soil biostimulants boost leaf N, P, K levels in onions (e.g. seaweed spray increased NPK in leaves) Microbial inoculants greatly enhanced nitrogen absorption: With S. indica with 100% fertiliser, N uptake in onion rose by 7–30% and P uptake by 14–22%. The organic + Azotobacter treatments enhanced soil organic matter and microbial activity, indicating long-term soil benefits. Some results imply partial replacement of fertiliser: for example, yields of full NPK were maintained when 50-75% of conventional NPK was mixed with biofertilisers.

5. Abiotic stress tolerance: Biostimulants may reduce drought, salinity or temperature stress in onions. At high salinity (4000 ppm NaCl), dual inoculation with Pseudomonas putida and Glomus mycorrhizae greatly protected onions under salt stress, and boosted bulb production 83% over non-treated. Moderate salinity (2000 ppm) increased the yield by 36%. These treatments retained chlorophyll, reduced oxidative damage and increased osmolytes. In greenhouse studies, foliar humic sprays have also been shown to maintain leaf turgor and yield and increase resistance of onion to water deficiency (not noted here). However, more field data are required. The tendency is that biostimulants enhance physiological tolerance (e.g. greater RWC, antioxidant enzyme activity) under stress.

6. Postharvest life: Little data is available on storage life. Higher bulb dry matter (vigorous growth) is often associated with extended shelf-life. One research (not onion specific) indicated that biostimulant treated bulbs had reduced sprouting and weight loss during storage. Anecdotal studies show that treatment with seaweed or amino acids may somewhat improve the shelf life of onions, perhaps by increasing the levels of sugars and phenolic antioxidants. This is a gap in onion research.

Table 2 below summarizes typical application methods and stages for various biostimulants:

Method	Applied Biostimulant	Timing
Seed treatment	Rhizobacteria (e.g. *Azotobacter* sp.), mycorrhizae, humic liquids	Pre-sowing or seedling transplanting
Soil drench/broadcast	Humic/fulvic acid, biofertilizer granules (N-fixers, composts)	At planting, early vegetative stage
Transplant dip	Mycorrhizae, *Bacillus* sp.	At transplanting (seedling stage)
Foliar spray	Seaweed extract, amino acids, humic acid, protein hydrolysates	During leaf growth (every 2–3 weeks) and early bulbing
Repeated sprays	(as above)	Typically 2–4 times across season

Interaction with Fertilizer Regimes and INM

Biostimulants are commonly used in conjunction with chemical fertilisers, or to partly replace them. Reduced NPK rates together with bio-inoculants is an integrated nutrient management (INM) method. For example, field testing indicated that Azotobacter added to 75% prescribed N yielded onion yields on par with 100% N controls (thus saving 25% fertiliser). The rhizobacteria + organic experiment using Azotobacter and 50% rabbit dung out-performed the entire synthetic

control, indicating synergy. Similarly, the S. indica and PSB research showed that 100% NPK + biostimulant was better than 100% NPK alone. These findings suggest biostimulants may be used to reduce fertiliser input without yield loss, leading to lower costs and less leaching. However, several studies indicate little advantage from biostimulants provided appropriate base NPK is available — showing they boost efficiency rather than replacing macronutrients totally. The optimum approach, then, is to use them in combination with balanced fertilisation and progressively reduce NPK as the data allow.

Environmental and Economic Considerations

Biostimulants and biofertilizers usually have positive environmental effects: they lessen the use of chemicals (and hence N 2 O emissions and P runoff) and they increase the health of the soil (more organic matter and microbial diversity). They are typically safe and they break down. Economically, biostimulant chemicals may be expensive to buy but production increases and savings in fertiliser may outweigh the expense. For example, a $100/ha biostimulant may provide a lucrative 15-20% yield increase on high-value onion. Microbial inoculants are inexpensive (typically $10-$20/ha). A simple cost–benefit analysis: seaweed spray adds $300–500 value/ha (by yield), at $50 application cost, positive ROI. But outcomes might vary by area, so farmers should do tiny plots initially. Another factor is product quality: almost 50% of commercial biostimulants do not work. Choosing established formulas and following label rates is a must.

Knowledge Gaps and Research Recommendations

Despite promising results, several knowledge gaps remain:

1. Standardisation: Biostimulants are complicated. More investigation is required to characterise the active elements and appropriate doses for onion in particular. Studies now employ various items at varying rates, making comparisons difficult.

2. Cultivar and Environment: The responses may depend on the cultivar, the soil type and the climate. Few experiments represent the range of growth conditions. Efficacy has to be confirmed in multi-location, multi-year studies.

3. Mechanisms in Onion: While broad modalities are recognised, the exact physiological changes in onion (e.g. gene expression, hormonal shifts) induced by each biostimulant are little described.

4. Application Best Practices: Adjusting for precise timing and combinations (e.g., which biostimulant works with which fertilisation plan). Evidence for trials on “stacking” many biostimulants (e.g. seaweed + PGPR) is minimal.

5. Economic analysis: There are very few farm-scale cost-benefit evaluations for onions in the real world. Future research should incorporate economic measures (improvement in yield per dollar input).

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Farmer Producer Organisations as Agribusiness Enterprises: From Collectives to Companies

Article ID: 74604

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Abstract
More than 86% of India's farm holdings are small or marginal. Individually, these farmers buy inputs at retail prices, sell small surpluses to local traders at low prices and lack access to credit, technology and modern markets. Farmer Producer Organisations (FPOs) are designed to overcome these disadvantages by bringing farmers together into member-owned business enterprises that can achieve economies of scale and bargaining power. This article examines FPOs through an agribusiness management lens. It explains the concept and legal forms of FPOs, especially the producer company, and describes their governance and organisational structure. It reviews the policy push behind FPOs, including the Central Sector Scheme for Formation and Promotion of 10,000 FPOs launched in 2020, which reached its target in 2025 with about 30 lakh farmers, around 40% of them women. The article sets out the main business models and revenue streams of FPOs, illustrates how collective action can raise farmers' net returns, and discusses financial viability indicators, a SWOT analysis and the persistent challenges of capital, professional management, market linkages and member loyalty. It concludes with strategies for transforming FPOs from scheme-driven collectives into sustainable, market-oriented agribusiness enterprises.

Keywords: Farmer Producer Organisation, producer company, collective action, agribusiness management, value chain, business model, small farmers.

What is an FPO?
A Farmer Producer Organisation is a legal entity formed by primary producers, such as farmers, milk producers, fishers, weavers or artisans, to undertake business activities related to their produce. The members are shareholders and share in profits. The FPO concept builds on India's long cooperative tradition, but adds a corporate structure designed to give greater autonomy from government and more professional management.

Legal Forms

Legal form	Governing law	Key features
Producer company	Companies Act, 2013 (Part XXIA; originally Companies Act, 1956, Part IXA introduced in 2002 following the Y. K. Alagh Committee)	Only producers can be members; one member one vote; limited liability; shares not publicly traded; profits shared as patronage bonus
Cooperative society	State Cooperative Societies Acts; Multi-State Cooperative Societies Act, 2002	Long tradition (e.g., Amul); greater state oversight in some states
Self-reliant / mutually aided cooperative	MACS Acts in some states (e.g., Andhra Pradesh, Telangana)	More autonomy than traditional cooperatives
Society or trust	Societies Registration Act, 1860; Trust Acts	Mainly non-profit; limited for business activities

The **producer company** has become the preferred form for new FPOs because it combines cooperative principles (member ownership, democratic control) with the flexibility of a company (ease of doing business, raising finance, entering contracts).

Governance and Structure
Members are organised into **Farmer Interest Groups (FIGs)** at the village level. The **General Body** of all members elects a **Board of Directors** from among the farmers, which sets policy and appoints a professional **Chief Executive Officer (CEO)** and accountant to run daily operations. The FPO then provides business services such as input supply, aggregation and marketing, value addition, and custom hiring and advisory services.

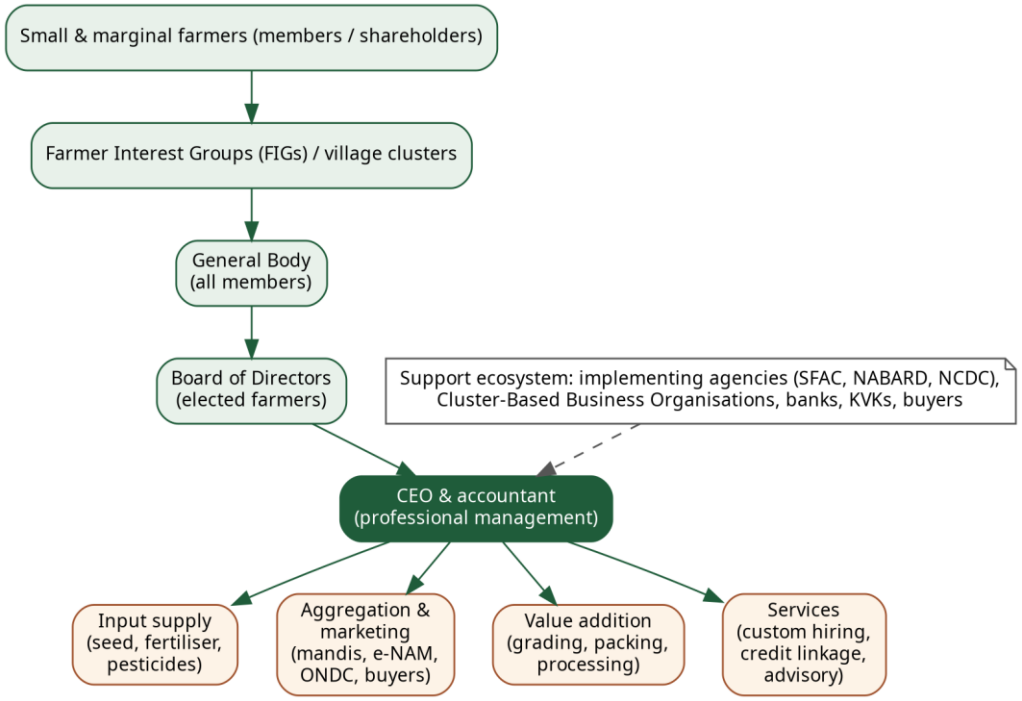


Figure 1: Typical organisational structure of an FPO and its business functions

Policy Push: 10,000 FPOs

FPO promotion began in earnest with the Small Farmers' Agribusiness Consortium (SFAC) pilot in 2011-12 and NABARD's Producers Organisation Development Fund. The biggest push came with the **Central Sector Scheme for Formation and Promotion of 10,000 FPOs**, launched on 29 February 2020 with a budget outlay of ₹6,865 crore up to 2027-28. The 10,000th FPO was registered in Khagaria district, Bihar, in February 2025.

Feature of the scheme	Provision / achievement
Budget outlay	₹6,865 crore (up to 2027-28)
Farmers mobilised	About 30 lakh, around 40% women
Management cost support	Up to ₹18 lakh per FPO over three years
Equity grant	Matching grant up to ₹2,000 per member, maximum ₹15 lakh per FPO; ₹254.4 crore released to 4,761 FPOs
Credit guarantee	Cover for project loans up to ₹2 crore per FPO; ₹453 crore guaranteed for 1,900 FPOs
Digital market linkage	About 5,000 FPOs onboarded on ONDC
Support structure	Implementing agencies (SFAC, NABARD, NCDC and others) and Cluster-Based Business Organisations (CBBOs) for handholding

(Source: Press Information Bureau, February 2025)

FPOs have also been allowed to obtain licences for selling seeds, fertilisers and pesticides, to operate as Common Service Centres, to trade on e-NAM and to run Pradhan Mantri Kisan Samridhi Kendras, opening new business lines.

Business Models of FPOs

As agribusinesses, FPOs must earn enough revenue to cover costs and reward members. Their business models fall into several types, often combined:

Business model	Activities	Revenue source	Example products
Input aggregation	Bulk purchase and sale of seed, fertiliser, pesticides, feed	Trading margin, dealer commission	All crops
Output aggregation and marketing	Collection, grading, bulk sale to mandis, processors, exporters, retail chains	Margin on sales, commission	Grains, pulses, vegetables, fruits
Value addition and processing	Cleaning, sorting, packing, milling, processing, branding	Value-added margin	Dal mill, flour, spices, honey, juices
Services	Custom hiring centre, cold storage, warehousing, soil testing, drone spraying	Rental and service fees	Machinery, storage

Contract and institutional sales	Agreements with companies, government procurement agencies	Assured volumes and prices	Seed production, procurement at MSP
Digital and direct-to-consumer	Sales via ONDC, e-commerce, farmers' markets	Retail margins	Organic produce, branded staples

The most successful FPOs usually start with **simple, low-risk activities** such as input supply, which generate regular cash flow and build member trust, before moving into riskier output marketing and processing.

How an FPO Raises Farmers' Returns

An FPO can increase a member's net return in several ways: a better selling price through bulk sales and access to wider markets; lower input costs through bulk purchase; premiums for graded and packed produce; and savings on transport and transaction costs. Against these, the FPO charges a small service fee or margin to cover its costs. Figure 2 illustrates this with hypothetical numbers.

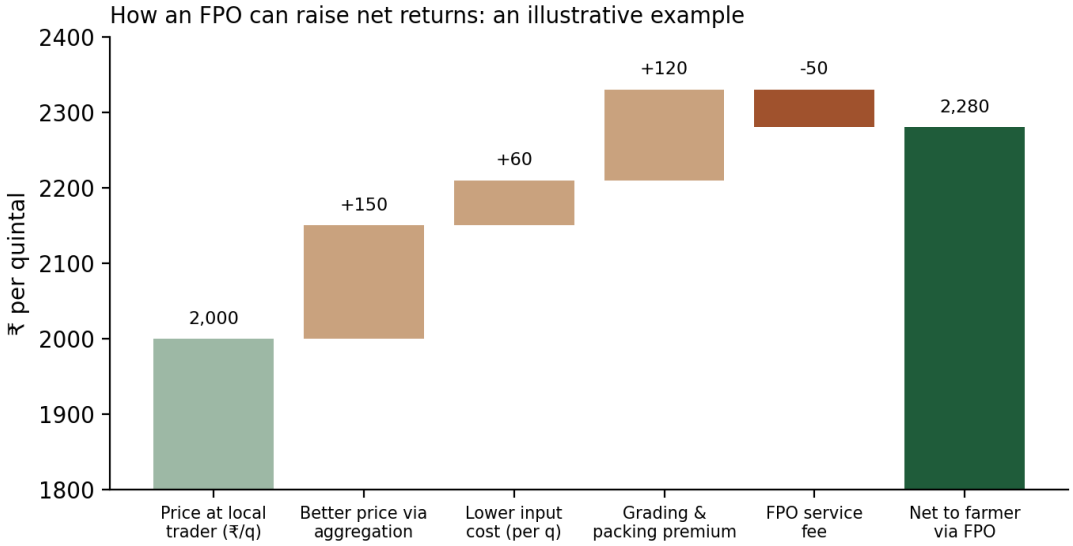


Figure 2: Illustrative breakdown of how FPO membership can raise a farmer's net return per quintal (hypothetical values)

In this example, a farmer who would receive ₹2,000 per quintal from a local trader receives a net ₹2,280 through the FPO, a gain of 14%. Field studies of well-functioning FPOs in India have reported gains of this kind, though results vary widely across organisations.

Managing an FPO as a Business

Like any enterprise, an FPO needs a **business plan**, **financial management** and **professional leadership**. Key financial indicators for assessing FPO viability include:

Indicator	Formula	What it shows	Desirable level
Current ratio	Current assets ÷ current liabilities	Short-term liquidity	Above 1.5
Debt-equity ratio	Total debt ÷ shareholders' equity	Financial leverage and risk	Below 2
Gross margin	(Sales − cost of goods sold) ÷ sales	Trading efficiency	Depends on business line
Net profit margin	Net profit ÷ sales	Overall profitability	Positive and rising
Asset turnover	Sales ÷ total assets	Efficiency in using assets	Higher is better
Member participation	Share of members transacting with the FPO	Member loyalty and business volume	Rising over time
Share capital per member	Paid-up capital ÷ members	Member commitment	Rising over time

(Benchmarks are general guidelines; appropriate levels vary by business type.)

Beyond finances, management functions include **procurement planning** (knowing when and how much members will supply), **market intelligence** (tracking prices and buyers), **quality control**, **logistics**, and **compliance** with company law, GST and licensing requirements. Many FPOs struggle because the CEO's salary is supported for only three years under the scheme, after which the FPO must pay from its own revenue.

SWOT Analysis of FPOs

Strengths	Weaknesses
Economies of scale in buying and selling	Small share capital and weak balance sheets
Bargaining power with traders and companies	Shortage of professional managers
Member ownership and local knowledge	Low member loyalty; side-selling to traders
Strong policy and institutional support	Dependence on grants and promoting agencies
Opportunities	**Threats**
Rising demand for traceable, organic and processed foods	Competition from established traders and companies
Digital platforms: e-NAM, ONDC, e-commerce	Price volatility and market risk
Linkages with exporters, retail chains, food processors	Climate shocks affecting supply
Government procurement and institutional buyers	Elite capture and governance failures

Key Challenges

1. Capital constraints. With small share capital and few assets, FPOs find it hard to obtain bank credit. Collateral requirements and lack of credit history limit borrowing, despite the credit guarantee scheme.

2. Professional management. Attracting and retaining competent CEOs and accountants in rural areas is difficult and costly.

3. Market linkages. Many FPOs remain input sellers and struggle to find reliable buyers for members' output at better prices.

4. Member loyalty and side-selling. When traders offer slightly better prices or immediate cash, members may sell outside the FPO, undermining its business volume and contracts.

5. Infrastructure. Lack of storage, grading and processing facilities limits value addition.

6. Governance. Weak board capacity, low member participation and elite capture can harm transparency and trust.

7. Scheme dependence. FPOs formed mainly to meet targets, without a viable business plan, risk becoming dormant when support ends.

Lessons from Successful FPOs

India has notable success stories. **Sahyadri Farms** in Nashik, Maharashtra, grew from a small group of grape growers into one of India's largest fruit and vegetable value chain companies owned by farmers, with export-quality packhouses and processing. Dairy cooperatives such as **Amul** show how collective processing and branding can transform smallholder incomes. Common factors behind such successes include:

1. A **focused commodity** with a clear market opportunity.
2. **Strong, committed leadership** and professional management.
3. **Gradual growth**, from simple services to complex value chains.
4. **Investment in quality and infrastructure** that adds value buyers will pay for.
5. **Transparent governance** and regular communication with members.
6. **Patient support** from promoting institutions and access to finance.

Strategies for the Way Forward

1. Business-plan-first approach: form FPOs around viable commodity clusters and market opportunities, not just numerical targets.

2. Federations and aggregation: link FPOs into state or commodity-level federations to achieve larger scale for processing, branding and exports.

3. Finance: expand working capital lines, warehouse receipt financing, blended finance and equity from impact investors.

4. Human capital: build a cadre of trained FPO managers through agricultural universities, management institutes and certification programmes.

5. Market access: strengthen links with e-NAM, ONDC, retail chains, exporters and public procurement.

6. Digital tools: use accounting software, member databases and traceability systems to improve efficiency and transparency.

7. Performance monitoring: rate FPOs on business, financial and governance indicators to guide support and investment.

Conclusion

FPOs represent India's most ambitious attempt to solve the problem of small scale in agriculture by organising farmers into member-owned businesses. With the 10,000 FPO target achieved and about 30 lakh farmers mobilised, the focus

must now shift from **formation to sustainability**. An FPO succeeds not because it is registered but because it runs a profitable business that members trust and use.

Seen through an agribusiness lens, the key ingredients are clear: a viable business model, professional management, adequate capital, reliable markets, sound governance and loyal members. FPOs that combine these can raise farmers' incomes, reduce costs, add value and connect smallholders to modern markets. For students of agribusiness management, FPOs offer a living laboratory where economics, management and rural development meet.

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GST and Indian Agriculture: Impacts on Farmers, Markets and Agribusiness

Article ID: 74605

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Abstract
The Goods and Services Tax (GST), introduced on 1 July 2017, replaced more than seventeen central and state indirect taxes with a single destination-based tax. Although most fresh agricultural produce is exempt, GST affects farmers every day through the tax on inputs such as tractors, pumps, irrigation equipment and agrochemicals, through the movement of produce across state borders, and through the taxation of processed food. This article explains the structure of GST and its treatment of farm produce, inputs and agricultural services. It highlights a key feature of the system for farmers: because their output is exempt and they are not registered, they cannot claim input tax credit, so GST paid on inputs becomes part of their cost of production. The article then reviews the "next-generation" GST reforms effective from 22 September 2025, which cut rates on tractors, farm machinery, drip and sprinkler systems, fertiliser raw materials and bio-pesticides to 5%. It also discusses the wider effects of GST on agricultural markets, including the removal of state border check-posts and the e-way bill system, and on agribusiness sectors such as food processing, dairy and fertilisers. Remaining challenges and policy suggestions, especially for farmer producer organisations, are outlined.

Keywords: Goods and Services Tax, input tax credit, farm inputs, agricultural marketing, agribusiness, inverted duty structure, GST 2.0.

Introduction
On 1 July 2017, India implemented its largest indirect tax reform since Independence: the **Goods and Services Tax (GST)**. Under the slogan "One Nation, One Tax, One Market", it merged more than 17 central and state levies, including excise duty, service tax, VAT, central sales tax, entry tax and octroi, into a single tax.

At first glance, GST seems to have little to do with farming, since most raw agricultural produce, such as fresh grain, fruits, vegetables, milk and seeds, is exempt. In reality, farmers encounter GST daily: when they buy a tractor, a pump, a drip system, a pesticide or fertiliser; when their produce crosses state borders; and when that produce is processed and sold in packets. The **"next-generation" GST reforms (often called GST 2.0)**, effective from 22 September 2025, cut tax rates on many agriculture-related goods and made this link even more important.

This article explains the structure of GST, how farm produce, inputs and services are taxed, what input tax credit means for farmers, and how GST has affected farmers, markets and agribusiness.

The Structure of GST
GST is a **destination-based, multi-stage consumption tax**. Tax is levied at each stage of production and distribution, but each registered business can deduct the tax paid on its purchases, so the burden ultimately falls on the final consumer. Revenue accrues to the state where consumption takes place. India adopted a **dual GST** model in which the Centre and the states levy tax simultaneously, as shown in Figure 1.

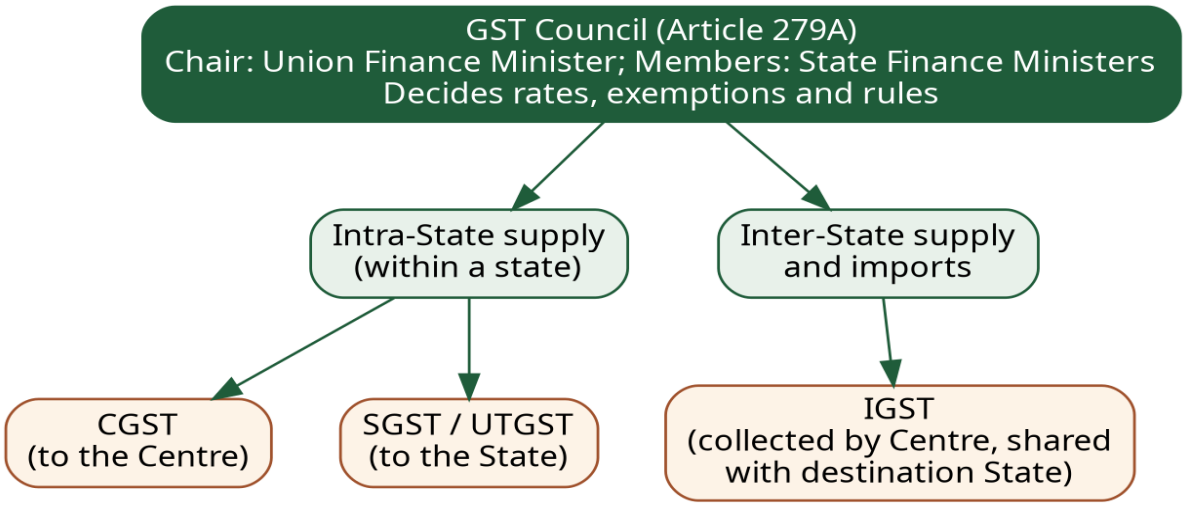


Figure 1: Structure of GST in India

The **GST Council**, created under Article 279A by the Constitution (101st Amendment) Act, 2016, is the apex body. It is a unique example of cooperative federalism, with the Centre and all states jointly deciding tax policy.

Rate Structure

At launch, GST had five main rates: 0%, 5%, 12%, 18% and 28%. Following the 56th meeting of the GST Council, the structure was simplified from 22 September 2025 into **two main rates of 5% and 18%**, with a special 40% rate for luxury and sin goods. Most essential and agriculture-related goods now fall in the 5% or nil category.

What Changed from the Pre-GST Regime?

Before 2017, a farm input such as a tractor bore central excise duty at the factory gate, central sales tax if sold across states, and state VAT at the point of sale, with entry tax or octroi in some states. Credit for taxes paid at earlier stages was only partly available, and taxes compounded along the chain. The comparison below summarises the main differences relevant to agriculture.

Feature	Pre-GST regime	GST regime
Number of indirect taxes	Many central and state levies	Single tax (CGST + SGST, or IGST)
Inter-state sales	Central Sales Tax, no credit	IGST with full credit
Movement of goods	Border check-posts, entry tax, octroi	E-way bill, no state border check-posts
Tax on farm machinery	Excise + VAT, varying by state	Uniform national rate (5% since Sep 2025)
Tax on fresh produce	Generally exempt under state VAT	Exempt
Rate setting	Separate decisions by Centre and each state	Joint decisions in the GST Council

The most important gain for agriculture was not a lower tax on produce, which was already largely exempt, but the creation of uniform rates and the removal of barriers to inter-state movement of goods.

How is Agriculture Taxed?

It helps to divide agriculture-related items into three groups: (1) the farmer's produce, (2) the inputs the farmer buys, and (3) agriculture-related services.

1. Farm produce: Most **fresh, unprocessed farm produce is exempt** from GST, including fresh fruits and vegetables, loose cereals and pulses, fresh milk, eggs, seeds and live animals. In addition, an **agriculturist is not required to register under GST for supplying produce from their own cultivation**, whatever the turnover.

Once produce is processed, packaged or branded, tax may apply. For example, loose rice or flour is exempt, but pre-packaged and labelled cereals attract 5% GST.

2. Farm inputs: This is where GST affects farmers most directly. The September 2025 reforms cut rates on several key inputs:

Input / item	Earlier rate	Rate from 22 Sep 2025
Tractors (below 1800 cc)	12%	5%
Tractor tyres, tubes, hydraulic pumps and other parts	18%	5%
Drip irrigation, sprinklers, harvesting and threshing machinery	12%	5%
Diesel engines above 15 HP, composting machines	12%	5%
Fertiliser raw materials: ammonia, sulphuric acid, nitric acid	18%	5%
Bio-pesticides and micronutrients (12 types)	12%	5%
Solar-powered devices	12%	5%
Milk cans (steel/aluminium)	12%	5%
Butter, ghee	12%	5%
Prepared / preserved fruits, vegetables, nuts and fish	12%	5%

(Source: Press Information Bureau, September 2025)

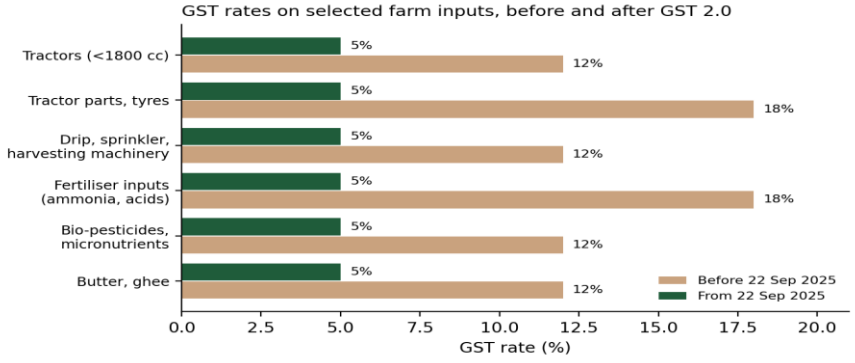


Figure 2: GST rates on selected farm inputs before and after the September 2025 reform

Government estimates suggest savings of about ₹41,000 on a 35 HP tractor, ₹53,000 on a 50 HP tractor and up to ₹1,87,500 on a combine harvester. This makes mechanisation more affordable for small farmers and custom hiring centres.

3. Agricultural services: Many services directly related to agriculture are exempt, including cultivation operations (ploughing, sowing, harvesting), renting of agricultural machinery with or without operators, storage and warehousing of agricultural produce, services of agricultural produce marketing committees (APMCs), transport of farm produce by road or rail, and veterinary services. This keeps custom hiring, cold storage and warehousing services from becoming costlier for farmers.

Input Tax Credit and the Farmer's Hidden Cost

The central feature of GST is the **input tax credit (ITC)**. A registered business can subtract the GST paid on its purchases from the GST due on its sales, which removes the cascading "tax on tax" of earlier regimes.

For farmers, however, there is a paradox. Because raw produce is exempt and farmers are not registered, **they cannot claim credit for the GST paid on their inputs**. The tax on a tractor, pump or pesticide becomes part of their cost of production.

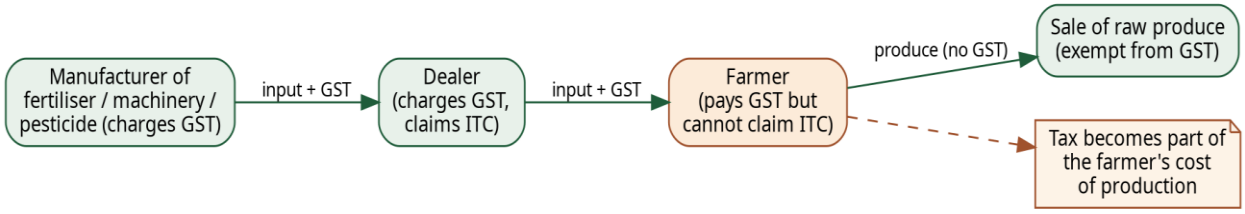


Figure 3: Position of the farmer in the input tax credit chain

A simple example illustrates the point:

Item	Food processing unit (registered)	Farmer (unregistered, exempt output)
Price of machine (before tax)	₹1,00,000	₹1,00,000
GST paid at 18%	₹18,000	₹18,000
Can claim ITC?	Yes	No
Effective cost	₹1,00,000	₹1,18,000
Effective cost if rate is 5%	₹1,00,000	₹1,05,000

(Hypothetical example for illustration.)

This is why low GST rates on farm inputs matter so much. For a farmer, every percentage point of GST cut is a direct cut in production cost. Economists have therefore argued either for very low rates on farm inputs or for mechanisms that let farmer producer organisations (FPOs) claim ITC.

An opportunity for FPOs. An FPO that registers under GST, buys inputs in bulk and sells processed or packaged products can claim ITC. By organising collectively, farmers can make better use of the GST system.

Effects on Agricultural Markets and Supply Chains

A major indirect benefit of GST has been progress towards an **integrated national market**.

1. End of check-posts. Before GST, trucks waited for hours at state border check-posts for entry tax and sales tax checks. Most such check-posts were dismantled after GST, and the **e-way bill** system tracks consignments online. Shorter transit times are especially valuable for perishables such as fruits, vegetables and milk.

2. Easier inter-state trade. Central sales tax previously made inter-state sales costly. IGST with ITC removed this barrier, making distant markets more viable for farm produce and supporting market integration.

3. Restructuring of warehousing and logistics. Firms once kept warehouses in every state to manage tax liabilities. They can now locate larger, modern warehouses based on cost and efficiency rather than tax.

4. Mandi fees remain separate. APMC market fees and commission agents' charges are not part of GST; they are levied under state agricultural marketing laws. The goal of "One Nation, One Market" is therefore not yet fully achieved for farm produce.

Effects on Agribusiness

Sector	Effect of GST
Food processing	5% rate on processed fruit, vegetable and fish products may raise demand and procurement of raw material from farmers
Dairy	Nil GST on UHT milk and paneer, 5% on butter and ghee, benefits cooperatives and private dairies
Farm machinery	5% rate on tractors and machinery expected to boost sales and rural demand

Fertilisers	Earlier 18% on raw materials vs 5% on finished fertilisers created an inverted duty structure that blocked ITC; the cut to 5% eases this
Unorganised traders	Compliance burden (returns, e-invoicing); composition scheme available for small traders
FPOs and agri-startups	Registration enables ITC and access to formal markets and institutional buyers

An **inverted duty structure** arises when inputs are taxed at a higher rate than the final product. Manufacturers accumulate unused ITC, which locks up working capital and raises costs. This was a long-standing issue in the fertiliser industry and was largely addressed by the 2025 reforms.

Challenges and Criticisms

1. High rates on chemical pesticides. Bio-pesticides now attract 5%, but most chemical pesticides remain in the 18% slab, adding to farm costs.

2. No ITC for farmers. As explained above, farmers cannot recover the tax paid on inputs.

3. Diesel and electricity outside GST. Petroleum products are not yet under GST, so diesel bears separate central and state taxes that affect irrigation and transport costs.

4. Compliance burden. Returns, e-way bills and e-invoicing are difficult for small agribusinesses, rural traders and FPOs.

5. Pass-through of rate cuts. It must be ensured that rate cuts reach farmers as lower prices rather than being absorbed into dealer or manufacturer margins.

Policy Suggestions

1. Extend the 5% rate to more farm inputs, including commonly used chemical pesticides, or create a mechanism for refunding GST on inputs to farmers through FPOs.

2. Provide simplified registration, filing and handholding support for FPOs so they can claim ITC and sell into formal value chains.

3. Monitor price pass-through of rate cuts on tractors, machinery and inputs through dealer-level price surveillance.

4. Complement GST with agricultural marketing reforms, such as rationalised mandi fees and wider e-NAM integration, to complete the national market for farm produce.

5. Consider bringing diesel under GST in a phased manner, with suitable compensation arrangements for states.

Conclusion

GST has affected Indian agriculture both directly and indirectly. Directly, by exempting most raw produce and agricultural services, it spared farmers additional tax and compliance burdens. Indirectly, by removing check-posts and simplifying inter-state trade, it laid the foundation for a more integrated national market for farm produce.

The September 2025 reforms are especially significant from the farmer's perspective. Cutting rates on tractors, machinery, irrigation equipment, bio-pesticides and fertiliser raw materials to 5% can directly reduce cultivation costs. Because farmers cannot claim ITC, low input rates are their only real relief. The way forward is to ensure that rate cuts reach farmers, to bring FPOs into the GST system so they can benefit from ITC, and to pursue agricultural marketing reforms alongside GST so that "One Nation, One Market" becomes a reality for agriculture too.

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Price Distortions in Agriculture: Measuring Who Gains and Who Pays with NPC, NRP and PSE

Article ID: 74606

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Abstract
Governments everywhere intervene in agricultural markets through tariffs, export restrictions, minimum support prices, input subsidies, stock limits and public procurement. These interventions create a gap, or "distortion", between the prices farmers and consumers actually face and the prices that would prevail without intervention. Measuring this gap tells us whether a country's policies, taken together, support or tax its farmers. This article explains the concept of agricultural price distortion and the main indicators used to measure it: the Nominal Protection Coefficient (NPC), the Nominal Rate of Protection (NRP), the Effective Protection Coefficient (EPC), the Nominal Rate of Assistance (NRA) and the OECD's Producer Support Estimate (PSE) family. It shows step by step how reference prices are calculated using import and export parity, with a worked example for rice, and illustrates the welfare effects of an export restriction. It then reviews evidence for India, where OECD estimates have repeatedly shown negative market price support, meaning that domestic farm prices for many products have been below world reference prices, largely because of export restrictions and domestic marketing regulations, partly offset by large input subsidies. The article discusses the limitations of these indicators and their implications for agricultural policy reform.

Keywords: Price distortion, nominal protection coefficient, effective protection, producer support estimate, market price support, agricultural policy, India.

Introduction
When India banned exports of non-basmati white rice in July 2023 to keep domestic prices in check, consumers benefited from lower prices, but rice farmers lost the chance to sell at higher world prices. When the government raised import duties on edible oils, domestic oilseed farmers gained while consumers paid more. When fertiliser is supplied at a fraction of its cost, farmers gain while taxpayers foot the bill. Each of these interventions moves domestic prices away from what they would be in an undistorted market.

Agricultural economists call this gap a **price distortion**. Whether a country's agricultural policies help or hurt farmers overall cannot be judged from any single policy. A high MSP for wheat may coexist with export bans on onions and stock limits on pulses. To get the full picture, we need systematic indicators that compare domestic prices with a benchmark, typically the world price adjusted to the farm gate.

The study of price distortions has a long history, from the pioneering World Bank study by Krueger, Schiff and Valdés (1988) to Anderson's (2009) global database of distortions to agricultural incentives and the OECD's annual Agricultural Policy Monitoring and Evaluation reports. This article explains the main indicators, how they are calculated and what they tell us about Indian agriculture.

What is a Price Distortion?
A price distortion exists when the price received by producers, or paid by consumers, differs from the **reference price**, usually the world price at the country's border adjusted for transport and marketing costs. Distortions arise from two broad types of policy:

Type	Instruments	Effect on domestic producer price
Border measures	Import tariffs, import quotas, export subsidies	Raise domestic price above world price (protection)
Border measures	Export bans, export duties, minimum export prices	Lower domestic price below world price (taxation)
Domestic market measures	MSP with procurement, price support schemes	Raise price, if effectively implemented
Domestic market measures	Stock limits, essential commodity regulation, market fees	Usually lower producer price
Input measures	Fertiliser, power, irrigation, credit subsidies	Lower input costs; do not change output price but raise net returns
Macroeconomic measures	Overvalued exchange rate	Lower domestic price of tradables (indirect taxation)

Krueger, Schiff and Valdés (1988) showed that in many developing countries, **indirect** taxation of agriculture through overvalued exchange rates and industrial protection was larger than direct agricultural policies. This "urban bias" depressed farm incentives for decades.

Measuring Distortions: The Main Indicators

1. Nominal Protection Coefficient (NPC): The NPC is the simplest and most widely used indicator:

$$NPC = \frac{P_d}{P_w}$$

where P_d is the domestic producer price and P_w the reference (world) price adjusted to the same point in the marketing chain.

NPC value	Interpretation
NPC > 1	Producers are **protected**; domestic price is above world price
NPC = 1	No distortion
NPC < 1	Producers are **taxed**; domestic price is below world price

2. Nominal Rate of Protection (NRP): The NRP expresses the same information as a percentage:

$$NRP = \frac{P_d - P_w}{P_w} \times 100 = (NPC - 1) \times 100$$

An NPC of 0.85 corresponds to an NRP of −15%, meaning farmers receive 15% less than the world reference price.

3. Effective Protection Coefficient (EPC): The NPC considers only output prices. But policies also affect input prices through fertiliser subsidies, cheap power or tariffs on machinery. The EPC compares **value added** (output value minus tradable input costs) at domestic and world prices:

$$EPC = \frac{VA_d}{VA_w} = \frac{P_d - \sum a_j P_{dj}}{P_w - \sum a_j P_{wj}}$$

where a_j is the quantity of input j per unit of output. A crop may have NPC < 1 (taxed on output) but EPC > 1 (net protection) if input subsidies are large enough.

4. Nominal Rate of Assistance (NRA): Used in the World Bank's distortions database (Anderson, 2009), the NRA combines output price distortions with input distortions and direct payments, expressed as a percentage of the undistorted price. It allows comparison of assistance across countries and over five decades.

5. The OECD Producer Support Estimate (PSE): The OECD's PSE measures the annual monetary value of all transfers from consumers and taxpayers to agricultural producers arising from policies. It has two main parts:

a. Market Price Support (MPS): the gap between domestic and border prices multiplied by production. It is negative when domestic prices are below world prices.

b. Budgetary transfers: payments based on output, input use (such as fertiliser and power subsidies), area, income and other criteria.

Indicator	Definition
PSE	Total transfers to producers (MPS + budgetary transfers)
%PSE	PSE as a share of gross farm receipts
Producer NPC	Ratio of producer price (including output payments) to border price
Producer NAC	Ratio of gross farm receipts including support to receipts at world prices
GSSE	General Services Support: research, extension, infrastructure, inspection, public stockholding
CSE	Consumer Support Estimate: transfers to or from consumers
TSE	Total Support Estimate: PSE + GSSE + transfers to consumers from taxpayers

Calculating the Reference Price

The key step in measuring distortions is calculating a comparable reference price. Since world prices are quoted at the border (FOB for exports, CIF for imports), they must be adjusted to the farm gate or wholesale market.

1. For an **exportable** product, the reference is the **export parity price**: FOB price, converted to rupees, minus port charges, transport from the market to the port and processing or marketing margins.

2. For an **importable** product, the reference is the **import parity price**: CIF price, converted to rupees, plus port charges and transport from the port to the domestic market.

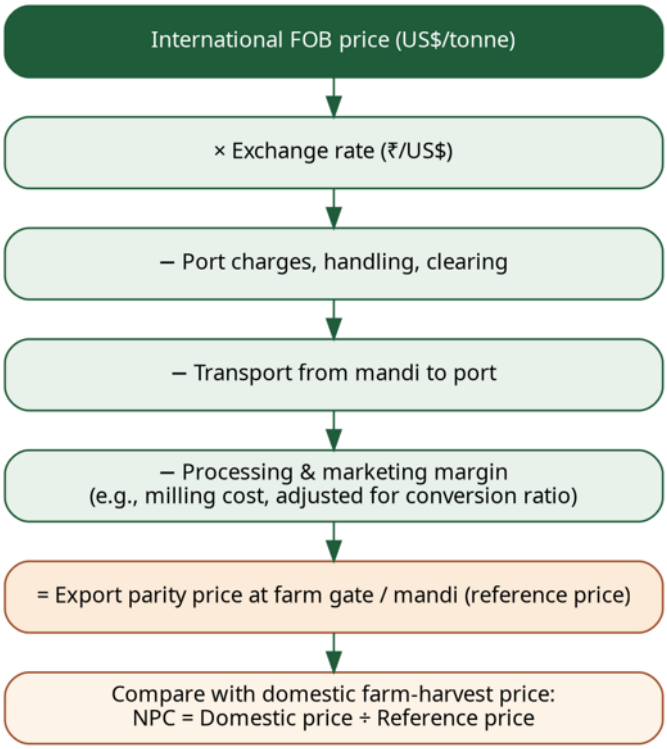


Figure 1: Steps in calculating the export parity reference price and the NPC

A Worked Example: Rice (Paddy)

Step	Value
FOB price of rice (US$/tonne$)|400||Exchange rate(₹/US$)$	85
FOB price in rupees (₹/tonne)	34,000
Less: port charges and handling (₹/tonne)	1,500
Less: transport from mandi to port (₹/tonne)	2,000
Export parity price of rice at mandi (₹/tonne)	30,500
Less: milling and marketing cost (₹/tonne of rice)	2,500
Value of rice ex-mill (₹/tonne)	28,000
Paddy equivalent at 67% milling outturn (₹/tonne of paddy)	28,000 × 0.67 = 18,760
Domestic farm-harvest price of paddy (₹/tonne)	21,000
NPC = 21,000 ÷ 18,760	**1.12**
NRP	**+12%**

(Hypothetical figures for illustration. Milling by-product values are ignored for simplicity.)

In this example, paddy farmers receive about 12% more than the export parity price, perhaps because of MSP and procurement. If the government then banned rice exports and the domestic price fell to ₹16,500 per tonne while world prices stayed unchanged, the NPC would drop to 0.88, indicating 12% implicit taxation.

The Welfare Effects of Distortion

Figure 2 shows the effect of an export restriction on an exportable crop. Without the restriction, the domestic price equals the world (export parity) price, and the country exports the gap between domestic supply and demand. A restriction pushes the domestic price below the world price. Consumers gain, producers lose the shaded area, and export earnings fall.

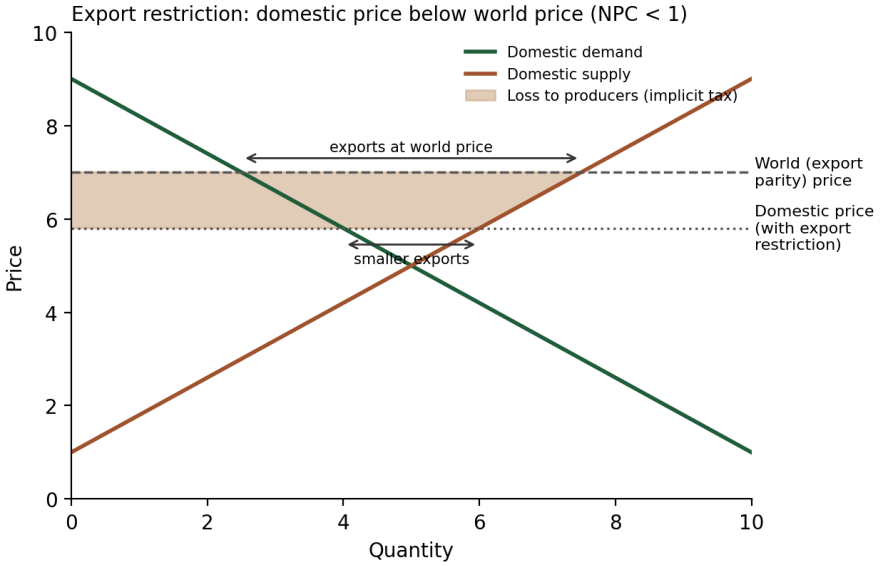


Figure 2: Effect of an export restriction on producers. The shaded area is the implicit tax on producers (negative market price support).

The producer loss is precisely what the OECD records as **negative market price support**. Part of this loss is a transfer to domestic consumers, and part is a pure efficiency loss to the economy. The reverse happens with an import tariff: producers gain, consumers lose, and there is again an efficiency loss.

Evidence for India

Studies of Indian agricultural price distortions over several decades show a consistent picture:

1. Negative output price support overall. OECD estimates for India have repeatedly found negative market price support, meaning domestic producer prices for many commodities have been below international reference prices. The OECD's 2024 report estimated India's negative market price support at about USD 110 billion in 2023, linked largely to export restrictions on rice, sugar and onions and other domestic measures, and noted that India accounts for a large share of all negative price support among the countries monitored (Drishti IAS summary of OECD, 2024).

2. Large input subsidies. Budgetary transfers through fertiliser, power, irrigation, credit and crop insurance subsidies, together with direct income support under PM-KISAN, partly offset the negative price support, but generally not enough to make total producer support positive.

3. Variation across commodities. Importables protected by tariffs, such as edible oils, some pulses and dairy, often show NPC above 1. Exportables subject to export controls, such as rice, wheat, sugar and onion in some years, often show NPC below 1.

4. Variation over time. Distortions change with world prices. When world prices spike, export restrictions widen the gap and NPCs fall; when world prices crash, MSP and tariffs push NPCs above 1.

5. Consumer bias. Policy in India has often prioritised keeping food affordable for consumers, through export restrictions, stock limits and public distribution, over maximising farm prices.

Commodity type	Typical policy instruments in India	Usual direction of NPC
Rice, wheat	MSP and procurement; periodic export restrictions	Varies: above 1 when world prices low, below 1 during export curbs
Edible oils, oilseeds	Import duties	Generally above 1
Pulses	Import duties, sometimes import quotas; stock limits	Varies with import policy
Sugar	FRP for cane; export quotas and controls	Varies
Onion	Export bans, minimum export prices, stock limits	Often below 1 during price spikes
Dairy	High import tariffs	Above 1
Cotton	MSP, import duty, export policy	Varies

(General patterns from published studies; actual values depend on year and methodology.)

Limitations of the Indicators

1. Choice of reference price. Results depend heavily on which world price, exchange rate, quality adjustment and marketing margins are used. Small changes can alter conclusions.

2. "Small country" assumption. The method assumes world prices are independent of the country's policy. For India, a major exporter of rice and sugar, its own export policy influences world prices, so the true undistorted price is uncertain.

3. Thin world markets. For commodities with limited world trade, world prices may be volatile or unrepresentative.

4. Exchange rate issues. Using the official exchange rate when it is misaligned can mismeasure distortions; some studies use a shadow exchange rate.

5. Partial picture. NPC ignores input subsidies; PSE includes them but cannot capture all regulatory effects, such as marketing restrictions or land laws.

6. Distortion is not always bad. Some interventions correct market failures or protect food security. A distortion indicator measures the gap, not whether the policy is justified.

Policy Implications

Measures of price distortion lead to several policy lessons for India:

1. Predictable trade policy would reduce the large negative support caused by sudden export bans, letting farmers benefit from favourable world prices.

2. Targeted consumer support through the Public Distribution System and direct transfers can protect poor consumers without taxing all farmers through export restrictions.

3. Rebalancing support from input subsidies, which encourage overuse of fertiliser, power and water, towards general services such as research, extension, irrigation infrastructure and markets would raise long-term productivity.

4. Regular monitoring of NPC and PSE by Indian institutions would make the costs of interventions transparent and support evidence-based policy.

Conclusion

Price distortion indicators answer a simple but important question: do a country's policies, taken together, help or hurt its farmers? The NPC and NRP compare domestic and world prices; the EPC adds input distortions; the NRA and the OECD's PSE family offer comprehensive measures of support. Each relies on carefully calculated reference prices using import or export parity.

For India, the evidence points to a paradox: despite large input subsidies, MSP and income support, overall market price support has often been negative because export restrictions and domestic regulations have kept many farm prices below world levels. Understanding these distortions is essential for designing reforms that protect consumers and food security while giving farmers fair and predictable incentives. For students of agricultural economics, these indicators provide a practical toolkit for evaluating agricultural and trade policy.

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Price Signals in the Field: Understanding How Farmers Decide What to Grow

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Abstract
Whether farmers respond to prices is one of the oldest questions in agricultural economics, and the answer shapes how governments design minimum support prices, input subsidies, trade policy and crop diversification programmes. Early development thinking held that peasant farmers were tradition-bound and unresponsive to prices; empirical work from the 1950s onwards, including Raj Krishna's pioneering estimates for Punjab, showed that farmers do respond, though often modestly in the short run. This article explains the concept of agricultural supply response and distinguishes it from the static supply curve of a firm. It describes the cobweb model and, in more detail, the Nerlovian adjustment model, which combines adaptive price expectations with partial adjustment of area, and shows how short-run and long-run elasticities are derived from its reduced form, with a worked example. It reviews other approaches, including profit-function and supply-system models, time-series cointegration methods and panel data, and summarises typical findings for India: acreage elasticities are generally low for foodgrains and higher for commercial crops, and non-price factors such as irrigation, technology, rainfall and assured procurement often matter as much as price. The article closes with implications for price policy and crop diversification.

Keywords: Supply response, Nerlove model, adaptive expectations, partial adjustment, price elasticity, cobweb model, acreage response.

Introduction
When onion prices soared in one season, how many farmers planted onions the next? When the government raised the minimum support price (MSP) of pulses, did farmers switch from wheat or paddy? When fertiliser became costlier, did output fall? These are questions about **agricultural supply response**: how farmers adjust what they grow, how much they grow and how intensively they grow it in response to changes in prices and other incentives.

The question has a long history. In the 1950s and 1960s, many economists believed that farmers in poor countries were bound by tradition and did not respond to price signals; some even argued for a "backward-bending" supply curve, where higher prices led to lower marketed supply because farmers needed to sell less to meet fixed cash needs. Empirical research overturned this view. Theodore Schultz's *Transforming Traditional Agriculture* (1964) argued that farmers were "poor but efficient", and Raj Krishna's (1963) study of Punjab showed that farmers' acreage decisions responded significantly to relative prices.

Understanding supply response remains essential. If farmers respond strongly to prices, price policy is a powerful tool; if responses are weak, investment in irrigation, technology and infrastructure may matter more. This article explains the main concepts, models and evidence.

Supply Function vs Supply Response
In textbook microeconomics, a firm's **supply function** shows how much it would produce at each price, holding technology and other factors constant. In agriculture, this static picture is incomplete for three reasons:

1. Time lags. Farmers decide area at sowing, but output and prices are known only at harvest. Decisions depend on **expected**, not actual, prices.

2. Adjustment constraints. Land, family labour, machinery, crop rotations and credit cannot be changed instantly, so farmers adjust gradually.

3. Uncertainty. Weather and pests mean that planned and actual output can differ widely.

Supply response therefore refers to the dynamic, total change in output, area or yield in response to price and non-price factors over time. Output can respond through **area** (extensive margin) or **yield** (intensive margin, through fertiliser, irrigation, labour and improved varieties). Because area is directly under the farmer's control at sowing and is less affected by weather than yield, most empirical studies estimate **acreage response**.

Concept	Meaning
Acreage response	Change in area under a crop in response to its own price and competing crop prices
Yield response	Change in output per hectare in response to prices and input use
Short-run elasticity	Response within one season, given adjustment constraints
Long-run elasticity	Total response after full adjustment

Own-price elasticity	Response to the crop's own price
Cross-price elasticity	Response to prices of competing crops
Aggregate supply response	Response of total agricultural output to the overall terms of trade

The Cobweb Model

The simplest dynamic model assumes that farmers plan this year's output based on last year's price, while this year's price is determined by this year's output and demand. This produces the famous **cobweb** pattern described by Ezekiel (1938).

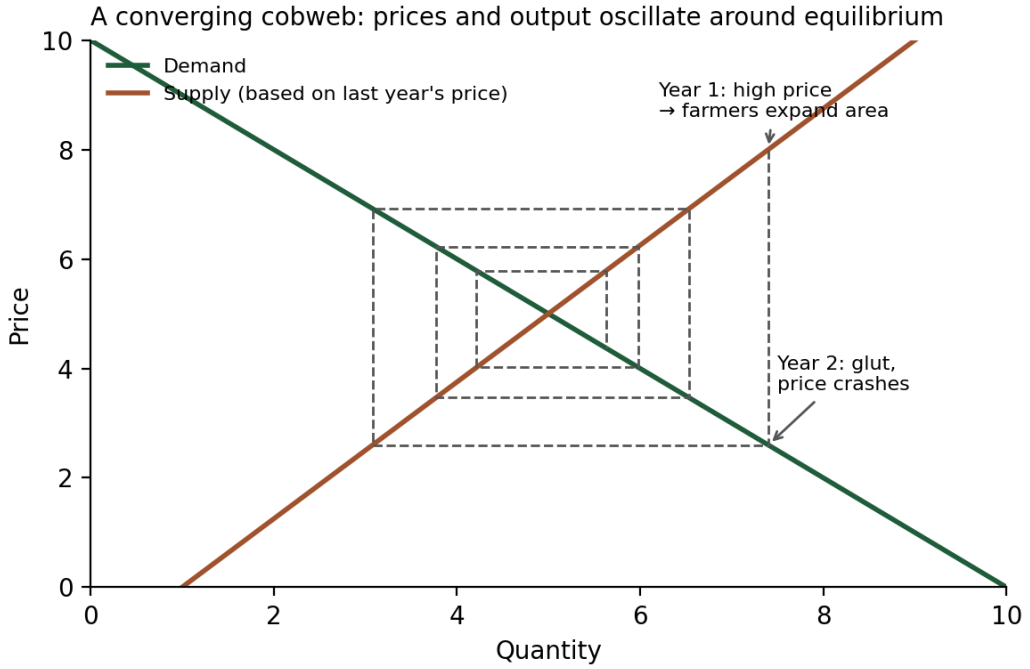


Figure 1: A converging cobweb. A high price in year 1 leads to a large crop and low price in year 2, which leads to a smaller crop and higher price in year 3, and so on.

Whether prices converge, oscillate permanently or explode depends on the relative slopes of the supply and demand curves. If supply is less elastic than demand, the cycle converges, as in Figure 1. The model explains the familiar boom-and-bust cycles in crops such as onion, potato and tomato, and pigs and cattle in livestock economies. Its weakness is the assumption that farmers naively expect last year's price to continue and never learn from repeated cycles.

The Nerlovian Supply Response Model

Marc Nerlove (1956, 1958) developed a more realistic model that remains the workhorse of supply response analysis. It has three building blocks, shown in Figure 2.

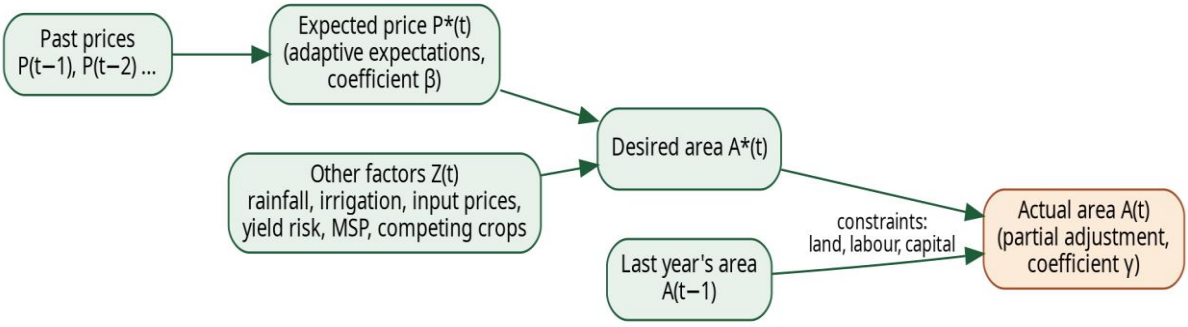


Figure 2: Structure of the Nerlovian supply response model

1. Desired area depends on expected price. The farmer's desired (long-run equilibrium) area under a crop is:

$$A_t^* = b_0 + b_1 P_t^* + b_2 Z_t + u_t$$

where A^*_t is desired area, P^*_t the expected price, and Z_t other factors such as rainfall, irrigation, input prices and yield risk.

2. Adaptive expectations. Farmers revise their expected price by a fraction ß of the error they made last time:

$$P_t^* - P_{t-1}^* = \beta(P_{t-1} - P_{t-1}^*), \quad 0 < \beta \leq 1$$

where ß is the **coefficient of expectation**. If ß = 1, the expected price equals last year's price, as in the cobweb model.

3. Partial adjustment. Because of constraints, farmers move only a fraction γ of the way from last year's area to the desired area:

$$A_t - A_{t-1} = \gamma(A_t^* - A_{t-1}), \quad 0 < \gamma \leq 1$$

where γ is the **coefficient of adjustment**.

Since expected price and desired area cannot be observed, the model is transformed into an estimable **reduced form**. In the commonly used version with partial adjustment and naive expectations (ß = 1), this becomes:

$$A_t = a_0 + a_1 P_{t-1} + a_2 A_{t-1} + a_3 Z_t + v_t$$

with $a_1 = \gamma b_1$ and $a_2 = (1 - \gamma)$. From the estimated coefficients:

- **Coefficient of adjustment:** $\gamma = 1 - a_2$
- **Short-run price elasticity:** $e_{SR} = a_1 \times$ (mean price ÷ mean area)
- **Long-run price elasticity:** $e_{LR} = e_{SR} \div \gamma$

Models are often estimated in logarithms, in which case a_1 is directly the short-run elasticity. Prices are usually entered as **relative prices** (own price divided by the price of a competing crop or an index of input prices), and **lagged yield** or yield variability is added to capture expected profitability and risk.

A Worked Example

Suppose a researcher estimates the following log-linear acreage equation for a crop:

Variable	Estimated coefficient
Lagged relative price, ln P_{t-1}	0.24
Lagged area, ln A_{t-1}	0.60
Rainfall	0.10
Irrigated area share	0.35

(Hypothetical estimates for illustration.)

Then γ = 1 − 0.60 = 0.40, meaning farmers close 40% of the gap between actual and desired area each year. The short-run elasticity is 0.24: a 10% rise in relative price raises area by 2.4% the next season. The long-run elasticity is 0.24 ÷ 0.40 = 0.60: after full adjustment, a 10% price rise raises area by 6%. The difference between short and long run shows why price policies take time to change cropping patterns.

Other Approaches

Approach	Description	Advantages
Nerlovian partial adjustment	Single-equation model of area or output with lagged variables	Simple, intuitive, data-light; widely used
Profit function / supply system	Derive output supply and input demand jointly from a profit function (duality)	Consistent with theory; captures cross-crop and input responses
Error correction and cointegration	ARDL bounds test, Johansen cointegration and ECM to separate long-run and short-run response	Handles non-stationary data; avoids spurious regression
Panel data models	Pool data across states or districts with fixed or random effects	More observations; controls for unobserved regional differences
Rational / quasi-rational expectations	Use futures prices, MSP or forecast prices as expected price	More realistic expectations, especially where MSP is announced before sowing
Risk-augmented models	Include price and yield variability as explanatory variables	Captures farmers' risk aversion

In India, an important refinement is the role of the **MSP announced before sowing**. For crops with effective procurement, such as wheat and paddy in Punjab and Haryana, the MSP is a better measure of expected price than last year's market price. Many studies therefore include MSP directly or use the higher of MSP and lagged market price.

Evidence for India

Six decades of Indian supply response research point to several broad findings:

1. Farmers do respond to prices. Price coefficients are positive and significant in most studies, confirming Krishna's early findings.

2. Short-run responses are generally modest. Acreage elasticities for foodgrains are typically low, often in the range of about 0.1 to 0.3, while commercial crops such as cotton, oilseeds, sugarcane and vegetables tend to show higher responses.

3. Long-run responses are larger, often two to three times the short-run elasticity, reflecting slow adjustment.

4. Non-price factors matter greatly. Irrigation, rainfall, technology (high-yielding varieties), credit, rural roads and market access often explain as much variation as prices.

5. Assured procurement shapes cropping patterns. Effective MSP procurement of wheat and paddy has encouraged rice–wheat monoculture in north-western India, contributing to groundwater depletion, despite efforts to promote pulses, oilseeds and millets.

6. Aggregate response is lower than crop-specific response. Farmers can shift land between crops easily, but expanding total agricultural output requires investment in land, water and technology.

Crop group	Typical short-run acreage response (indicative)	Main drivers besides price
Rice, wheat	Low	Irrigation, MSP and procurement, rotation constraints
Coarse cereals, millets	Low to moderate	Rainfall, competing crops
Pulses	Low to moderate	Rainfall, yield risk, procurement uncertainty
Oilseeds	Moderate	Rainfall, import prices of edible oils
Cotton	Moderate to high	Bt technology, pest incidence, export prices
Sugarcane	Moderate	FRP/SAP pricing, mill payment arrears, water availability
Vegetables (onion, potato, tomato)	High, cobweb-type	Last season's price, storage, perishability

(Indicative ranges based on general findings of Indian studies; values vary by region, period and method.)

Policy Implications

1. Price policy works, but slowly. Because short-run responses are modest, a change in MSP or input subsidy will not transform cropping patterns in one season. Policies need to be stable and credible over several years.

2. Relative prices matter more than absolute prices. To encourage pulses or millets, their profitability must improve relative to rice and wheat. Raising MSP alone, without effective procurement, has limited impact.

3. Non-price factors deserve equal attention. Irrigation, seeds, extension, credit and market infrastructure can raise supply response by relaxing constraints that slow adjustment.

4. Information can break cobweb cycles. Pre-sowing price forecasts and acreage advisories can help farmers avoid the boom-bust cycles common in onion, potato and tomato.

5. Risk reduction raises response. Crop insurance, assured procurement and stable trade policies reduce risk and encourage farmers to shift towards higher-value crops.

Conclusion

The question "do farmers respond to prices?" has been answered decisively: yes, they do. But they respond within constraints, gradually, and alongside many non-price influences. The Nerlovian model, with its ideas of adaptive expectations and partial adjustment, offers a simple yet powerful framework for measuring this behaviour and distinguishing short-run from long-run effects. Modern extensions using cointegration, panel data and risk variables have refined these estimates.

For India, the lessons are clear. Price incentives such as MSP influence what farmers grow, sometimes powerfully, as the dominance of rice and wheat shows. But to diversify cropping patterns, raise farm incomes and conserve natural resources, price policy must be combined with investment in irrigation, technology, markets and risk management. For students and researchers, supply response analysis remains one of the most practical tools for linking economic theory to agricultural policy.

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Price Volatility in Indian Agriculture: Causes, Measurement and Management

Article ID: 74608

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Abstract
Price volatility, the unpredictable component of price movements, is one of the most serious risks faced by farmers and one of the most visible drivers of food inflation for consumers. This article explains what agricultural price volatility is and how it differs from price levels, trends and seasonality. It discusses the structural causes of volatility in farm markets, including weather and climate shocks, inelastic demand and supply, perishability, cobweb cycles, links to world markets and policy uncertainty. Commonly used measures are reviewed, from the coefficient of variation and the Cuddy–Della Valle instability index to ARCH and GARCH models of time-varying volatility. Indian evidence shows a clear pattern: commodities backed by public procurement and storage, such as wheat and rice, are relatively stable, while perishables such as tomato, onion and potato are the most volatile. The article examines the effects of volatility on farm incomes, investment, nutrition and macroeconomic stability, and sets out a three-level framework of risk management tools at the farm, market and government levels. It concludes that the goal is not to eliminate price movements, which carry useful signals, but to reduce excessive volatility and strengthen the capacity of farmers and consumers to cope with it.

Keywords: Price volatility, price risk, instability index, GARCH, cobweb model, price stabilisation, agricultural marketing.

Introduction
Farming is arguably the riskiest business in the world. At sowing, a farmer does not know how large the harvest will be four or five months later, nor, more importantly, what price it will fetch. Onions may sell at ₹50 per kilogram one year and fail to find buyers at ₹5 the next. This uncertainty is what economists call **price volatility**.

Price changes in themselves are not a problem. Prices carry signals about supply and demand: scarcity raises prices, which encourages more production. The problem arises when price movements are **large, rapid and unpredictable**. Such volatility discourages farmers from investing, makes food expensive for consumers and creates food security challenges for governments.

Research on agricultural price volatility expanded rapidly after the global food price crises of 2007-08 and 2010-11, and again after the COVID-19 pandemic and the Russia-Ukraine war. This article explains what price volatility is, why it occurs, how it is measured, what effects it has, and what tools exist to manage it.

What is Price Volatility?
Volatility refers to the **degree of variation in prices over time**, specifically the unpredictable part of that variation. It is important to distinguish it from related concepts:

Concept	Meaning	Example
Price level	Whether prices are high or low	Pulses cost ₹150/kg
Trend	Long-run direction of prices	Pulse prices rise about 5% per year
Seasonality	Regular, predictable within-year pattern	Prices fall at harvest, rise in the lean season
Volatility	Unpredictable fluctuation beyond trend and seasonality	A flood doubles prices within weeks

Economists distinguish **historical volatility**, measured from past price data, from **implied volatility**, derived from futures and options prices, which reflects the market's expectation of future volatility. Predictable changes, such as harvest-time price falls, are less of a risk because farmers can plan for them. The real risk lies in the **unexpected**.

Causes of Price Volatility
Agricultural prices are more volatile than most manufactured goods because of several structural and external factors, summarised in Figure 1.

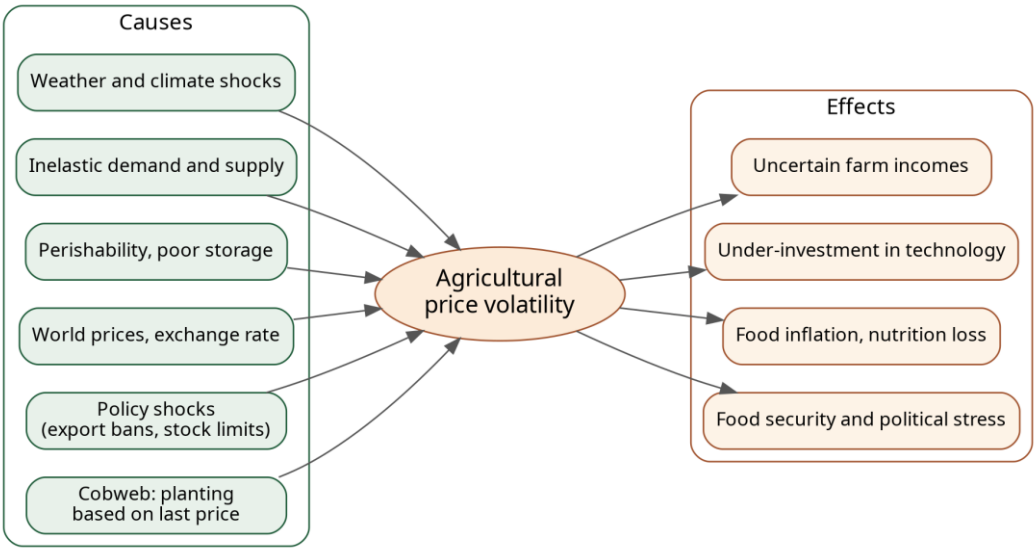


Figure 1: Causes and effects of agricultural price volatility

1. Weather and climate dependence. About half of India's cropped area remains rainfed. Weak monsoons, floods, droughts, hailstorms or heatwaves can suddenly cut output, and climate change is making such events more frequent.

2. Inelastic demand and supply. Food is a necessity, so consumers do not cut consumption much when prices rise. Once a crop is sown, supply cannot be increased for months. When both demand and supply are inelastic, a small supply shortfall causes a large price increase. This relationship, observed by Gregory King in the 17th century, is known as **King's Law**.

3. Perishability and limited storage. Fruits, vegetables, milk and fish spoil quickly. Grains can be stored, which is why cereal prices are generally less volatile than vegetable prices.

4. The cobweb phenomenon. Farmers often decide what to plant based on last season's prices. High onion prices this year lead many farmers to plant onions next year, causing a glut and a price crash, which in turn reduces planting and causes another price spike. Prices and output chase each other in a web-like cycle.

5. World markets and exchange rates. Domestic prices of edible oils, pulses, cotton and sugar are linked to world prices and the rupee–dollar exchange rate. Crude oil prices affect fertiliser, diesel and transport costs, and biofuel policies have linked maize, sugarcane and vegetable oil prices to energy markets.

6. Policy uncertainty. Sudden export bans, changes in import duties, stock limits and minimum export prices can cause abrupt price changes. When traders and farmers cannot anticipate policy, uncertainty rises.

7. Speculation and hoarding. Expectations of shortage can lead traders to hold stocks, creating artificial scarcity. Economists continue to debate whether futures markets increase or reduce spot price volatility.

Measuring Price Volatility

Researchers use a range of statistical and econometric tools to measure volatility, from simple to advanced:

Method	Formula / idea	Uses and limitations
Standard deviation	Average deviation of prices from the mean	Simple; depends on units, hard to compare across commodities
Coefficient of variation (CV)	(SD ÷ mean) × 100	Unit-free and comparable; but treats trend as volatility
Cuddy-Della Valle Index (CDVI)	CV × √(1 − adjusted R^2)	Removes trend before measuring instability; widely used in Indian studies
SD of log returns	SD of $\ln(P_t / P_{t-1})$	Based on percentage changes; standard in finance
ARCH / GARCH models	Today's variance depends on past shocks and past variance	Captures volatility clustering and time-varying risk
EGARCH / TGARCH	Asymmetric extensions of GARCH	Tests whether positive and negative shocks have different effects

The **Cuddy-Della Valle Index** is popular because it corrects for trend. If a price rises steadily at 10% a year, the CV will be high, but this is a predictable trend rather than instability. The CDVI removes the trend component.

The **GARCH model** (Bollerslev, 1986), an extension of Engle's (1982) ARCH model, is now the most widely used advanced method. It captures the fact that turbulent periods cluster together: after a large shock, prices remain more volatile for

some time before calming down. In a GARCH(1,1) model, the sum α + ß measures the **persistence** of volatility; the closer it is to one, the longer a shock's effect lasts.

A Worked Example

Suppose a researcher studies monthly wholesale onion prices for ten years. The mean price is ₹2,000 per quintal and the standard deviation ₹800, so the CV is 40%. A linear trend regression gives an adjusted R^2 of 0.36, meaning 36% of the variation is explained by the steady upward trend. The CDVI is then $40 \times \sqrt{(1 - 0.36)} = 40 \times 0.8 = 32\%$. The instability net of trend is 32%, lower than the raw CV but still high. Comparing CDVI values across periods, for example before and after the launch of a policy, or across markets, lets the researcher judge whether instability has changed.

Step	Value
Mean price (₹/quintal)	2,000
Standard deviation (₹/quintal)	800
Coefficient of variation	40%
Adjusted R^2 of trend regression	0.36
Cuddy–Della Valle Index	$40 \times \sqrt{0.64} = 32\%$

(Hypothetical figures for illustration.)

If the same series is modelled with GARCH(1,1) and the estimates are α = 0.15 and ß = 0.80, persistence is 0.95. A shock today would still affect volatility months later, signalling that once onion markets turn turbulent, they stay turbulent for a long time. Policymakers can use such results to decide how long buffer stock releases or trade measures need to remain in place.

In recent years, researchers have also used **systematic reviews and meta-analyses** to synthesise findings from hundreds of volatility studies across commodities, methods and countries.

Evidence from India

Indian studies show a consistent pattern: commodities with strong public procurement and storage have relatively stable prices, while perishables with little public support are the most volatile.

Commodity group	Relative volatility	Main reasons
Wheat, rice	Low	Large-scale MSP procurement, buffer stocks, Public Distribution System
Milk	Low to moderate	Regular procurement and processing by dairy cooperatives
Pulses, oilseeds	Moderate	Import dependence, world prices, limited procurement
Cotton, spices	Moderate to high	Linked to export demand and world markets
Tomato, onion, potato	Very high	Perishability, weather dependence, cobweb cycles, limited storage
Fruits and other vegetables	High	Perishability, fragmented markets

(Summary of general findings from Indian research; relative rankings are indicative.)

This is why tomato and onion prices often move India's headline Consumer Price Index on their own, and why the Reserve Bank of India tracks "core" inflation excluding food and fuel separately.

Effects of Price Volatility

On farmers. Volatile prices make farm incomes uncertain. Small and marginal farmers, with little savings or access to credit, can fall into debt after one bad season. Uncertainty discourages investment in improved seed, irrigation, machinery or high-value crops, keeping farmers locked into "safe", low-return crops and slowing diversification and modernisation.

On consumers. Poor households spend a large share of income on food. When prices spike, they eat less or switch to cheaper, less nutritious food. Rising prices of pulses and vegetables directly reduce intake of protein and micronutrients.

On the economy. Food price spikes raise inflation expectations and wage demands and may force the central bank to raise interest rates. Governments respond with emergency imports, export bans or subsidies, which sometimes add to market instability.

On agribusiness. Processors, exporters and retailers face uncertain raw material costs, making long-term contracts and investment harder.

Managing Price Risk

Eliminating price movements is neither possible nor desirable, since prices carry useful signals. The objective should be to reduce excessive, harmful volatility and help farmers and consumers cope with the risk that remains. Tools operate at three levels.

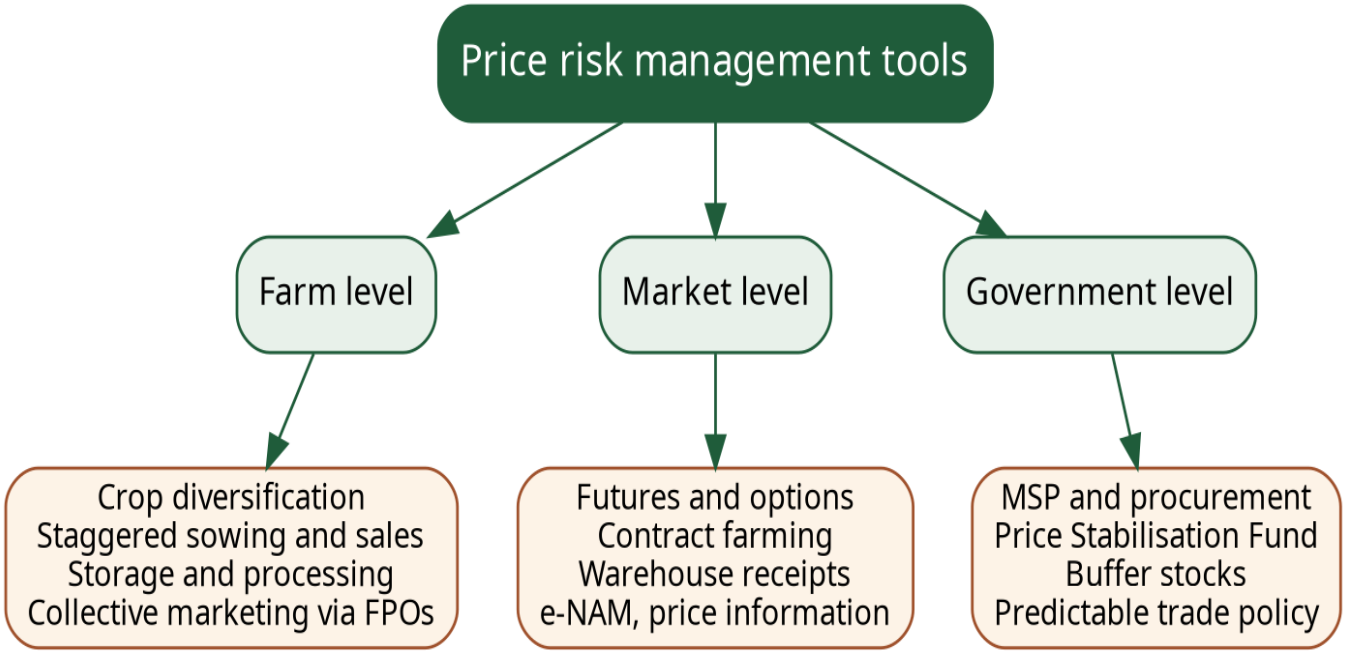


Figure 2: Price risk management tools at three levels

Farm Level

1. **Diversification** across crops and allied activities such as dairy, poultry and beekeeping.
2. **Staggered sowing and sales**, rather than selling the whole harvest at once.
3. **Farmer producer organisations (FPOs)**, which strengthen bargaining power and enable investment in storage and processing.

Market Level

1. **Futures and options** on exchanges such as NCDEX and MCX allow price discovery and hedging. Participation by small farmers remains very low, and since December 2021 SEBI has suspended futures trading in several major agricultural commodities, a suspension that has been extended more than once.
2. **Contract farming**, which fixes prices with a buyer before sowing.
3. **Warehouse receipt financing** through WDRA-registered warehouses, allowing farmers to borrow against stored produce instead of selling in distress at harvest.
4. **e-NAM and price information services**, helping farmers choose better markets.

Government Level

Instrument	Objective	Challenge
MSP and procurement	Set a price floor	Concentrated in wheat, rice and a few states
Price Stabilisation Fund (PSF)	Build buffers of pulses and onion; release in shortages	Storage losses, timing of interventions
Price deficiency payments (Bhavantar)	Pay the gap between market price and MSP	Risk of price manipulation, fiscal cost
Operation Greens (TOP)	Strengthen tomato, onion, potato value chains	Pace of implementation
Predictable trade policy	Avoid abrupt changes in import and export rules	Political pressure from food inflation
Crop insurance (PMFBY)	Protection against yield risk	Does not cover price risk

Long-Term Structural Measures

The most durable solutions address the roots of volatility: expanding irrigation to reduce monsoon dependence; investing in cold chains and storage; developing food processing to absorb gluts; breeding climate-resilient varieties; and improving weather and price forecasting. If farmers receive reliable signals before sowing about likely acreage and prices, the cobweb cycle can be broken.

Conclusion

Agricultural price volatility is a shared challenge for farmers, consumers and policymakers. Its causes are multiple: weather, climate change, perishability, inelastic demand and supply, world markets and policy uncertainty. Tools such as the CV, the Cuddy–Della Valle index and GARCH models help measure where volatility is concentrated and how it evolves.

India's experience shows that where public procurement, storage and organised marketing are strong, prices are stable; where they are weak, farmers and consumers both bear large swings. The solution therefore lies not in a single policy but in a balanced mix: diversification and collective action at the farm level, risk-transfer tools and transparent information at the market level, and stable, predictable policy at the government level. For students of agricultural economics, the subject brings together theory, econometrics and policy in one rich field of research.

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SAFTA and India's Agricultural Trade: Promise, Performance and the Road Ahead

Article ID: 74609

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Abstract

South Asia is home to nearly a quarter of the world's population but accounts for only a small fraction of world trade, and trade among South Asian countries is a much smaller share of their total trade than in the European Union, North America or ASEAN. The South Asian Free Trade Area (SAFTA), signed in 2004 and in force from 2006, was designed to change this by phasing tariffs down to 0–5% among the eight SAARC members. Agriculture should be a natural beneficiary: the region shares food habits, borders and supply chains, and India is the dominant agricultural exporter to its neighbours. This article reviews SAFTA's origins, provisions and the place of agriculture in it, and explains the toolkit agricultural economists use to evaluate a regional trade agreement: compound growth rates, the Cuddy–Della Valle instability index, export and import intensity indices, Balassa's revealed comparative advantage and gravity models. Drawing on published research, it finds that India's agricultural exports to Bangladesh, Nepal and Sri Lanka have grown and become more stable, but SAFTA's overall impact has been modest because of long sensitive lists, non-tariff barriers, weak connectivity and political conflict, particularly between India and Pakistan. The article concludes with practical steps to unlock regional agricultural trade.

Keywords: SAFTA, SAARC, regional trade agreement, agricultural trade, trade intensity, revealed comparative advantage, instability index.

Introduction

South Asia contains about 24% of the world's population yet accounts for less than 6% of world trade. More striking still, trade **within** South Asia is only around 5% of the region's total trade, among the lowest of any region in the world. A truck carrying onions from Nashik to Dhaka, or fruit from Bhutan to Delhi, often faces more delays and paperwork than a container shipped from India to Europe.

The **South Asian Free Trade Area (SAFTA)** was created to bridge this gap. Agriculture is central to the story. The countries of the region share similar diets based on rice, wheat, pulses, onions, sugar and edible oils; they share long land borders; and India, as the largest producer, is a natural supplier to its smaller neighbours. Bangladesh, Nepal and Sri Lanka are among the most important destinations for Indian farm exports, while India imports dry fruits and nuts from Afghanistan, and various products from Nepal, Bhutan and Bangladesh.

This article explains what SAFTA is, how agricultural trade has evolved under it, how economists measure the performance of a trade agreement, and what is needed for SAFTA to deliver on its promise.

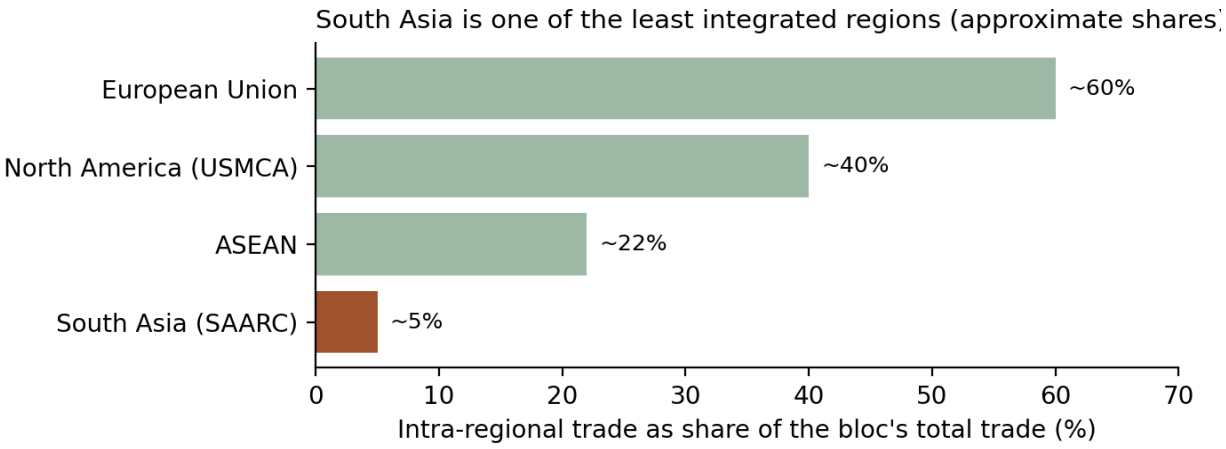


Figure 1: Intra-regional trade as a share of total trade, selected regional blocs (approximate, widely cited estimates)

From SAARC to SAFTA

Regional economic cooperation in South Asia has developed in stages, as shown in Figure 2.

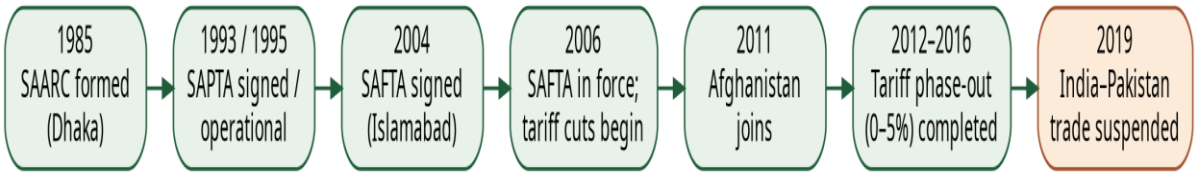


Figure 2: Milestones in South Asian trade integration

The **South Asian Association for Regional Cooperation (SAARC)** was founded in Dhaka in 1985. Its first trade initiative, the **SAARC Preferential Trading Arrangement (SAPTA)**, signed in 1993 and operational from 1995, offered tariff concessions on a product-by-product basis, but its coverage was limited.

SAFTA was signed in Islamabad in January 2004 and entered into force on 1 January 2006, with tariff liberalisation starting in July 2006. Its members are Afghanistan (which joined in 2011), Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka.

Key Provisions

Provision	Content
Tariff Liberalisation Programme	Non-LDC members (India, Pakistan, Sri Lanka) to reduce tariffs to 0–5%; LDC members over a longer period
Special and differential treatment	Longer timelines and greater flexibility for least developed members (Afghanistan, Bangladesh, Bhutan, Maldives, Nepal)
Sensitive lists	Each country can exclude products from tariff cuts; many agricultural goods are on these lists
Rules of origin	Products must meet value-addition and change-in-tariff-heading criteria to qualify
Safeguards and institutions	Safeguard measures against import surges; SAFTA Ministerial Council and Committee of Experts
Compensation mechanism	Revenue loss compensation for LDCs during the transition

The **sensitive list** is the most important feature for agriculture. Because farming supports large numbers of poor households, governments were reluctant to open agriculture fully, and many farm products were kept out of tariff cuts. India reduced its sensitive list for LDC partners to 25 tariff lines in 2011, a significant gesture, but Pakistan, Sri Lanka and others retained long lists for agricultural products.

Pattern of India's Agricultural Trade in the Region

India is a net agricultural exporter to South Asia. Bangladesh is by far the largest destination for Indian farm exports, followed by Nepal and Sri Lanka. Main export items include cotton and cotton yarn, sugar, rice, maize, onions, spices, fresh vegetables and wheat in normal years. On the import side, India buys dry fruits and nuts from Afghanistan, along with products such as jute, spices, tropical fruits, beverages and vegetable oils from other partners.

Partner	Nature of India's agricultural trade relationship
Bangladesh	Largest export market; cotton, sugar, rice, onions, maize, spices; growing imports from Bangladesh
Nepal	Open border and bilateral trade treaty; cereals, vegetables, fruits, processed food; imports of spices and vegetable oils
Sri Lanka	India–Sri Lanka FTA (2000) predates SAFTA; onions, sugar, rice, spices
Bhutan	Free trade under bilateral agreement; small but stable trade
Afghanistan	India relies on it for dry fruits and nuts; land-locked, trade routed through third countries
Maldives	Small, import-dependent market for food
Pakistan	Large potential, but trade highly volatile and largely suspended since 2019

Two caveats are important. First, much of India's regional trade is governed by **bilateral agreements** (with Sri Lanka, Nepal and Bhutan) that are more generous than SAFTA, which makes SAFTA's separate effect harder to identify. Second, **informal cross-border trade**, especially across the India–Bangladesh and India–Nepal borders, is believed to be substantial and is not captured in official statistics.

How Economists Evaluate a Trade Agreement

Agricultural economists use a standard set of indicators to judge whether an agreement has made trade larger, more stable, more concentrated within the region and more competitive. Studies typically divide the period into phases, for example **pre-SAFTA (1996–2005)**, **implementation (2006–2015)** and **consolidation (2016 onwards)**, and compare indicators across phases.

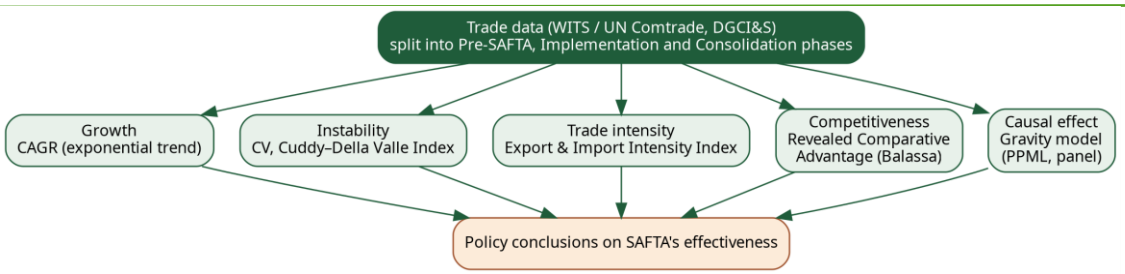


Figure 3: A typical analytical framework for evaluating SAFTA's effect on agricultural trade

Indicator	Formula / idea	What it reveals
Compound Annual Growth Rate (CAGR)	Fit $\ln(Y) = a + bt$; CAGR = $(e^b - 1) \times 100$	Speed of trade expansion in each phase
Coefficient of Variation (CV)	SD ÷ mean × 100	Raw variability of trade values
Cuddy–Della Valle Index (CDVI)	CV × √(1 − adjusted R^2)	Instability after removing trend
Export Intensity Index (EII)	$(X_{ij} / X_i) \div (M_j / M_w) \times 100$	Whether India exports more to a partner than the partner's share of world imports would predict (>100 = strong link)
Import Intensity Index (III)	$(M_{ij} / M_i) \div (X_j / X_w) \times 100$	Whether India imports more from a partner than its share of world exports would predict
Revealed Comparative Advantage (RCA)	$(X_{ik} / X_i) \div (X_w_k / X_w)$	Competitiveness in product k; RCA > 1 indicates comparative advantage
Gravity model	Trade ∝ GDPs ÷ distance, plus an FTA dummy	Causal effect of SAFTA after controlling for size and distance

(Note: Intensity indices are expressed differently in different studies; some scale the ratio by 100, others report the raw ratio where 1 is the benchmark.)

The **Balassa RCA** is commonly interpreted as follows: RCA ≤ 1, no comparative advantage; 1–2, weak; 2–4, moderate; above 4, strong. Comparing India's RCA with that of competitors such as China, Pakistan, Brazil or Thailand in the regional market shows where Indian products are winning or losing ground.

The **gravity model**, first applied to trade by Tinbergen (1962), has become the workhorse for estimating the effect of trade agreements. Modern studies use panel data with importer and exporter fixed effects and the Poisson Pseudo Maximum Likelihood (PPML) estimator, which handles zero trade flows and heteroskedasticity.

What Does Evidence Show?

Published research on SAFTA and South Asian agricultural trade points to several broad conclusions:

1. Growth with variation across partners. India's agricultural exports to Bangladesh, Sri Lanka and Nepal have grown substantially since 2006. Trade with Pakistan has stagnated or collapsed, and trade with Afghanistan has been disrupted by conflict and transit problems.

2. Declining instability for most partners. For several partners, instability indices show that trade became more stable after SAFTA, suggesting deeper and more regular trade relationships. Trade with Pakistan and Afghanistan remains the most volatile.

3. Strong regional orientation. Trade intensity indices are consistently well above the benchmark, showing that India trades far more with its neighbours than their size in world trade would predict, as expected given proximity and shared consumption patterns.

4. Selective competitiveness. India shows comparative advantage in products such as cotton yarn, rice, sugar and maize in the regional market, but faces strong competition from China, Pakistan, Brazil and others in some lines.

5. Modest overall effect. Gravity-model studies generally find that SAFTA's independent effect on agricultural trade is positive but small, because of sensitive lists, non-tariff barriers and the prior existence of bilateral FTAs.

Why Hasn't SAFTA Done More?

Constraint	Description
Sensitive lists	Many agricultural tariff lines remain excluded from tariff cuts
Non-tariff barriers	Sanitary and phytosanitary rules, testing and certification, para-tariffs, import licensing, quality standards
Political conflict	India–Pakistan trade largely suspended since 2019; SAARC summits stalled since 2014
Weak connectivity	Congested land ports, poor roads, limited rail links and lack of cold chain at borders

Land-locked members	Nepal, Bhutan and Afghanistan depend on transit through neighbours
Policy volatility	Sudden export bans (for example, on onions, rice or wheat) disrupt partner markets and erode trust
Informal trade	Large unrecorded flows reflect high costs of formal trade

The issue of **policy volatility** deserves emphasis. When India restricts exports of onions, wheat or rice to control domestic prices, neighbouring countries that depend on Indian supplies face sudden shortages. Such measures may be domestically justified but undermine India's reputation as a reliable regional supplier and encourage partners to diversify towards other sources.

Lessons from Other Regions

South Asia can learn from regional blocs that have integrated agricultural trade more successfully. In **ASEAN**, tariff cuts under the ASEAN Free Trade Area were accompanied by trade facilitation measures such as the ASEAN Single Window for customs documentation and work on mutual recognition of standards. The **European Union** went much further, creating common food safety rules and a single market in which a product approved in one member state can be sold in all. Even where politics was difficult, these regions built technical cooperation, such as shared laboratories, common standards and joint customs procedures, that kept trade flowing.

The lesson for South Asia is that tariffs are only one part of trade costs. World Bank research has repeatedly found that for many South Asian products, the cost of moving goods across borders, including documentation, inspection, waiting time at land ports and informal payments, is a larger barrier than the tariff itself. For perishable agricultural products, where a delay of a day or two can mean spoilage, these costs are decisive. A tomato exporter in Bengaluru may find it easier to sell to the Gulf by sea than to Bangladesh by road. Reducing these "behind-the-border" and "at-the-border" costs could do more for regional agricultural trade than any further tariff cut.

The Way Forward

1. Prune sensitive lists for agricultural products, starting with items where regional complementarity is high.

2. Harmonise standards through mutual recognition of SPS certificates, accredited regional laboratories and common quality standards for fruits, vegetables and processed food.

3. Invest in trade infrastructure: integrated check posts, cold storage and testing facilities at land ports, and better rail and road links, especially for land-locked partners.

4. Make export policy predictable, for example through government-to-government supply arrangements with neighbours during domestic shortages instead of blanket bans.

5. Promote high-value and processed agri-trade such as organic products, horticulture, dairy and processed foods, where regional demand is rising.

6. Strengthen sub-regional cooperation through frameworks such as BBIN (Bangladesh–Bhutan–India–Nepal) and BIMSTEC when SAARC-wide progress stalls.

7. Build institutions for research and market intelligence, such as a regional agricultural trade observatory and joint R&D on agricultural technology.

Conclusion

SAFTA was a bold idea: to turn South Asia's geography, shared food systems and complementary production patterns into a regional market. For Indian agriculture, the region offers natural, nearby markets for cereals, sugar, cotton, vegetables and processed food. Evidence shows that India's agricultural trade with Bangladesh, Nepal and Sri Lanka has grown and become more stable, and that India's trade ties with its neighbours are far more intense than their weight in world trade would suggest.

Yet SAFTA's overall impact remains modest. Long sensitive lists, non-tariff barriers, weak infrastructure, policy volatility and, above all, political conflict have kept intra-regional trade far below its potential. Unlocking that potential will require more than tariff cuts. It requires trust, predictable policy, harmonised standards and better connectivity. For researchers, SAFTA remains a rich case for applying trade indicators and gravity models to the question of how regional agreements shape agricultural trade.

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From Seed to Genetic Resource: Conserving and Maintaining Maize Germplasm for Future Breeding

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Summary
Conservation of maize germplasm requires careful management at each stage to ensure that accessions remain viable and genetically representative over time. Seed moisture, storage conditions and viability monitoring determine when regeneration becomes necessary, while population size, mating system and pollen control are critical for maintaining genetic integrity during regeneration. These requirements differ among heterogeneous populations, heterotic pools, inbred and DH lines, genetic stocks and wild relatives. Integrating appropriate conservation practices with documentation, characterization and evaluation facilitates effective maintenance and utilization of maize genetic resources.

Introduction
Maize (*Zea mays* L.) encompasses substantial genetic diversity represented by landraces, farmers' varieties, indigenous and improved populations, synthetics, composites, inbred and doubled haploid (DH) lines, donor lines, mutants, genetic stocks and wild relatives. These genetic resources provide valuable variation for improving yield, adaptation, resistance to diseases and insect pests, tolerance to abiotic stresses, along with grain and nutritional quality. Their conservation therefore safeguards valuable genetic diversity for present and future maize improvement and ensures its continued availability for research and breeding (FAO, 2014).

Safeguarding this diversity over time, however, requires more than simply storing seed under cold conditions. Effective conservation requires a coordinated sequence of operations beginning with acquisition and accessioning, followed by appropriate documentation, seed-health management, drying and storage. Stored accessions must subsequently be monitored for seed viability and quantity and regenerated when required, while taking particular care to maintain their genetic identity and integrity. Characterization, evaluation, distribution and safety duplication further ensure that conserved germplasm remains secure, accessible and useful. Thus, maize germplasm conservation is best viewed as a continuous cycle from acquisition and conservation to regeneration and utilization, rather than as a one-time storage activity (FAO, 2014; FAO, 2022).

In-Situ and *Ex-Situ* Conservation: Complementary Approaches
Maize germplasm is conserved through *in-situ*/on-farm and *ex-situ* approaches. On-farm conservation maintains landraces and farmers' varieties within their production environments, where they remain dynamic under environmental influences and farmer selection. In contrast, *ex-situ* conservation safeguards germplasm outside its original production environment, most commonly as seed in gene banks. The two approaches are complementary: on-farm conservation allows continued adaptation and evolution, while *ex-situ* conservation provides systematic preservation and access to germplasm. Maize is particularly suited to seed-gene bank conservation because its orthodox seeds tolerate drying to low moisture levels and storage at low temperatures (FAO, 2014).

The Maize Germplasm Conservation Cycle
Maize germplasm conservation is a continuous process involving acquisition, documentation, seed preparation, storage, monitoring, regeneration, characterization and distribution. Together, these steps aim to maintain the identity, viability and genetic integrity of each accession while ensuring its availability for research and crop improvement (FAO, 2014; FAO, 2022). The major steps in this cycle were illustrated in Figure 1, while the key operational components were discussed below (FAO, 2014; FAO, 2022).

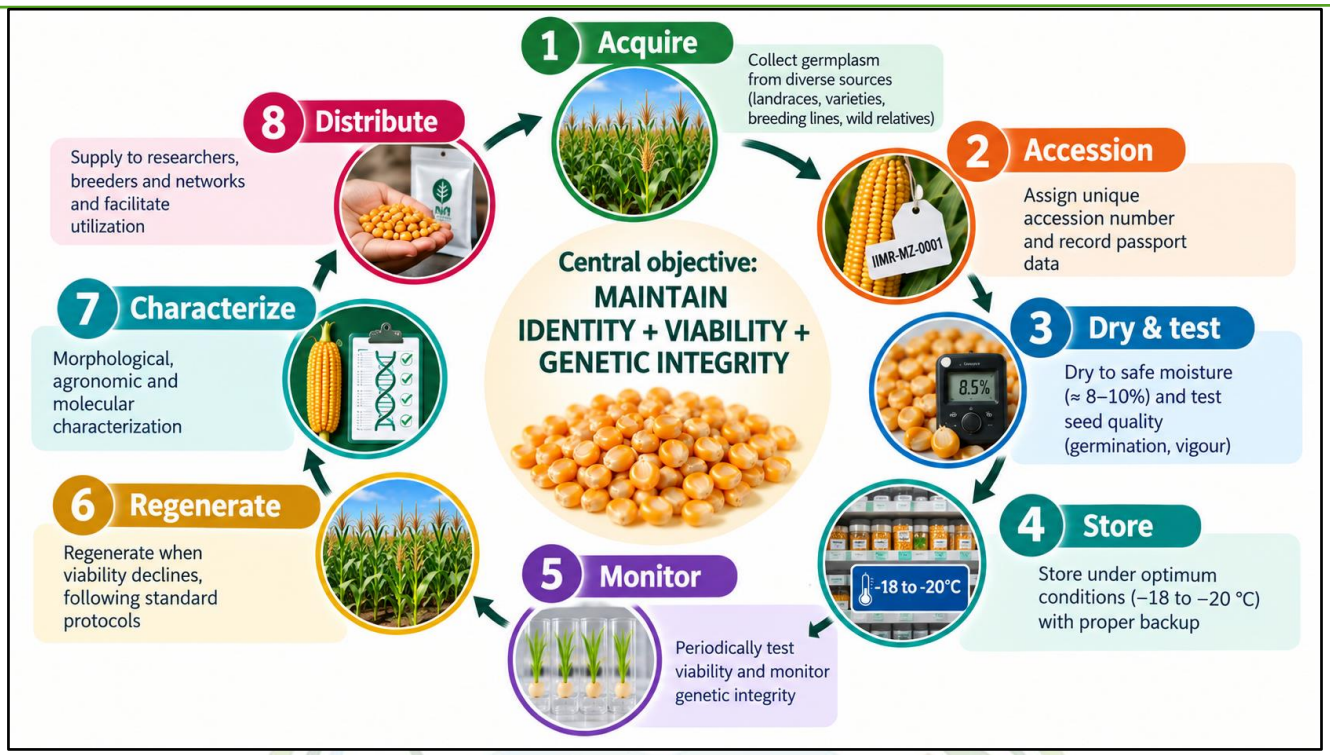


Figure 1. The maize germplasm conservation cycle—from acquisition to utilization

Step 1. Accessioning and documentation: safeguarding germplasm identity: Effective conservation begins with the correct identification and documentation of each accession. A unique accession number, linked to reliable passport data on its origin, source, biological status and pedigree/parentage where available, establishes the identity of the germplasm and enables its subsequent use and interpretation. Equally important is maintaining traceability throughout the conservation cycle. Records of seed viability, regeneration and multiplication history, characterization and evaluation, storage and distribution allow changes in an accession to be tracked over time and help safeguard its identity and genetic integrity. Thus, documentation is an integral component of genetic resource conservation rather than merely a record-keeping exercise.

Step 2. Drying, packaging and storage: Seed longevity during storage is strongly influenced by initial seed quality, seed moisture content and storage temperature. Mature, healthy seed with high initial viability should therefore be dried to the recommended moisture level before being sealed in moisture-proof packaging. For orthodox seeds, FAO recommends drying to equilibrium under controlled conditions of 5–20°C and 10–25% relative humidity, depending on the species (FAO, 2014). For maize, the CGIAR/CIMMYT regeneration guidelines recommend secondary drying at 10–15°C and 15–20% RH for at least four weeks, until seed moisture reaches approximately 6–8%. Where controlled drying facilities are unavailable, a suitable desiccant may be used to achieve approximately 7–8% seed moisture (Taba and Twumasi-Afriyie, 2008).

Following drying and packaging, storage conditions should be selected according to the intended conservation period and frequency of seed access. Most-original samples and safety duplicates intended for long-term conservation should be maintained at −18 ± 3°C, whereas active collections intended for medium-term conservation and more frequent access may be stored at 5–10°C (FAO, 2014). Appropriate drying, moisture-proof packaging and low-temperature storage together help extend seed longevity and thereby reduce the need for frequent regeneration.

Step 3. Viability monitoring and decision to regenerate: Periodic monitoring of seed viability and available seed quantity is essential for timely regeneration of maize germplasm. Regeneration is recommended when the number of viable seeds falls below 1,500 seeds per accession for panmictic populations or 250 seeds for inbred lines in active or base collections. In active collections, regeneration is also recommended when seed viability declines below 85% of the initial germination percentage (Taba and Twumasi-Afriyie, 2008).

Step 4. Regeneration: maintaining genetic integrity while renewing seed: Once regeneration is required, the objective is to produce sufficient viable seed without altering the genetic identity and diversity of the accession. This is particularly critical in heterogeneous maize populations, where inadequate population size, genetic drift, inbreeding, unintended selection and pollen contamination can alter genetic composition during regeneration. Empirical assessment of regenerated maize landraces has demonstrated changes in allele frequencies in some accessions, highlighting the importance of appropriate population size and mating procedures (Wen *et al.*, 2011; Silva *et al.*, 2021).

Regeneration procedures should therefore be tailored according to the genetic structure and mating system of the germplasm. Heterogeneous materials such as landraces, open-pollinated populations, synthetics, composites and broad-based heterotic pools require maintenance of within-population genetic diversity, whereas fixed materials such as inbred and DH lines require preservation of genetic purity and line identity.

a. Panmictic populations: Maize landraces, open-pollinated populations, synthetics and composites are heterogeneous, intermating populations; their regeneration should therefore maintain within-population genetic diversity. Adequate population size and representative sampling are essential to minimize genetic drift and shifts in allele frequencies during regeneration (Wen *et al.*, 2011; Fu, 2024). The CIMMYT controlled-regeneration procedure uses approximately 256 plants per accession, with >100 ears represented, and recommends plant-to-plant (sib) or chain crossing to promote intermating while preventing foreign pollen contamination (Taba and Twumasi-Afriyie, 2008). The 256-plant figure is an operational reference rather than a universal biological threshold; the key principle is to maintain a sufficiently large, representative population with appropriate mating and balanced contribution to the regenerated seed lot (Taba and Twumasi-Afriyie, 2008; Fu, 2024).

b. Heterotic pools: Broad-based heterotic pools are heterogeneous, intermating populations whose maintenance should conserve genetic diversity within each pool while retaining differentiation between complementary pools (Labroo *et al.*, 2021; Li *et al.*, 2022). Each pool should therefore be regenerated separately, with adequate population representation and strict pollen control; controlled sib or chain crossing may be used following regeneration principles for heterogeneous maize populations (Taba and Twumasi-Afriyie, 2008). Conservation-oriented regeneration should minimize unintended selection, whereas recurrent or reciprocal recurrent selection is used for genetic improvement of heterotic pools and is therefore distinct from routine germplasm maintenance (Labroo *et al.*, 2021). As no heterotic-pool-specific population-size standard is available, the CIMMYT panmictic-maize procedure of approximately 256 plants with >100 ears represented may serve as a practical reference rather than a prescribed standard (Taba and Twumasi-Afriyie, 2008). Where a heterotic group consists of established inbred or DH lines, each line should be maintained separately to preserve its identity rather than intermated as a population.

c. Inbred and doubled-haploid lines: For inbred lines, regeneration should maintain genetic purity, homozygosity and line identity through controlled self-pollination of true-to-type plants. The CIMMYT maize regeneration guideline recommends approximately 168 plants per accession, with seed from selected self-pollinated ears retained for subsequent regeneration (Taba and Twumasi-Afriyie, 2008). Doubled-haploid (DH) lines, being fixed homozygous lines, should similarly be maintained as individual lines, with careful avoidance of pollen and seed contamination (Chaikam *et al.*, 2019). As no separate DH-specific regeneration population size is prescribed in the maize regeneration guideline, maintenance should emphasize genetic purity and individual line identity rather than assigning the inbred-specific numerical recommendation to DH lines.

d. Genetic stocks, mutants and wild relatives: Maize genetic stocks and mutants represent defined genetic variants, including mutant alleles, cytoplasmic variants, chromosomal aberrations, aneuploids and polyploids. Their regeneration should preserve the specific genetic constitution and associated phenotype for which the stock is maintained. Accordingly, controlled self- or cross-pollination should be used as required by the genotype and inheritance of the trait. The Maize Genetics Cooperation Stock Center uses hand pollination for seed increase, maintains ears individually and records pedigrees using genetic symbols to preserve stock identity (USDA-ARS Maize Genetics Cooperation Stock Center, 2026). Thus, population size and mating procedure should be determined according to the genetic characteristics of the individual stock.

Maize wild relatives, particularly teosinte (*Zea* spp.) and *Tripsacum* spp., require taxon-specific conservation and regeneration because of differences in reproductive biology and growth habit. Teosinte is generally maintained through seed regeneration, with consideration of its outcrossing nature, seed dormancy and seed dispersal, whereas *Tripsacum* germplasm may also be maintained as perennial plants or clones in field collections (Taba *et al.*, 2004; Cruz-Cárdenas *et al.*, 2019). Thus, regeneration procedures for wild relatives should be determined by the biology of the individual taxon rather than by applying a uniform cultivated-maize protocol (Taba *et al.*, 2004).

Step 5. From conservation to utilization: Conservation has greatest value when germplasm is well documented, characterized, evaluated and accessible for use. Characterization using morphological and agronomic descriptors helps establish accession identity and describe diversity, while evaluation for economically important traits facilitates the identification of potential donors for breeding. Molecular information can complement phenotypic characterization where appropriate. Characterization, evaluation, documentation and distribution are therefore integral components of plant genetic resource management and facilitate the effective use of conserved diversity in crop improvement (FAO, 2014; FAO, 2022).

Conclusion

Maize germplasm represents a valuable reservoir of genetic diversity for crop improvement. Its long-term value, however, depends on maintaining this diversity accurately and making it accessible for effective use. As breeding priorities evolve in response to changing production environments, emerging stresses and new market requirements, well-maintained germplasm will continue to provide essential genetic resources for maize improvement. The ultimate

success of conservation therefore lies in keeping genetic diversity available, reliable and ready for use by present and future generations of maize breeders.

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One Cell at a Time: Single-Cell Sequencing in Plant Science and Plant Pathology

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Abstract
A plant organ is a mosaic of cell types and, during infection, a mosaic of dying, defending and unaffected cells. Bulk RNA sequencing averages them, so responses confined to a few cells disappear. Single-cell and single-nucleus sequencing barcode transcripts from thousands of individual cells in parallel, recovering cell identity, developmental trajectories and response heterogeneity in one experiment. This article explains why the plant cell wall delayed adoption, compares protoplast and nucleus isolation, and reviews the first plant cell atlases, single-cell chromatin accessibility and spatial transcriptomics. It then considers applications in plant pathology, including single-cell profiles of infected leaves, dual host–pathogen sequencing and bacterial single-cell RNA sequencing, and outlines common pitfalls and practical guidance for a first experiment.

Keywords: Single-cell RNA sequencing, single-nucleus RNA sequencing, spatial transcriptomics, plant–pathogen interaction, cell atlas.

Introduction
A leaf is not one thing. It contains epidermis, mesophyll, guard cells, vascular bundles and trichomes and, during infection, a shifting mosaic of cells that are dying, defending or unaware that anything is wrong. Extracting RNA from the whole leaf blends all of this into one average, so a gene strongly induced in the few cells around an infection site can vanish against thousands of untouched ones. Cell-level resolution once required laser capture microdissection, which cuts identified cells from a section before RNA extraction (Kerk et al., 2003), but it is slow and requires knowing in advance which cells matter. Single-cell sequencing removes that constraint by barcoding transcripts from thousands of individual cells in parallel (Fig. 1). In animal systems this became routine around 2015; plants took longer, for a reason that is entirely physical.

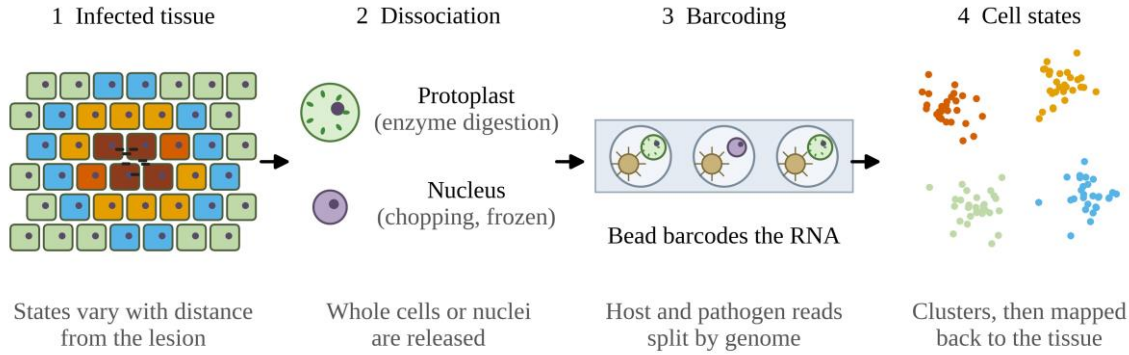


Figure 1. Single-cell workflow for infected plant tissue. Cell states in an infected leaf vary with distance from the lesion; cells are released as protoplasts by enzyme digestion or as nuclei by chopping; each cell or nucleus is encapsulated with a barcoded bead, and host and pathogen reads are separated by genome; cell states are then recovered as clusters and mapped back to the tissue. Drawn schematic; colours denote cell states and cluster positions are illustrative, not measured.

Why Plants Were Late: The Cell Wall?
Animal tissue dissociates after a brief protease treatment, but plant cells are cemented together inside rigid polysaccharide walls. Releasing them requires digestion with cellulases and pectinases to produce protoplasts, which takes one to several hours under osmotic support. Protoplasting is itself a stress treatment that induces a large set of genes unrelated to the biological question, and these must be identified and removed computationally before interpretation (Denyer et al., 2019). Digestion efficiency also varies by cell type, so vasculature, sclerenchyma and mature leaf cells are under-represented. The workaround is to sequence nuclei instead: single-nucleus RNA sequencing (snRNA-seq) releases nuclei from frozen tissue by mechanical chopping, avoiding enzymatic stress and opening recalcitrant and archived material to analysis (Farmer et al., 2021). Nuclei hold less RNA, so sensitivity is lower, but for woody tissue, field-grown roots or stored samples it is often the only option.

The First Plant Cell Atlases

Plant single-cell biology began in 2019 with several independent studies of the *Arabidopsis thaliana* root, chosen for its simple, well-characterised anatomy (Denyer et al., 2019; Jean-Baptiste et al., 2019; Ryu et al., 2019). Known root cell types were recovered without supervision, and developmental trajectories from the stem-cell niche to differentiated cells were reconstructed from transcriptome similarity alone. Profiling heat-stressed roots showed that the response differed strongly between cell types (Jean-Baptiste et al., 2019), a pattern that generalises: a bulk stress profile is a weighted average of several cell-type programmes and may resemble none of them. Crop atlases followed, for example resolving meristem populations in the maize shoot apex (Satterlee et al., 2020), and coordinated efforts now aim to build reference cell atlases across plant species (Rhee et al., 2019).

Beyond the Transcriptome

Single-cell ATAC-seq maps accessible chromatin in each cell and has linked cell identity to regulatory elements in the *Arabidopsis* root (Dorrity et al., 2021); pairing it with snRNA-seq in the same tissue connects accessibility to expression (Farmer et al., 2021). In maize, a single-cell atlas of accessible chromatin identified cell-type-specific cis-regulatory elements genome-wide and connected them to phenotypic variation (Marand et al., 2021), showing breeders which regulatory variants act in which cells. Dissociation, however, destroys position. Spatial transcriptomics captures transcripts on barcoded slides from intact sections and has been adapted to plant tissues (Giacomello et al., 2017), while PHYTOMap provides multiplexed, single-cell-resolution spatial gene expression in whole-mount plant tissue without protoplasting or transgenic reporters (Nobori et al., 2023). Current best practice combines the two: single-cell sequencing defines the states present, and spatial methods place them back in the tissue.

Single-Cell Approaches in Plant Pathology

Infection is spatially heterogeneous and asynchronous: within one lesion, neighbouring cells may be undergoing hypersensitive death, mounting salicylic acid-dependent defence, being pushed towards susceptibility by effectors or simply responding to signals, and bulk sequencing collapses these into one profile (Fig. 2). Single-cell profiling of more than 11,000 cells from *Arabidopsis* leaves infected with *Pseudomonas syringae* resolved distinct immune and susceptible cell populations and a continuum between them; reporter imaging placed immune-state cells around colonised substomatal cavities, whereas susceptible states were more widespread and dominated later in infection (Zhu et al., 2023). Because host and pathogen transcripts are captured in the same library, reads can also be split between the two genomes, in principle linking effector expression to the state of the host cell it targets, although few pathogen reads early in infection limit this.

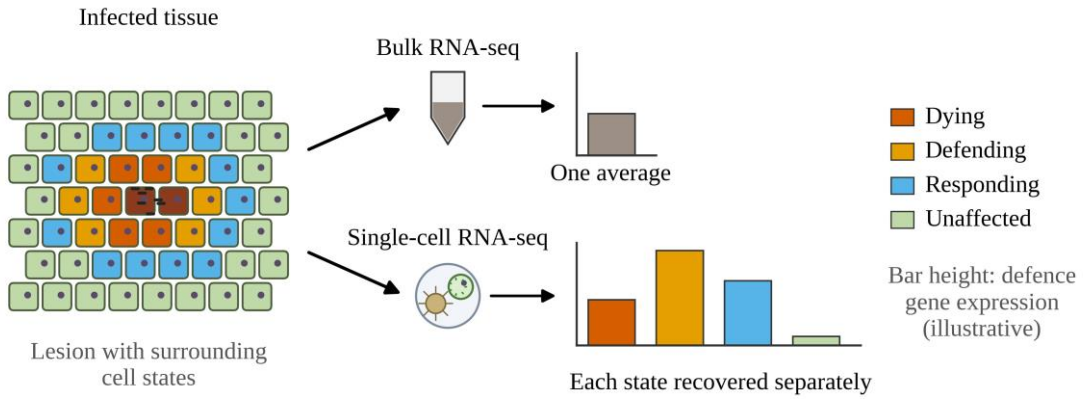


Figure 2. Bulk and single-cell measurement of an infected leaf. Cell states are arranged around the lesion; bulk RNA sequencing returns one weighted average of a defence gene across all cells, whereas single-cell sequencing recovers each state separately. Drawn schematic; bar heights are illustrative, not experimental data.

Bacteria are harder to profile because their mRNA lacks a polyA tail, transcripts are scarce and cells are small. MATQ-seq profiles individual bacteria (Imdahl et al., 2020), and PETRI-seq and microSPLiT barcode transcripts inside fixed cells by split-pool indexing without isolating them (Blattman et al., 2020; Kuchina et al., 2021), revealing transcriptionally distinct subpopulations within clonal cultures. Subpopulations of a pathogen in the apoplast, or of a biocontrol agent on the root, may differ in motility, effector secretion or activity, and these can decide the outcome. The same tools apply to beneficial interactions: single-nucleus profiling of *Medicago truncatula* nodulation distinguished infected from uninfected cells within the same nodule (Cervantes-Pérez et al., 2022).

Pitfalls and Practical Guidance

Protoplasting bias and stress. Cell types that resist digestion are lost, and the protoplasting stress programme overlaps with genuine defence responses (Denyer et al., 2019); in pathology experiments, where defence genes are the readout,

mock-treated protoplast controls are essential, and nuclei are often the safer choice for infected leaves. **Organellar reads.** Chloroplast and mitochondrial transcripts can dominate libraries from green tissue. **Annotation.** Assigning identity to clusters needs marker genes, which are abundant for *Arabidopsis* but scarce in most crops, where orthology to *Arabidopsis* markers is not always sound. **Shallow sampling.** Only a few thousand genes are detected per cell, so lowly expressed regulators are often missed and absence is weak evidence. **Replication.** Thousands of cells from one plant are not independent replicates, so treatment effects must be tested at the level of the plant. A sound first experiment therefore includes mock-inoculated tissue processed identically, several early time points rather than one late one because infection is asynchronous, and a planned spatial or reporter follow-up to confirm where the inferred cell states lie.

Conclusion

Single-cell and spatial methods have turned plant tissues from averages into populations of cells with distinct identities and responses. For plant pathology, the next steps are integrated single-cell and spatial atlases of infected tissue, dual host–pathogen profiling that links effector expression to the host cell it manipulates, and extension to field crops and their pathogens, which depends mainly on genome quality and marker annotation. The broader shift is conceptual: resistance and susceptibility are increasingly seen as properties of cell populations distributed unevenly in space and time. What looks like partial resistance at the whole-plant level may be complete resistance in most cells and failure in a few, and knowing which changes what breeders and engineers should target.

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Exploring the Synergy Between Bamboo and Livestock in Agriculture

Article ID: 74612

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Introduction

Agriculture requires building various structures like fencing and sheds. Building various structures requires building materials. Concrete, metal and plastic is structural making material but it lacks sustainability. Also, it increases the initial investment cost drastically. It is one of the fastest growing plants in the world, capable of growing approximately 90 cm / day.

Importance of Bamboo

Bamboo is highly sustainable with remarkable engineering properties, including high compressive strength (40-80 N/mm^2), and a lightweight nature. It is a versatile natural composite composed of cellulose, lignin, and fiber, commonly used in construction, flooring, textiles, and furniture. Additionally, it has comparatively higher tensile strength than that of steel and various conventional fibers. Due to these properties, it is often referred to as "natural steel". Properly treated bamboo structures can last 10-20 years, while untreated bamboo may last 2-5 years depending on climate and management. Bamboo housing can reduce construction costs by 30-50% compared to conventional brick, cement, or steel structures, making it highly beneficial for small and marginal farmers.

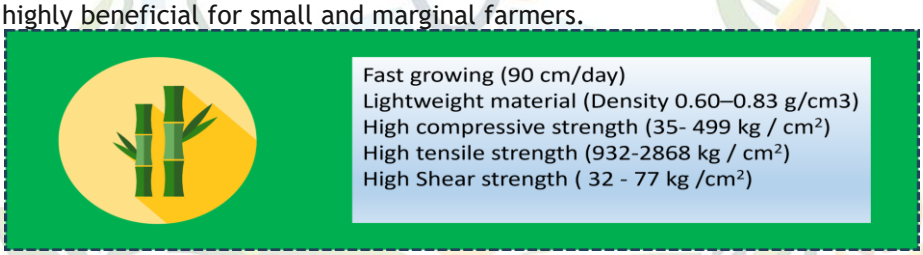


Fig 1. Properties of bamboo

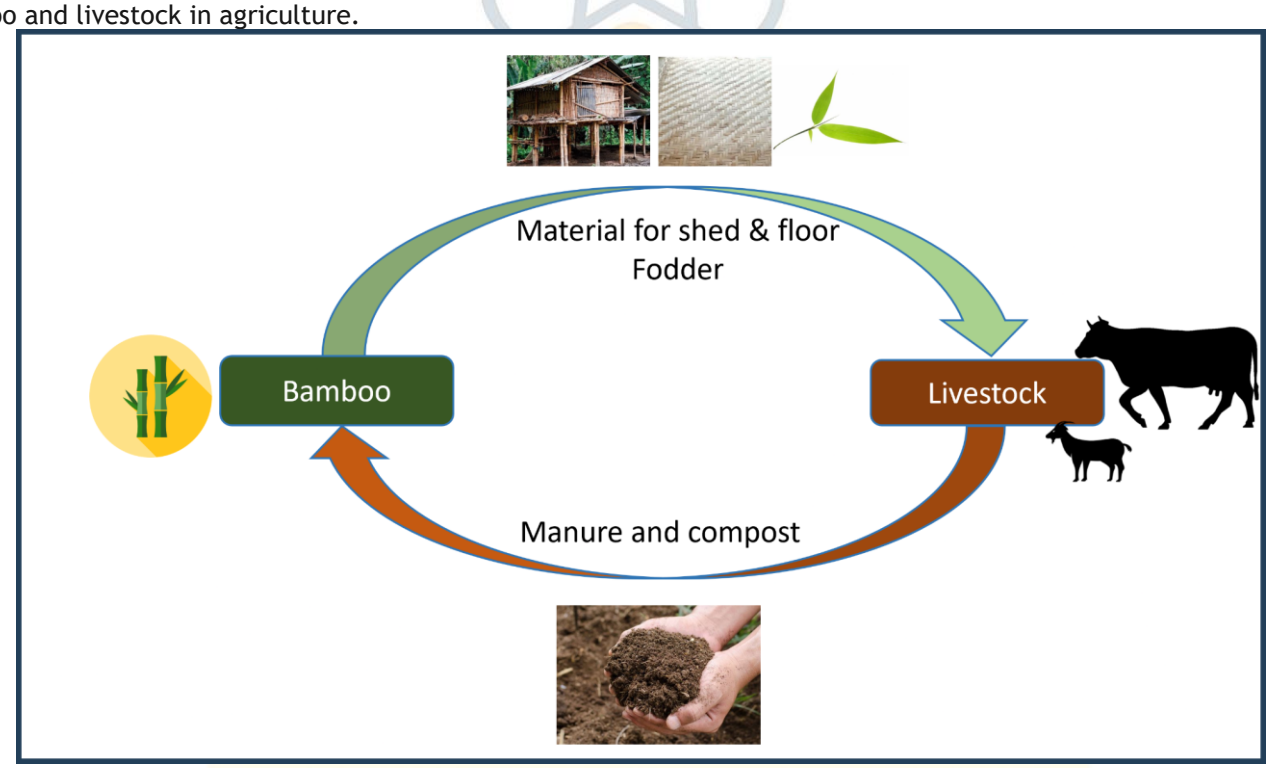
Integrated farming and agro-silvopastoral system is suitable for India particularly for north east. It has livestock rearing as one of the components which requires sheds for their protection from weather elements (heat, cold and rain). Bamboo, along with other natural materials, is a sustainable solution for making such housing structures. Bamboo has hollow culms which provide natural insulation. Owing to its low thermal conductivity reducing surrounding air temperature by up to 8°C. It is economical, often locally available and has a high strength to weight ratio. It has low thermal conductivity making the shed cooler in hot summers compared to metal sheds. This reduces biotic and abiotic stress on livestock enhancing its health and wellbeing consequently generating high profits. It can also be used as flooring for goats and poultry sheds allowing manure and urine to fall through, which keeps the living area dry and reduces gastrointestinal parasite infections. Also, the structures made from bamboo are modular and adaptable and can be easily assembled and disassembled. Some of the bamboo species cultivated for such purpose are *Bambusa tulda*, *Bambusa bambos* (Thorny Bamboo), *Dendrocalamus strictus* (Male Bamboo), *Bambusa tulda* (Bengal Bamboo), and *Melocanna baccifera* (Muli Bamboo).



Fig 2. Bamboo shed for poultry in the North east region of India

Additionally bamboo leaves and young shoots are rich in protein (8–12%), 20-35% crude fiber, 45-60% neutral detergent fiber (NDF), and various minerals which makes it a perfect fodder source for livestock. It contains bioactive compounds (flavonoids, antioxidants) that enhance immunity and promote better weight gain in livestock. It remains green and retains its nutritional value during winter or dry periods making it a secure source of fodder for goats, cows, and horses. Pellet-based bamboo feed, especially using *M. baccifera* in formulation, can effectively meet livestock dietary requirements while supporting feed security and sustainability. It also reduces the dependency on expensive and conventional feed concentrates bringing down the cost of livestock rearing. This is the region why bamboo is often referred to as "Green Gold.

On the other hand, livestock manure is an excellent organic nutrient source for bamboo growth. It supplies essential nutrients such as nitrogen (N), phosphorus (P) and potassium (K) while improving soil structure and microbial activity. On average, well-decomposed cattle manure contains about 0.5-1.5% N, 0.2-0.8% P_2O_5 and 0.5-1.0% K_2O, whereas goat manure is comparatively richer, containing 1.5-3.0% N, 1.0-2.0% P_2O_5 and 1.0-3.0% K_2O. Application of 10-20 kg farmyard manure (FYM) per bamboo clump annually or 5-10 tonnes manure per hectare has been reported to enhance shoot emergence, culm production and biomass yield. Organic manure also increases soil organic carbon, moisture retention and root development, which are especially beneficial for bamboo due to its shallow fibrous root system. Integrating livestock with bamboo cultivation allows efficient recycling of animal waste into productive biomass, reducing dependence on chemical fertilizers and promoting sustainable farming systems. Hence there exist a synergy between bamboo and livestock in agriculture.



The major constraint is that bamboo has been still used traditionally. Research and development for its processing, product and feed is the need of the hour for making it readily available for everyone. National bamboo mission is underway for developing the complete value chain of the bamboo sector. This centrally sponsored mission focuses on increasing plantations, improving processing, and strengthening marketing. Like the revolution the wood industry has seen with the advent of plywood. A similar revolution is the need of the hour for the bamboo industry. Cultivation in large areas and product development will enhance availability, sustainably, and accessibility of farmers to bamboo as structure and fodder material for livestock.

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Awareness of Soil Testing Among Farmers in Nashik District, Maharashtra

Article ID: 74613

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Abstract
Soil testing is an important scientific tool for assessing soil fertility and promoting balanced fertilizer application. The present article discusses farmers' awareness of soil testing in Nashik district, Maharashtra. The district has diverse agricultural systems, including grape, onion, pomegranate, and vegetable cultivation. A study by Pagar (2020), based on interviews with 210 farmers conducted in 2019, reported considerable gaps in knowledge about soil testing, soil sample collection, soil nutrients, and the Soil Health Card (SHC) scheme. The findings highlight the need for farmer education, accessible soil testing facilities, and effective agricultural extension services. Increasing awareness can help farmers improve nutrient management, reduce unnecessary fertilizer expenditure, and promote sustainable agriculture.

Keywords: Soil testing, farmer awareness, soil fertility, Soil Health Card, Nashik district, sustainable agriculture.

Importance
Agriculture plays an important role in the economy of Nashik district, Maharashtra. Farmers cultivate various crops, including grapes, onion, pomegranate, vegetables, and cereals. Maintaining soil fertility is essential for improving crop productivity and agricultural income. Soil testing is the scientific analysis of soil to determine its nutrient status and other important properties, such as pH and electrical conductivity. It helps farmers understand the nutrient requirements of their crops and apply fertilizers according to soil test recommendations. However, farmers may continue using fertilizers based on traditional practices, previous experience, or advice from input suppliers without knowing the actual nutrient status of their fields. This can increase cultivation costs and contribute to imbalanced nutrient application. Therefore, assessing farmers' awareness of soil testing is important for developing effective agricultural extension programmes.

Objectives of the Study
1. To assess farmers' awareness of soil testing in Nashik district.
2. To examine farmers' knowledge of soil sample collection and soil nutrient status.
3. To study awareness of the Soil Health Card scheme.
4. To identify challenges affecting farmers' access to soil testing facilities.
5. To suggest measures for improving awareness and adoption of soil testing practices.

Review of the Existing Study
Pagar (2020) investigated awareness of soil testing among farmers in Nashik district using primary data collected from 210 farmers through structured questionnaires in 2019. The study reported the following findings:

Awareness indicator	Reported finding
Farmers who had no idea about soil testing	44.79%
Farmers without knowledge of proper soil sample collection	Approximately 33%
Farmers with average knowledge of soil sample collection	37.5%
Farmers without knowledge of soil nutrients	66.67%
Farmers with no idea about the Soil Health Card scheme	60.42%
Farmers who had heard of the scheme but were not willing to benefit from it	25%

These findings indicate gaps in farmers' knowledge of soil testing and the use of soil test-based recommendations. The results describe the surveyed farmers in the 2019 study and should not be interpreted as current estimates for all farmers in Nashik district.

Importance of Soil Testing for Nashik Farmers
Soil testing is particularly relevant to farmers growing horticultural and field crops in Nashik district. Regular soil analysis can help farmers:
1. Determine the availability of major and micronutrients.
2. Identify soil acidity, alkalinity, and salinity issues.
3. Apply suitable fertilizers according to crop requirements.
4. Improve fertilizer-use efficiency and manage cultivation expenses.

5. Maintain soil fertility and support long-term crop productivity.

The Soil Health Card system provides soil nutrient information and recommendations for fertilizers and soil amendments. The Government of India's official portal describes the process of soil sampling, laboratory testing, and generation of fertilizer recommendations. Official Soil Health Card Portal information.

Major Constraints Faced by Farmers

The published study identified limited awareness and uneven distribution of soil testing laboratories as important concerns. It also recommended expanding laboratory facilities and strengthening information dissemination through mass media.

Suggestions for Improving Awareness

Awareness can be improved through village-level training programmes, farmer meetings, field demonstrations, and soil testing camps. Agricultural extension officers should explain how to collect representative soil samples, submit them to laboratories, and interpret the results. Information should be communicated in Marathi and other locally understood languages where appropriate. Agricultural universities, Krishi Vigyan Kendras, the Department of Agriculture, and farmer producer organizations can help connect farmers with testing facilities and soil-specific fertilizer recommendations. The Krishi Vigyan Kendra at Nashik also provides soil and water testing and agricultural advisory services. KVK Nashik facilities.

Conclusion

Awareness of soil testing is essential for sustainable agricultural development in Nashik district. The study by Pagar (2020) documented substantial knowledge gaps among surveyed farmers regarding soil testing, soil nutrients, sample collection, and the Soil Health Card scheme. Improving access to testing facilities, providing practical training, and strengthening agricultural extension services can encourage more informed fertilizer management. Further field research is needed to assess current awareness levels and identify differences among farmers across the district's talukas.

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Blue Carbon and Coastal Forestry: Mangrove Conservation for Climate Resilience along Odisha's Vulnerable Coast

Article ID: 74614

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Introduction

Odisha's coastline, stretching along the Bay of Bengal, supports a rich diversity of mangrove forests, coastal wetlands, estuaries, fisheries and rural livelihoods. However, the coastal region faces recurring cyclones, storm surges, coastal erosion, saline-water intrusion and the growing threat of sea-level rise. These hazards pose serious challenges to coastal ecosystems, agriculture, fisheries and the safety of coastal communities. In this context, mangroves are much more than trees growing in seawater. They are natural coastal defence systems and powerful carbon reservoirs. Their capacity to capture carbon dioxide and store carbon in woody biomass, roots and waterlogged sediments has brought them into the spotlight as a nature-based solution to climate change. The carbon stored in mangroves, tidal marshes and seagrass ecosystems is commonly known as blue carbon. Integrating blue-carbon conservation with coastal forestry could help Odisha strengthen climate resilience, conserve biodiversity and support sustainable livelihoods.

Blue Carbon

Blue carbon refers to carbon captured and stored by coastal and marine ecosystems, particularly mangroves, tidal salt marshes and seagrass meadows. Through photosynthesis, plants absorb atmospheric carbon dioxide and convert it into organic matter. Some of this carbon remains stored for long periods in woody biomass and, especially, in sediments where low oxygen conditions slow decomposition.

How Mangroves Store Carbon?

Organic carbon preserved in waterlogged coastal sediments, potentially for centuries or longer when the ecosystem remains intact. Unlike many terrestrial ecosystems, mangroves can store substantial amounts of carbon belowground. When mangrove forests are cleared or sediments are disturbed, part of this stored carbon can be released as greenhouse gases. Protecting existing mangroves is therefore essential, not just planting new trees

1. **Aboveground carbon:** Carbon stored in trunks, branches, leaves and other living vegetation.
2. **Belowground carbon:** Carbon accumulated in roots and associated organic matter beneath the soil surface.

Mangrove Forests of Odisha

A natural heritage: Odisha's mangrove ecosystems are concentrated in estuaries, river deltas, sheltered creeks and tidal wetlands.

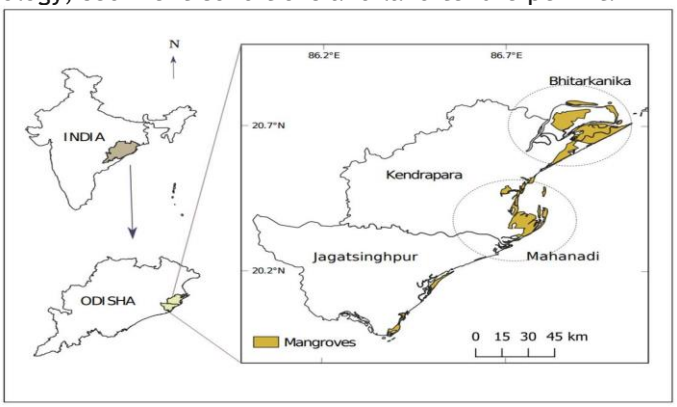
Important mangrove landscapes include:

a. Bhitarkanika and the Brahmani–Baitarani delta: Important for mangrove biodiversity, estuarine habitats and wildlife conservation.

b. Mahanadi delta and associated coastal wetlands: Important for estuarine ecology, fisheries and the conservation of coastal vegetation.

c. Dhamra and adjoining estuarine landscapes: Areas where mangrove conservation must be integrated with development planning and habitat protection.

d. Other suitable tidal creeks and coastal wetlands: Potential sites for scientifically assessed mangrove restoration, where hydrology, sediment conditions and land tenure permit.



How can Mangroves Protect Odisha's Coast?

1. Reduction of wave energy and coastal erosion: Mangrove trunks, aerial roots and dense vegetation interact with incoming water, creating drag and reducing wave energy under suitable conditions. Root networks also help bind sediments and stabilise shorelines. The extent of protection depends on forest width, vegetation structure, water depth, wave characteristics, tides and coastal geomorphology.

2. Buffering storm surges and cyclone impacts: Odisha is vulnerable to severe cyclones originating over the Bay of Bengal. Where mangrove belts are suitably located and sufficiently developed, they can attenuate waves and help reduce some coastal impacts. Their protective effectiveness varies with storm intensity, surge height, local topography and the continuity of the forest. Mangrove conservation can complement cyclone shelters, early-warning systems, evacuation plans and resilient coastal infrastructure.

3. Supporting fisheries and coastal food security: Mangrove roots, tidal creeks and adjacent wetlands provide feeding, nursery and refuge habitats for many fish, crustaceans and other aquatic organisms. These habitats can contribute to productive fisheries and local food systems. Maintaining connections between mangroves, rivers, estuaries and nearshore waters is crucial to sustaining these benefits.

4. Capturing and storing atmospheric carbon: Mangroves absorb carbon dioxide through photosynthesis and store carbon in biomass and sediments. Protecting existing carbon-rich habitats prevents avoidable emissions from degradation, while successful restoration can rebuild carbon stocks over time. The IPCC recognises the mitigation and adaptation benefits of conserving and restoring blue-carbon ecosystems, although outcomes vary with ecological and site conditions.



Mangrove Species Suitable for Odisha's Coastal Landscapes

Mangrove restoration should use locally appropriate native species selected according to tidal elevation, salinity, soil characteristics, inundation frequency and reference ecosystems. Planting every species at every site is neither scientifically sound nor ecologically desirable. Natural regeneration may be preferable wherever seed supply, hydrology and site conditions are already suitable.

Important Mangrove Species of Odisha and Their Ecological Significance

Sl. No.	Common name	Scientific name	Ecological significance
1	Grey mangrove	*Avicennia marina*	Tolerates a wide range of salinity conditions and plays an important role in sediment stabilisation and coastal ecosystem functioning.
2	White mangrove	*Avicennia officinalis*	Contributes to mangrove forest structure, sediment retention and the maintenance of estuarine biodiversity.
3	Loop-root mangrove	*Rhizophora mucronata*	Develops prominent stilt roots that provide habitat for aquatic organisms, trap sediments and help stabilise suitable intertidal areas.
4	Large-leaved orange mangrove	*Bruguiera gymnorhiza*	Contributes to mangrove diversity, forest structure and habitat provision in suitable tidal environments.
5	Yellow mangrove	*Ceriops decandra*	Occurs in suitable intertidal habitats and contributes to vegetation diversity and the ecological stability of mangrove communities.
6	Cannonball mangrove	*Xylocarpus granatum*	Contributes to the structural diversity of mangrove forests and provides habitat for associated fauna in suitable estuarine environments.

7	Mangrove apple	*Sonneratia apetala*	Contributes to sediment stabilisation, coastal habitat development and the ecological functioning of suitable estuarine mangrove systems.

Blue Carbon and Economic Opportunities for Coastal Communities

Mangroves provide economic benefits through fisheries, non-timber forest products where harvesting is permitted, nature-based tourism, restoration employment and potential climate-finance mechanisms. The Government of India's Mangrove Initiative for Shoreline Habitats & Tangible Incomes (MISHTI), launched in June 2023, aims to promote mangrove restoration and conservation while strengthening coastal livelihoods.

Coastal Communities Earn Carbon-Credit Income

Mangrove restoration and conservation projects may qualify for carbon finance if they meet the requirements of an applicable carbon-credit programme. However, carbon credits are not automatic payments for planting trees.

A credible project must establish:

1. A scientifically defensible baseline and additional climate benefits.
2. Reliable measurement of carbon-stock changes and greenhouse gas emissions.
3. Permanence safeguards against future forest loss, erosion and other carbon reversals.
4. Procedures to address leakage, uncertainty and double counting.
5. Clear land and carbon rights, community consent, benefit sharing and independent verification.

A Roadmap for Strengthening Coastal Forestry in Odisha

1. Mangrove Conservation: Protect existing mangrove forests and prevent habitat degradation.

2. Scientific Restoration: Promote natural regeneration and restore tidal hydrology before undertaking plantation activities.

3. Integrated Coastal Planning: Incorporate mangrove conservation into coastal zone management and climate adaptation plans.

4. Blue Carbon Assessment: Quantify carbon stored in mangrove biomass and sediments through field surveys.

5. Remote Sensing and GIS: Monitor mangrove cover, degradation and restoration success using satellite imagery.

6. Community Participation: Engage local communities, women's self-help groups and panchayats in conservation and livelihood development.

7. Research and Monitoring: Establish long-term monitoring sites to assess biodiversity, carbon stocks and ecosystem health.

8. Policy Coordination: Strengthen collaboration among forest departments, coastal authorities, research institutions and local communities.

Conclusion

Mangroves represent one of Odisha's most valuable natural assets in the face of climate change. They store carbon, support fisheries, sustain biodiversity, trap sediments and can reduce certain coastal hazards when ecological and physical conditions are favourable. Their conservation can also create opportunities for restoration employment, environmental education and sustainable livelihoods. Odisha's future coastal forestry strategy should therefore move beyond counting seedlings and measuring green cover. The way forward is clear: protect what remains, restore what has been degraded, measure what improves and involve the people whose lives are closely connected to the coast.

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Scientific Approaches to Seed Storage

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Seed is the fundamental input in agriculture and plays a crucial role in ensuring good crop establishment, higher productivity, and food security. The quality of seed directly influences germination, plant vigor, crop growth, and final yield. However, after harvest, seeds are highly vulnerable to deterioration caused by moisture, insects, fungi, rodents, and improper storage conditions. Therefore, scientific seed storage and proper precautions are essential to maintain seed viability and quality until the next sowing season. Cereals, millets, oilseeds, and pulses differ in their seed composition and storage behavior, requiring specific care during storage.

Seed storage refers to the process of preserving seeds under suitable environmental conditions to maintain their germination capacity and vigor for future use. The main objective of seed storage is to minimize seed deterioration and protect the seed from physical, biological, and environmental damage. Good storage practices help farmers reduce post-harvest losses, ensure timely seed availability, and maintain genetic purity.

Among all factors affecting seed storage, moisture content is the most critical. Seeds with high moisture content respire more actively, generating heat and favoring the growth of insects and storage fungi. Generally, cereal and millet seeds should be dried to about 10–12% moisture before storage, while oilseeds require even lower moisture levels, around 7–8%, due to their high oil content. Pulses should also be adequately dried to avoid fungal infection and insect infestation. Proper sun drying before storage is one of the simplest and most effective methods adopted by farmers.

Safe Moisture Levels for Seed Storage

Seed group	Examples	Recommended moisture level
Cereals	Rice, wheat, maize	10-12%
Millets	Sorghum, pearl millet, finger millet	10-12%
Oil seeds	Groundnut, soybean, mustard, sunflower	7-8%
Pulses	Chickpea, pigeon pea, mungbean, blackgram	9-10%

Seeds should be dried on clean floors or tarpaulins and protected from sudden rains or excess heat exposure.

Storage structures also play an important role in preserving seed quality. Traditional storage structures such as earthen pots, bamboo bins, gunny bags, and metal containers are commonly used in rural areas. However, improved storage structures like airtight bins, HDPE bags, silos, and scientific godowns provide better protection against moisture and pests. The storage room should be clean, dry, cool, and well ventilated. Seeds should never be stored directly on the floor; instead, wooden pallets should be used to avoid moisture absorption from the ground. Regular cleaning and disinfection of storage structures before filling seeds are necessary to prevent carryover of insects and pathogens.

Cereal seeds such as rice, wheat, and maize are comparatively easier to store because of their lower oil content. However, they are highly susceptible to insect pests like rice weevil, grain moth, and lesser grain borer. Therefore, cereal seeds should be cleaned properly to remove broken grains and foreign materials before storage. The use of neem leaves, ash, or botanical protectants can help reduce insect infestation under traditional storage systems. In scientific storage, fumigation with approved chemicals may be carried out under expert supervision.

Millets such as sorghum, pearl millet, finger millet, and foxtail millet are known for their better storage ability compared to other grains. Finger millet, in particular, can be stored for several years without serious deterioration if maintained under dry conditions. However, moisture and insect attack can still reduce seed quality. Millet seeds should be thoroughly dried and stored in moisture-proof containers to preserve their germination and nutritional quality. Since millets are gaining importance as climate-resilient and nutritious crops, proper storage is essential to minimize losses and ensure seed availability for future cultivation.

Oilseeds such as mustard, groundnut, soybean, sesame, and sunflower are more difficult to store because their high oil content accelerates seed deterioration. Oilseeds are highly sensitive to temperature and moisture fluctuations, leading to rapid loss of viability and rancidity. Groundnut and soybean seeds, for example, lose germination quickly under humid conditions. Therefore, oilseeds should be dried carefully to safe moisture levels and stored in cool and dry environments. Excessive drying temperatures should also be avoided because they may damage seed embryos and reduce germination. Airtight storage containers are often preferred for oilseeds to prevent moisture absorption and oxidative damage.

Pulses such as chickpea, pigeon pea, lentil, mungbean, and blackgram are highly prone to storage pests, particularly bruchids or pulse beetles. These insects damage seeds internally, reducing both seed quality and market value. Pulses should be cleaned, dried properly, and stored in insect-proof containers. Farmers often use traditional practices such as mixing edible oils, ash, turmeric powder, or neem products with pulse seeds to reduce insect attack. Regular inspection during storage is important to detect early infestation and prevent severe damage.

Apart from insects and moisture, fungal contamination is another major concern during storage. Fungi such as Aspergillus and Penicillium grow rapidly under humid conditions and may produce harmful toxins that affect seed quality and human health. Proper drying, aeration, and maintenance of low humidity can effectively reduce fungal growth. Damaged or infected seeds should be removed before storage to prevent contamination of healthy seeds.

Temperature management is equally important for long-term seed storage. High temperatures accelerate seed respiration and ageing, leading to rapid loss of viability. Cool storage conditions help prolong seed life. In seed processing units and research institutions, cold storage facilities are often used to preserve breeder and foundation seeds for extended periods. However, even under farm-level conditions, maintaining seeds in shaded, cool, and dry places can significantly improve storage life.

Regular monitoring of stored seeds is essential to maintain quality. Farmers and seed handlers should inspect seeds periodically for signs of insect infestation, fungal growth, moisture accumulation, or rodent damage. Rodents not only consume seeds but also contaminate them with urine and droppings. Proper sanitation, traps, and rodent-proof storage structures are necessary to minimize losses.

Major Steps of Scientific Seed Storage

HARVESTED SEED
↓
PROPER DRYING
↓
CLEANING AND GRADING
↓
SAFE MOISTURE CONTENT
↓
SUITABLE STORAGE STRUCTURE (Dry + Cool + Clean)
↓
PEST & FUNGUS CONTROL
↓
REGULAR MONITORING
↓
MAINTAIN SEED QUALITY (Viability + Vigour)
↓
HEALTHY SEED FOR NEXT SEASON

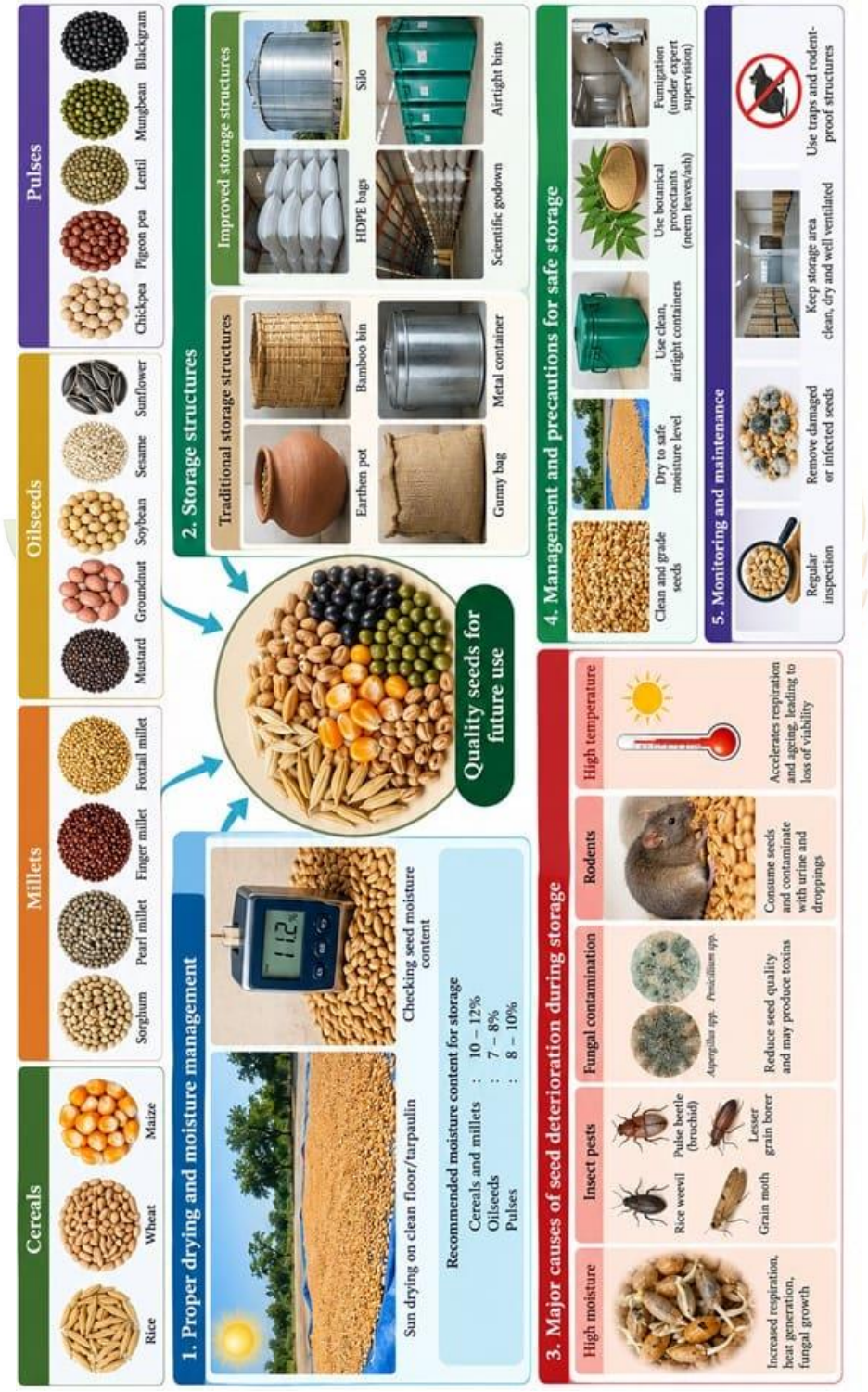
Storage of Kharif and Rabi Crop Seeds

Aspect	Kharif crops	Rabi crops
Major crops	Rice, maize, sorghum, pearl millet, soybean, ground nut, cotton	Wheat, chickpea, lentil, mustard, peas, linseed
Usual sowing time	Monsoon season	Winter season
Usual harvesting time	Oct-nov	Apr-may
Harvest-time conditions	Often warm and humid, late seasons may occur	Generally cooler and drier
Main storage concern	High moisture at harvest, fungal growth and insects	Insects, moisture fluctuation and deterioration during warm summer storage
Important precaution	Thorough drying before storage is especially important	Proper drying and cool, dry storage are important for maintaining viability until next season

In conclusion, seed storage is a vital component of sustainable agriculture and food security. Proper drying, cleaning, moisture management, pest control, and suitable storage structures are key factors in maintaining seed quality during storage. Cereals, millets, oilseeds, and pulses each require specific precautions based on their seed characteristics and storage behaviour. Adoption of scientific storage practices can greatly reduce post-harvest losses, preserve seed viability, and ensure healthy crop production in the next season. By improving awareness and implementing proper storage techniques, farmers can safeguard their valuable seed resources and enhance agricultural productivity.

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Role of Plant Quarantine in Safeguarding Agricultural Ecosystems Against Invasive Alien Pests

Article ID: 74616

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Abstract

The increasing international movement of agricultural commodities, seeds, planting materials, and other biological products has increased the risk of introducing and spreading invasive alien pests. These organisms can damage crops, reduce agricultural productivity, threaten biodiversity, disturb ecological balance, and cause substantial economic losses. Plant quarantine is a fundamental component of agricultural biosecurity that prevents the introduction and dissemination of harmful plant pests and pathogens through inspection, pest risk analysis, laboratory diagnosis, surveillance, phytosanitary certification, and appropriate treatments. International frameworks, particularly the International Plant Protection Convention (IPPC) and the World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures, provide the foundation for phytosanitary regulation. In India, the Plant Quarantine (Regulation of Import into India) Order, 2003, and the Destructive Insects and Pests Act, 1914, support the regulation of plant materials. Modern technologies, including molecular diagnostics, artificial intelligence, remote sensing, and digital traceability, can further strengthen quarantine operations. This article discusses the importance, functions, challenges, and future prospects of plant quarantine in protecting agricultural ecosystems and promoting sustainable agriculture.

Keywords: Plant quarantine, invasive alien pests, agricultural biosecurity, phytosanitary measures, pest risk analysis, invasive species, sustainable agriculture.

Introduction

Agriculture supports food security, rural livelihoods, economic development, and environmental stability. However, agricultural ecosystems are increasingly threatened by invasive alien pests and plant pathogens. Globalization, international trade, tourism, climate change, and the movement of planting materials have increased the possibility of pests entering areas where they were previously absent.

Invasive alien pests are organisms introduced outside their natural geographical range that establish and spread in new environments, causing or potentially causing economic, environmental, or social harm. They include insects, mites, nematodes, fungi, bacteria, viruses, and invasive weeds. Their introduction can reduce crop yields, damage native vegetation, disturb ecological interactions, and increase pesticide use.

Plant quarantine involves legal and scientific measures to prevent the introduction and spread of regulated plant pests. Unlike conventional pest management, which generally controls pests after establishment, quarantine emphasizes prevention, early detection, and rapid response. An effective quarantine system is therefore essential for protecting agricultural production, biodiversity, and national food security.

Impact of Invasive Alien Pests on Agricultural Ecosystems

Invasive alien pests can cause serious agricultural, economic, and ecological problems. Their establishment depends on factors such as climatic suitability, host availability, reproductive capacity, and the absence of effective natural enemies.

1. Agricultural and economic losses: Invasive pests damage plant leaves, roots, stems, flowers, fruits, and seeds, reducing yield and market quality. Farmers may incur additional costs for pesticides, labour, monitoring, and crop protection. Pest interceptions may also result in restrictions on agricultural exports.

2. Ecological disturbance: Some invasive organisms attack native plants, compete with indigenous species, and disrupt food webs. Damage to native vegetation may affect pollinators, birds, beneficial insects, and other organisms dependent on those plants.

3. Increased pesticide use: Newly introduced pests may multiply rapidly in the absence of natural enemies. Increased pesticide applications can raise production costs, harm beneficial organisms, contaminate soil and water, and contribute to pesticide resistance.

4. Threats to food security: Severe infestations can reduce food availability and farmers' incomes, particularly when staple crops or economically important horticultural crops are affected. Preventing pest introduction is generally more effective and less costly than controlling widely established populations.

Concept, Objectives, and Major Functions of Plant Quarantine

Plant quarantine is a preventive regulatory system governing the movement of plants, seeds, plant products, and other regulated articles. Its main objectives are to prevent exotic pest introduction, restrict pest movement, detect infestations early, support eradication and containment, protect biodiversity, and facilitate safe agricultural trade.

1. Inspection of plant materials: Inspection is conducted at designated entry points, including airports, seaports, and land-border stations. Regulated consignments are examined for insects, eggs, larvae, disease symptoms, fungal growth, and other signs of infestation. Samples may be collected for laboratory diagnosis.

Depending on applicable regulations and the identified risk, consignments may be released, treated, detained, re-exported, or destroyed. Since visual inspection cannot detect all microscopic organisms or latent infections, it must be supported by appropriate sampling and laboratory testing.

2. Pest Risk Analysis: Pest Risk Analysis (PRA) evaluates the likelihood of pest introduction, establishment, and spread, together with the potential economic and environmental consequences. It considers pest biology, host range, geographical distribution, entry pathways, and available management options.

PRA enables authorities to identify high-risk commodities and determine suitable phytosanitary measures. These measures should be scientifically justified and proportionate to the assessed risk.

3. Phytosanitary certification: Phytosanitary certificates are issued by authorized plant protection authorities to confirm that regulated consignments meet the applicable import requirements of the receiving country. Certification supports safe international trade and reduces the risk of transporting regulated pests. Its effectiveness depends on reliable inspection, sampling, testing, and certification procedures.

4. Treatment and post-entry quarantine: Phytosanitary treatments may include approved heat treatment, cold treatment, fumigation, or other validated methods, depending on the pest and commodity. Treatment must effectively control the target organism without causing unacceptable damage to the product or unnecessary risks to workers and the environment.

High-risk planting materials may also undergo post-entry quarantine, during which they are maintained under controlled conditions and inspected or tested for latent infections before being released for cultivation.

5. Surveillance and rapid response: Surveillance involves regular field inspections, trapping, laboratory testing, and monitoring of nurseries, markets, and high-risk agricultural areas. Early detection allows authorities to confirm pest identity, conduct delimiting surveys, trace affected consignments, impose movement restrictions, and implement eradication or containment measures before the pest spreads widely.

International and National Plant Quarantine Frameworks

1. International frameworks: The **International Plant Protection Convention (IPPC)** is an international treaty administered through the Food and Agriculture Organization of the United Nations (FAO). It aims to prevent the introduction and spread of plant pests and promotes cooperation among national plant protection organizations. The IPPC develops International Standards for Phytosanitary Measures (ISPMs) covering pest risk analysis, inspection, surveillance, certification, and other plant health procedures.

The **World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement)** provides a framework for measures protecting plant, animal, and human health. It emphasizes scientific justification, risk assessment, transparency, and the avoidance of unjustified restrictions on international trade.

2. Plant quarantine system in India: India's plant quarantine system is important because of its diverse agricultural crops, varied climatic conditions, and extensive domestic and international movement of agricultural commodities.

The principal legal instruments include the **Destructive Insects and Pests Act, 1914**, and the **Plant Quarantine (Regulation of Import into India) Order, 2003, as amended**. These provide the regulatory basis for controlling the import of plants, plant products, and specified materials through prescribed phytosanitary conditions, inspection, and treatment.

The Directorate of Plant Protection, Quarantine and Storage (DPPQ&S), under the Department of Agriculture and Farmers Welfare, Government of India, plays an important role in plant protection and quarantine administration. Effective implementation requires coordination among quarantine authorities, research institutions, customs agencies, agricultural universities, traders, nursery operators, and farmers.

Examples of Invasive Alien Pests

Several invasive pests demonstrate the importance of quarantine, early detection, and coordinated management.

Pest or organism	Major host	Significance
Fall armyworm (*Spodoptera frugiperda*)	Maize and other grasses	Rapid spread and serious crop damage
Tomato leaf miner (*Tuta absoluta*)	Tomato	Leaf mining and fruit damage

Cotton mealybug (*Phenacoccus solenopsis*)	Cotton and other plants	Sap feeding and plant weakening
Citrus greening-associated *Candidatus Liberibacter* species	Citrus	Serious disease affecting tree health and fruit production

Note: Pest distribution and regulatory status vary by country and over time.

Fall armyworm, originally from the Americas, has spread to Africa and Asia. Its larvae damage maize foliage and growing points, while adult moths can disperse over long distances. Surveillance, early reporting, and integrated pest management are therefore important alongside quarantine.

Tuta absoluta, a tomato pest originating in South America, damages leaves, stems, and fruits. Monitoring traps, clean planting materials, inspection of relevant pathways, and timely control measures help reduce its spread.

Citrus greening, or Huanglongbing, is associated with *Candidatus Liberibacter* bacteria and is transmitted by psyllid insect vectors. The disease causes leaf symptoms, malformed fruits, reduced productivity, and tree decline. Healthy, appropriately tested planting material and vector management are important measures for reducing its spread.

These examples demonstrate that quarantine must be integrated with field surveillance, reliable diagnostics, and effective management after detection.

Emerging Technologies for Plant Quarantine

Modern technologies can improve the accuracy, speed, and coverage of quarantine operations.

1. Molecular diagnostics: Polymerase chain reaction (PCR), real-time PCR, and DNA-based identification methods can detect pests and pathogens that are difficult to identify visually. These techniques are particularly useful for latent infections and organisms present at low concentrations.

2. Artificial intelligence and machine vision: AI-based image analysis can assist in identifying insects, recognizing plant symptoms, and prioritizing suspicious consignments. However, its results require validation and, where necessary, expert examination or laboratory confirmation.

3. Remote sensing and geographical information systems: Satellite imagery, drone surveys, and GIS can help map host crops, assess environmental suitability, identify affected areas, and support landscape-level surveillance. Field verification remains necessary because remote sensing often identifies symptoms rather than the pest itself.

4. Electronic certification and digital traceability: Digital systems can improve certificate verification, treatment records, consignment tracking, and communication between exporting and importing authorities. Reliable data, trained staff, cybersecurity, and interoperable systems are essential for their success.

5. Predictive surveillance: Climate data, host distribution, transport routes, and historical pest records can be combined to identify areas at greater risk of pest introduction and establishment. Such models can guide surveillance priorities but should complement statutory requirements and expert judgment.

Challenges and Strategies for Improvement

Plant quarantine faces several challenges, including increasing global trade, informal movement of seeds and plants, limited diagnostic facilities, shortages of trained personnel, changing climatic conditions, and insufficient public awareness. Inconsistent implementation and the cost of advanced technologies can further weaken quarantine systems.

The following strategies can improve plant biosecurity:

1. Strengthen risk-based inspection: Prioritize high-risk commodities, pathways, and entry points through appropriate sampling and validated testing.

2. Improve surveillance networks: Coordinate monitoring among agricultural universities, research institutions, extension agencies, nurseries, and farmers.

3. Build diagnostic capacity: Invest in plant health laboratories, molecular testing, taxonomic expertise, and trained personnel.

4. Promote awareness: Educate farmers, traders, nursery operators, and travellers about regulated plant materials and the importance of reporting unusual pests.

5. Develop rapid-response plans: Establish procedures for pest confirmation, tracing, containment, eradication, and emergency communication.

6. Encourage international cooperation: Share pest alerts, diagnostic information, and surveillance findings through recognized phytosanitary channels.

7. Integrate quarantine with sustainable pest management: Combine prevention with integrated pest management, biological control, resistant varieties, and crop sanitation to minimize environmental damage.

Future Prospects

The future of plant quarantine will depend on integrating scientific research, digital technologies, international cooperation, and ecosystem-based management. Automated screening, molecular identification, electronic phytosanitary certification, and predictive surveillance can improve early detection and response. An important priority is the development of interconnected plant health information systems linking border interceptions, laboratory results, field surveillance, climate information, and commodity traceability. Such systems can help authorities identify emerging threats and respond before pests become widely established.

Nevertheless, technology must be supported by trained personnel, adequate infrastructure, reliable funding, and transparent governance. Plant quarantine should be viewed as a preventive investment that protects agricultural productivity, biodiversity, rural livelihoods, and sustainable development.

Conclusion

Plant quarantine is a cornerstone of agricultural biosecurity and an essential instrument for safeguarding agricultural ecosystems against invasive alien pests. Inspection, pest risk analysis, phytosanitary certification, diagnostic testing, surveillance, and rapid response reduce the likelihood that harmful organisms will enter and establish in new environments. Increasing international trade, changing climatic conditions, and emerging pest threats make preventive measures more important than ever. In India, effective implementation of quarantine regulations, modern diagnostic technologies, stronger surveillance, farmer awareness, and international cooperation can protect crops, biodiversity, and rural livelihoods.

Ultimately, plant quarantine is not merely a border-control activity but an integrated plant health strategy. A proactive, science-based, and risk-oriented quarantine system is essential for resilient agricultural ecosystems, sustainable agriculture, and long-term food security.

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Decorative Berries

Article ID: 74617

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Blueberries

These berries grow in wild and cultivated forms in Canada and the Northern regions of the United States of America. The British wild type *Vaccinium myrtillus* (known as whortle berry, whin berry, bil berry and blae berry) is related to them. It grows on acid moorlands and produces small fruits that, although palatable, are inferior to garden forms. The fruiting season for cultivated varieties is from late summer to late autumn.

Species of Cultivated Blue Berry

The species most grown for its fruits is *Vaccinium corymbosum,* known as the high bush blueberry; this has also been a recognized ornamental garden plant for a considerable time. Several named varieties with improved fruits have been raised from it.

The general habit of the species is dense, rounded and twiggy with a height of 1.5- 2.2 m according to variety. The leaves vary in size from about 2-9 cm long. They are bright green in summer, turning gradually to red in the autumn. Clusters of six or more small, white or pale pink flowers appear in early summer (May) before the leaves are fully expanded. The black, blue bloomed berries also appear in clusters and ripen during early and mid-autumn (August and September). They make delicious pies and other desserts, and are sweet enough for eating fresh.

The other main type is the low bush blueberry *Vaccinium ungustifolim,* a compact, and dwarf shrub with leaves that become richly coloured in autumn. The flowers and berries are very similar to those of the high bush. Another dwarf species, *Vaccinium deliciosum,* produces solitary flowers and sweet black berries.

An evergreen, red – berried form is *Vaccinium floribundum.* As its name implies, this produces an abundance of flowers. The densely- clustered, rosy- tinted flowers appear in mid- summer (June) and the fruit follows in early autumn (August). This is the most attractive species; the young shoots are red, and the leaves change from purplish-red to dark green. It is probably not sufficiently winter- hardy for cooler regions but it will thrive in mild areas.

Soil Requirement

Blueberries need an acid soil with a pH of 4.5. If your soil grows good azaleas or rhododendron it will usually suit blue berries. They also require a good supply of moisture. The native British blue berries grow not only on moorland in high rainfall areas, but also on sandy heathlands where rainfall is much higher, and the species *Vaccinium corymbosum* is known in North America as the swamp blueberry, a name that clearly indicates its need for abundant moisture.

Blue berries will not grow in chalk or limestone soils, so in these conditions you will have to prepare special beds or planting holes for them. One way is to dig holes 30 cm deep and 45cm square, and to fill them with a mixture of moist peat and 25 % sharp sand. The sand is included to improve drainage; blueberries need plenty of moisture but they will not stand being waterlogged. Peat and sand do not, of course, provide the plants with much nourishment; so apply sulphate of ammonia at 35 g/ sq.m in early spring (March) and sulphate of potash at 17 g/ sq.m in winter. Another way of cultivating the plants where the soil is alkaline is to grow a bush in a tub, using the peat and sand mixture.

Planting and Tending

In the garden, set the plants 1.2-1.8 m apart, with the crowns about 10cm below soil level to encourage the growth of new shoots from the base. Give them a good mulch of peat or compost annually to help conserve moisture.

Adequate summer moisture is essential and, since watering may become prohibited in some regions if drought sets in, this is all the more reason why soil water must be conserved. If the plants establish themselves quickly they should make some 30-45 cm of growth during the first season.

Dn't prune newly planted bushes and confine routine pruning to the removal of some of the old shoots from time to time. Pests and diseases are practically non – existent, so no routine spraying is required, but netting is advisable to protect the fruit from birds.

Cranberries

Vaccinium oxycoccus, the small cranberries, are natives of the northern hemisphere. They are very small evergreens with a spreading habit, bearing red, somewhat acid berries that make delicious tarts, pies and jellies. The leaves are

small and silvery on the underside, and the tiny delicate flowers are pink petalled. There is an American form, *Vaccinium macrocarpum,* with much larger oval berries, but it is not very readily available in Britain.

Planting and Tending

The cultivation and soil requirement of cranberries are very similar to those of blueberries except that the bushes, being smaller, may be planted close together; 60-90 cm apart is suitable. Birds can soon eat up much of a cranberry harvest so, as with blueberries, you would be wise to protect the berries with netting.

Worcester Berry

Confusion over the history of Worcester berries has existed for many years. The myth that the berry arose as a black currant gooseberry hybrid has been around for over half a century. Some versions even gave its parents as Boskoop Giant black current and Whinham's industry gooseberry. Hybrids between currants and gooseberries have long been known but they are completely sterile and thornless, whereas Worcester berries are very fertile and thorned.

Science, however, has established that it is a hybrid between two gooseberry species; technically it is an interspecific hybrid, known as *Ribes divaricatum*, this being the name of one of the two species from which it is thought to have arisen. It is sometimes listed as an American wild gooseberry. The reddish purple berries are roughly mid-way in size between black currants and goose berries.

Planting and Tending

The worcester berries makes a hardy, free growing bush with strong branches reaching about 1.2- 1.5 m in height and arching over at the tips. To accommodate the arching habit, and to see it at its best, bushes should be planted 1.8 m apart. The soil should be well drained and loamy, with a good organic content, and the bushes will always benefit from mulching. Although gooseberries in general need fairly heavy supplies of potash (without which they are liable to show marginal leaf scorch). Worcester berries do not seem so prone to potash deficiency. If leaf scorch does appear, apply sulphate of potash at 17-25 per sq.m. of root area in autumn.



Vaccinium myrtillus



Vaccinium corymbosum



Vaccinium ungustifolim



Vaccinium floribundum



Vaccinium oxycoccus



Vaccinium macrocarpum



Vaccinium meridionale



Ribes divaricatum



Blue Berry- Blue Ray

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Integrated Disease Management for Anthracnose of Dragon Fruit (*Hylocereus costaricensis*)

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Abstract
The red-fleshed dragon fruit (*Hylocereus costaricensis*), or Thanh Long, is a high-value climbing cactus native to Mexico and widely cultivated across Asia and the Americas. Prized for its sweet red pulp, it is a vital functional food rich in fiber, lycopene, beta-carotene, and vitamin E, which clinically aid in managing cholesterol, diabetes, and digestive health. However, its high export potential is severely threatened by anthracnose, a destructive pre- and post-harvest disease caused by *Colletotrichum* species (*C. gloeosporioides, C. truncatum, C. siamense, and C. aenigma*). This fungal complex inflicts devastating crop losses of 10 to 80%. The pathogen survives for years in soil or debris as micro-sclerotia or acervuli, spreading rapidly *via* rain or irrigation splashes. Understanding this lifecycle and its environmental triggers is critical to developing targeted post-harvest treatments, successfully inhibiting the fungus before visual lesions destroy marketable yield.

Keywords: Dragon fruit, *Hylocereus costaricensis, Colletotrichum* species, post-harvest treatments.

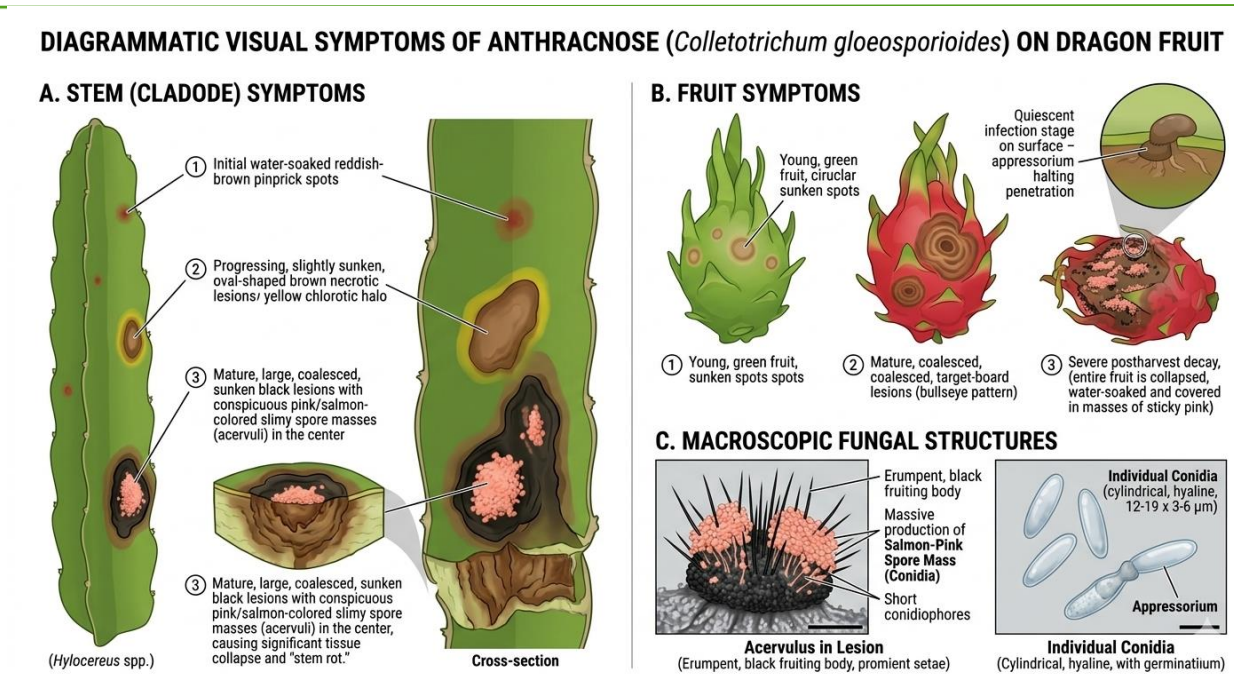
Introduction
The **red-fleshed dragon fruit** (*Hylocereus costaricensis,* family Cactaceae), widely recognized by diverse regional commercial titles such as Kamlam, Thanh Long, or Buah naga, is a premium perennial, epiphytic climbing cactus native to Mexico. Driven by rapid macroeconomic growth within the global agroindustry, it is now heavily cultivated across primary Asian production hubs—including Vietnam, Taiwan, Southern China, and Malaysia—as well as expanding markets in Thailand, Australia, Israel, and the United States. Characterized by its striking red peel, prominent green scales, and intensely sweet red pulp embedded with tiny edible seeds, this versatile fruit is highly sought after for fresh consumption and processing into premium jellies, jams, juices, and wines. It is regarded as a powerful functional food due to its rich supply of dietary fiber, vital antioxidants, and essential vitamins—averaging 3.4 µg of lycopene, 1.4 µg of beta-carotene, and 0.26 µg of vitamin E per 100g. Regular intake is documented to lower cholesterol, stimulate digestive health, and aid in preventing colon cancer and diabetes, heavily influencing global consumer preference and international export investments.

However, the economic viability of this high-value fruit is severely compromised by anthracnose, a catastrophic global disease caused by a complex of *Colletotrichum* species, including *C. gloeosporioides*, *C. truncatum*, *C. siamense*, and *C. aenigma*. Operating aggressively as both a pre- and post-harvest pathogen, it inflicts devastating crop losses ranging from 10 to 80%. The resilient fungus survives for years in the soil or seed matrix as micro-sclerotia or acervuli. Spores spread rapidly when rain or overhead irrigation water dislodges conidia, splashing them onto healthy plant tissue. In high-humidity environments, these spores germinate, penetrate the plant cuticle, and remain latent until fruit ripening triggers a rapid breakout of sunken, black necrotic lesions. Understanding this complex lifecycle and its specific environmental triggers is absolutely critical for growers. It provides the required framework to develop targeted pre-harvest management and post-harvest sanitation protocols, effectively inhibiting fungal proliferation before visible symptoms destroy marketable yield and export value.

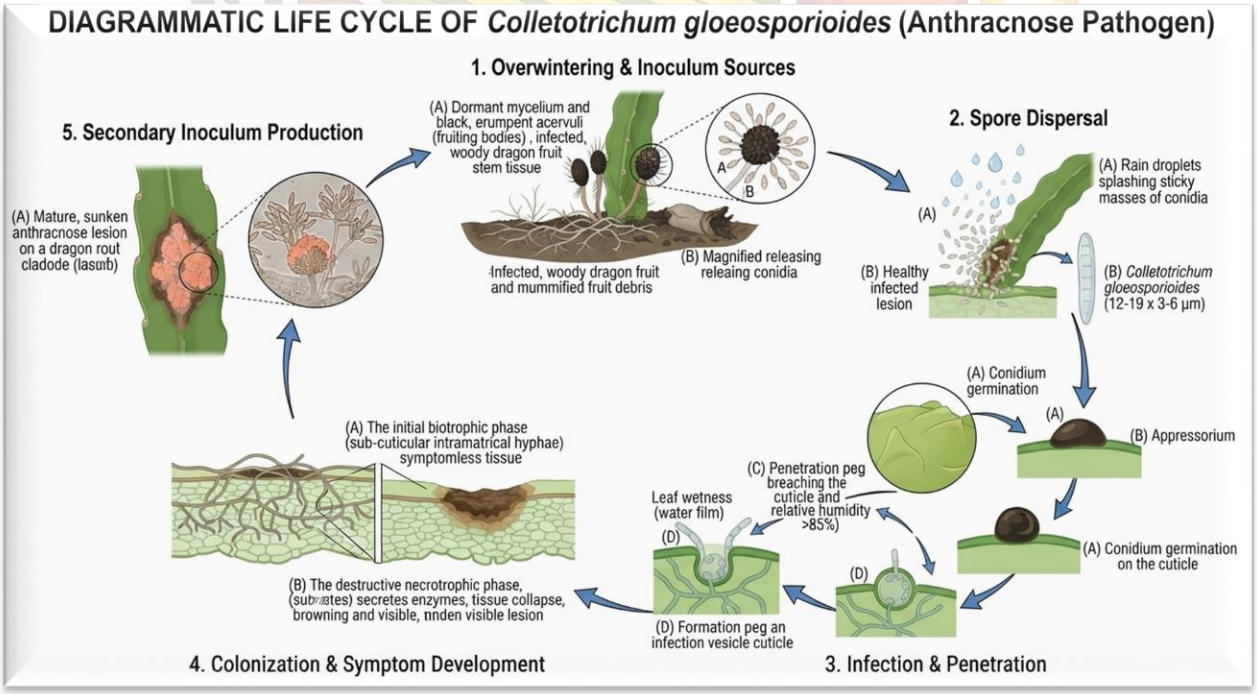
Symptoms and Sign
Anthracnose can be diagnosed visually by distinct patterns on the stems and the fruit:

On Stems (Cladodes): Early symptoms present as small, reddish to dark-brown water-soaked spots. As the disease progresses, these develop into sunken lesions surrounded by chlorotic (yellowish) haloes. In advanced stages, these turn into mature necrotic patches with prominent black spots (acervuli) at the center.

On Fruits: Small, light-brown dots quickly expand into large, sunken, water-soaked lesions. These lesions often form concentric rings containing black fungal structures, leading to rapid fruit rot near maturity.



Life cycle: The hemibiotrophic life cycle of *Colletotrichum gloeosporioides* kicks off when dormant mycelia or fruiting bodies (acervuli) overwinter on infected dragon fruit stems and mummified debris. With the return of warm temperatures and high humidity, these structures release millions of microscopic, sticky asexual spores called conidia. Lacking wind transport, these spores rely entirely on rain splashes or overhead irrigation to breach new host surfaces. Upon landing on a healthy cladode or fruit, a spore germinates in free water to form a germ tube, which swells into a dark, pressurized anchor called an appressorium. This structure forces an infection peg through the tough plant cuticle. Initially, the fungus behaves like a stealthy biotroph, keeping host cells alive or remaining dormant (quiescent) on immature fruit until ripening begins. Once host defenses drop, it shifts to a destructive necrotrophic phase, unleashing cell-wall-degrading enzymes that cause sunken, water-soaked, dark brown lesions. Finally, new acervuli erupt within these necrotic centers, producing a characteristic salmon-pink to orange slimy spore mass that splashes onto neighboring tissues, triggering destructive secondary infection cycles throughout the orchard.



Epidemiological Factors: The epidemic spread of dragon fruit anthracnose relies on a delicate triad of optimal microclimates, host vulnerability, and spore density. The primary driver is environmental; *Colletotrichum gloeosporioides* requires a combination of warm temperatures between 22°C and 32°C (with a peak at 25°C) and prolonged relative humidity exceeding 90%. Furthermore, a continuous film of surface water from heavy dew or rain

must persist for 6 to 12 hours, as the sticky conidia cannot travel by wind and rely completely on rain splashes to dissolve their gelatinous matrix and germinate. Orchard layout heavily influences this climate, as dense, unpruned canopies trap moisture and delay drying times. On the host side, succulent young tissues pushed by excessive nitrogen are easily breached, while young green fruits host hidden, quiescent infections that trigger sudden decay only when ripening drops the fruit's natural defenses. Ultimately, the severity of the outbreak is dictated by orchard sanitation; failing to remove infected cladodes or hanging, mummified debris maintains a massive reservoir of primary inoculum that explodes into secondary infection cycles the moment warm monsoon windows arrive.

Integrated Disease Management (IDM) Strategy

Cultural control:

a. Use only disease-free, certified healthy cuttings for new plantations to avoid introducing the pathogen.
b. Maintain adequate plant spacing and prune excess or diseased branches.
c. Promptly remove and burn or bury infected stems and fruits.
d. Disinfect pruning tools with 70% alcohol/ sodium hypochlorite@ 1% between plants to prevent mechanical cross-contamination.
e. Transition to **drip irrigation** instead of overhead sprinklers to eliminate leaf wetness, which triggers spore germination.
f. Avoid excessive application of nitrogen fertilizers, which triggers weak, succulent vegetative growth that is more susceptible to fungal entry.

Biological & Alternative Control:

a. Introduce soil-borne antagonists like *Trichoderma* spp. @1.0 Kg+100 Kg FYM broadcasting or *Bacillus subtilis QST713 / Paenibacillus polymyxa/ Streptomyces philanti/ B. amyloliquefaciens D747/* @ 1.0 L+100 Kg FYM to outcompete pathogens and enhance plant defense mechanisms.
b. Spray of lemongrass, ginger, savory and thyme oils@ 2% suppressing disease severity.
c. Modern postharvest formulations blending natural plant extracts such as ginger or turmeric crude extracts@ 5% with a 10% Gum Arabic coating have proven highly sustainable in suppressing disease severity during storage.

Pre-Harvest Chemical Control:

a. Apply a preventive spray of Chlorothalonil 75 WP/ Propineb 70 WP/ Zineb 75 WP/ Copper Oxychloride @ 2g/L to protect healthy tissues and seal pruning wounds.
b. For systemic therapeutic control, apply combination fungicides such as Propiconazole 25 EC/ Azoxystrobin 18.2% + Difenoconazole 11.4% SC (@ 1 ml/L) or carbendazim 50 WP@ 2ml/L or Thiophanate methyl 70 WP@ 1 ml/L Mancozeb 75% WP (2.5 g/L). Always rotate chemical classes to avoid resistance buildup.

Postharvest Management:

a. Utilize commercial hot air, vapor heat, or short hot-water dips to inhibit fungal development without chemical residues.
b. Exporters use natural calcium solutions (like "Umikai") or **Sodium nitroprusside** coatings, which significantly arrest postharvest *Colletotrichum* decay.
c. Pre-cool harvested fruits at 14°C for 18 hours, and maintain storage/transport temperatures strictly between **3°C and 10°C** to suppress fungal incubation.

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How Blockchain is Improving Seafood Transparency

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Abstract
Seafood supply chains span numerous actors, including fishers, processors, distributors, wholesalers, and retailers, creating opportunities for fraud, mislabeling, and illegal, unreported, and unregulated fishing practices. Blockchain technology, with its decentralized and tamper-resistant ledger, has emerged as a promising tool to address these challenges by enabling secure, traceable, and transparent record-keeping across the seafood value chain. Recent research highlights how blockchain supports traceability and storytelling of seafood products, helps verify origin and catch documentation, and builds consumer trust through real-time visibility of supply chain data. At the same time, studies point to barriers including regulatory uncertainty, implementation costs, and resistance from influential actors such as wholesalers who may see their information advantages reduced. This article synthesizes recent findings on blockchain applications, traceability enablers, adoption barriers, and broader implications for transparency and sustainability in global seafood trade.

Introduction
Sustainability and transparency of information in value chains have become standards in international trade and markets, and managing global value chains is challenging due to the complex network of chain actors and the uncertainties posed by changing technologies, markets, and political environments (Tolentino-Zondervan et al., 2023). Fishery and aquaculture sectors use blockchains to enhance traceability and transparency in value chains and to fight illegal, unreported, and unregulated fishing (Tolentino-Zondervan et al., 2023). The use of blockchain for transparency and traceability is needed as a market requirement and for business competitiveness, and this need is expected to grow further based on developments in the macro-environment (Tolentino-Zondervan et al., 2023).

Blockchain is a new technology that is seen to be transforming businesses across various industries, providing transparency at all levels of business and supporting traceability across supply chains in ways that older technologies could not reach (Meera et al., 2023). Digital technologies such as blockchain, smart contracts, QR codes, and fintech are forecast to improve the transparency, sustainability, and efficiency of supply chains in numerous sectors, although such innovations may face greater resistance and implementation challenges in some sectors more than others (Thompson & Rust, 2023). Ensuring sustainability and ethical practices in global fish supply chains requires robust implementation of digital technologies that conform to traceability and transparency policies in the fisheries industry, with blockchain and the Internet of Things identified among the key enabling technologies for this purpose (Cromwell et al., 2025). This article examines how blockchain is improving seafood transparency by reviewing its use cases, the barriers to its adoption, the social and institutional dynamics it encounters, and the broader digital ecosystem within which it operates.

Blockchain Use Cases for Traceability and Storytelling
Within the vertical dimension of fishery and aquaculture value chains, almost all use cases of blockchain apply traceability and storytelling to address quality, food safety, fraud, illegal and unregulated fishing, and working condition issues (Tolentino-Zondervan et al., 2023). It is becoming a requirement at regional and international levels that products being imported across borders should be traceable and anchored on a database, as part of consumer protection and the fight against illegal, unreported, and unregulated fishing (Tolentino-Zondervan et al., 2023). In the United States, several imported fish products need to be traceable as part of customs requirements, while in the European Union, seafood traceability is required at all stages of production (Tolentino-Zondervan et al., 2023).

Beyond traceability and storytelling, blockchain use cases extend to the distribution of incentives to chain actors for anchoring their data in the blockchain, the use of smart contracts for coordinating transaction requirements within the value chain, peer-to-peer transactions that eliminate middlemen, and the tracking of inventory along the chain (Tolentino-Zondervan et al., 2023). However, there have been limited use cases of blockchain at the horizontal level, such as decentralized finance solutions that could enable fishers to gain capital access and enter global markets, indicating that enhancing the adoption of blockchain should address suitability, incentives, and trust factors in its use (Tolentino-Zondervan et al., 2023).

Enabling Technologies and Traceability Parameters
A systematic review of digital technologies for fish supply chain traceability identifies three key research streams: enabling technologies such as blockchain and the Internet of Things, critical traceability parameters for transparency including fraud prevention and consumer trust, and sustainability benefits such as enhanced regulatory compliance and

cold-chain efficiency (Cromwell et al., 2025). Among the enabling technologies, blockchain, the Internet of Things, and radio frequency identification are identified as key technologies for fish supply chain traceability, with these tools ensuring real-time data collection and accurate recording of supply chain steps (Cromwell et al., 2025).

Technologically enabled traceability systems are critical to achieving transparency in fish supply chains, as they must collect data on product history, the condition of production, and product quality, and share this data with both internal and external stakeholders (Cromwell et al., 2025). The fundamental principle of food traceability is the efficient tracking and tracing of unique logistical physical units in a way that enables monitoring of products and components to preserve food safety, quality, and sustainability (Cromwell et al., 2025). Regulatory requirements on food traceability place responsibility on companies by authorities, and the physical movement or information flow linked to a traceable resource unit of goods between supply chain actors is critical to achieving both internal and external traceability (Cromwell et al., 2025).

Sustainability Dimensions of Blockchain Adoption

The application of blockchain technology in seafood is not pursued solely for traceability purposes but is also linked to broader sustainable supply chain objectives. Research exploring various factors affecting the adoption of blockchain technology in seafood toward sustainable supply chains for exports gathered feedback from seven companies and applied a technique for order performance by similarity to ideal solution to identify important factors for sustainable supply chain solutions (Meera et al., 2023). This technology provides transparency under all levels of business and supports traceability across various supply chains which older technologies could not reach, underscoring its relevance to sustainability-oriented strategies in seafood exports (Meera et al., 2023).

At the same time, sustainability benefits identified through systematic review include enhanced regulatory compliance and cold-chain efficiency, both of which depend on the accurate and timely sharing of data enabled by digital traceability technologies (Cromwell et al., 2025). The combination of traceability, transparency, and sustainability objectives suggests that blockchain functions not merely as a record-keeping tool but as part of a wider effort to align seafood supply chains with international trade standards and consumer expectations regarding sustainable sourcing (Tolentino-Zondervan et al., 2023; Cromwell et al., 2025).

Barriers to Blockchain Adoption in Seafood Exports

Despite its potential, blockchain adoption in seafood supply chains faces significant barriers. Research focused on seafood exports found that regulatory uncertainty emerges as the major factor affecting blockchain adoption, calling for reforms in regulatory compliance, while implementation costs rank second and need to be reduced for better adoption of the technology (Meera et al., 2023). These findings indicate that the path toward improved transparency through blockchain is not purely technical but is shaped by the regulatory and financial environment within which exporting companies operate (Meera et al., 2023).

Complementary evidence on adoption challenges comes from interviews with fishers, aquaculturists, restaurants, and industry experts around existing blockchain applications seeking to enhance seafood traceability and trackability (Thompson & Rust, 2023). This research found that digital technology uptake and usage can be resisted by some supply chain actors, a pattern particularly true for wholesalers in seafood supply chains in Australia (Thompson & Rust, 2023).

Social and Institutional Resistance Among Supply Chain Actors

The reasons behind resistance to blockchain adoption are deeply tied to the existing power structures within seafood supply chains. Wholesalers defend their competitive advantages related to trade and price information, and results suggest that blockchain could threaten this competitive advantage by reversing existing asymmetries around trade, price, and provenance information (Thompson & Rust, 2023). Digital technology could also expose undesirable behaviors related to food fraud, which provides an additional disincentive for actors who may benefit from a lack of transparency (Thompson & Rust, 2023).

Even though other supply chain actors favored the decentralization and information sharing that blockchain provides, they were hesitant to adopt it due to fear of jeopardizing relationships with the wholesalers upon which their business models rely (Thompson & Rust, 2023). This dynamic illustrates that blockchain will only drive transformative change in seafood supply chains if the most influential supply chain actors see value in using it, highlighting that technological capability alone is insufficient without alignment of incentives among all participants (Thompson & Rust, 2023).

Toward Integrated and Transparent Seafood Value Chains

Bringing together the use cases, enabling technologies, sustainability dimensions, and adoption barriers reveals a coherent picture of how blockchain is reshaping seafood transparency. On one hand, blockchain offers concrete mechanisms for traceability and storytelling that respond directly to regulatory requirements in major markets such as the United States and the European Union, while also supporting smart contracts, incentive distribution, and inventory tracking across the value chain (Tolentino-Zondervan et al., 2023). On the other hand, the technology's effectiveness

depends on its integration with complementary digital tools such as the Internet of Things and radio frequency identification, which together form the technological backbone needed to ensure real-time data collection and accurate recording of supply chain steps (Cromwell et al., 2025).

However, the technological readiness of blockchain is only part of the picture. Adoption is shaped by regulatory uncertainty and implementation costs on one side (Meera et al., 2023), and by the social and institutional dynamics among supply chain actors, particularly the resistance of wholesalers who stand to lose informational advantages, on the other (Thompson & Rust, 2023). Together, these findings suggest that improving seafood transparency through blockchain requires not only technical readiness but also regulatory clarity, cost reduction strategies, and alignment of incentives among all actors within the supply chain (Meera et al., 2023; Thompson & Rust, 2023; Tolentino-Zondervan et al., 2023; Cromwell et al., 2025).

Conclusion

Blockchain technology is playing an increasingly important role in improving seafood transparency by enabling traceability, storytelling, and verifiable record-keeping across complex global supply chains. Its use cases span regulatory compliance, fraud prevention, consumer trust building, and the coordination of transactions through smart contracts, while complementary technologies such as the Internet of Things and radio frequency identification strengthen real-time data collection. Yet the path to widespread adoption is constrained by regulatory uncertainty, high implementation costs, and resistance from powerful supply chain actors such as wholesalers who may perceive reduced transparency as advantageous to their position. For blockchain to deliver on its promise of improving seafood transparency at scale, technical innovation must be matched by regulatory reform, cost-effective implementation strategies, and genuine buy-in from all participants across the seafood value chain, from fishers to final retailers.

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Unlocking the Hidden Wealth of Calcareous Soils: Chemistry, Nutrient Dynamics, and Practical Management

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Abstract

Calcareous soils, covering over 30% of global agricultural land, feature high calcium carbonate levels and alkaline pH (7.5–8.5). Despite good structural stability, their chemical environment severely restricts crop nutrition. High bicarbonate activity and rapid precipitation reactions immobilize essential macronutrients particularly phosphorus while inducing acute deficiencies in iron, zinc, and manganese. Furthermore, surface-applied nitrogen suffers severe ammonia volatilization. Bypassing these chemical bottlenecks requires tailored agronomic practices. Integrating precision band placement, acid-forming fertilizers, organic amendments, and stable chelates like Fe-EDDHA enables growers to prevent nutrient fixation and sustainably unlock crop yield potential in arid and semi-arid agroecosystems.

Keywords: Calcareous soils, Calcium carbonate, Phosphorus fixation, Micronutrient chlorosis, Nutrient availability.

Introduction

Calcareous soils are widespread in arid, semi-arid and sub-humid regions. They contain appreciable amounts of free calcium carbonate ($CaCO_3$), generally have alkaline pH, and are naturally rich in calcium. Their good aggregation and drainage can favour crop production; however, their unique chemistry can severely restrict nutrient availability. High pH, bicarbonate, calcium and strong interactions between soil minerals and nutrients can immobilize phosphorus (P), iron (Fe), zinc (Zn), manganese (Mn) and other micronutrients. Surface-applied nitrogen (N), particularly urea, may also be lost through ammonia volatilization. Thus, the major challenge is often not the total amount of nutrients present in the soil, but their availability to plants.

What makes Soil Calcareous?

A calcareous soil contains significant free calcium carbonate. Such soils may develop from limestone, marl and other lime-rich parent materials or through the accumulation of secondary carbonates where evaporation exceeds rainfall and calcium is not sufficiently leached. Carbonates may occur as fine particles, nodules, coatings or cemented layers. In strongly developed soils, hard calcareous horizons may restrict water movement and root growth (FAO, 1973). The high $CaCO_3$ content gives these soils strong buffering capacity, making them resistant to changes in pH. Therefore, attempting to acidify the entire soil is generally impractical. A better approach is to create favourable root-zone microsites where nutrients remain available to crops.

Why do Nutrients Become Unavailable?

Nitrogen: valuable N can escape: In alkaline conditions, ammonium (NH_4^+) is readily converted to ammonia (NH_3). When urea remains on the soil surface, its hydrolysis temporarily increases pH around the fertilizer granule, increasing the possibility of ammonia loss, particularly under warm and dry conditions. Consequently, simply increasing urea application may not improve crop nutrition. Proper placement, split application and synchronization with crop demand can improve N-use efficiency (Motasim et al., 2024).

Phosphorus: the classic nutrient lock-up: Phosphorus availability is one of the major nutritional challenges in calcareous soils. A soil may contain considerable total P while supplying insufficient P to crops. Following fertilizer application, phosphate interacts with calcium and soil mineral surfaces, resulting in adsorption and precipitation and the formation of relatively insoluble calcium phosphate compounds. With time, these forms may become increasingly stable and less available to plants (von Wandruszka, 2006). Therefore, increasing P fertilizer rates alone is not always the solution. Band placement can be more effective than broadcasting because it concentrates P near the root zone and reduces its

immediate contact with reactive soil surfaces. Sustainable P management should consider soil pH, lime content, moisture, clay minerals and organic matter rather than fertilizer quantity alone (Adnan et al., 2025).

The micronutrient challenge: Iron and zinc deficiencies are common concerns in calcareous soils. Although total Fe and Zn may be adequate, their soluble and plant-available forms can be extremely low under alkaline conditions. Iron deficiency, commonly known as lime-induced chlorosis, appears as yellowing of young leaves while the veins remain relatively green. High pH reduces Fe solubility, while bicarbonate can further interfere with Fe acquisition by plants. This problem is particularly important in high-value crops grown on calcareous soils (Abadía et al., 2011). Zinc availability is also reduced in alkaline, carbonate-rich soils. Zinc may be strongly retained by carbonate surfaces, resulting in deficiency even when total soil Zn is adequate. Symptoms may include stunted growth, shortened internodes and chlorotic striping. This highlights an important principle: the amount of a nutrient present in soil is not necessarily the amount available to the plant.

Physical and Biological Constraints

The problems of calcareous soils extend beyond chemistry. Fine carbonate particles may contribute to surface crusting following rainfall or irrigation, restricting seedling emergence and gas exchange. Cemented layers or hardpans may also restrict root penetration. Low organic matter can further reduce soil quality. Compost, farmyard manure, crop residues and green manures can improve aggregation, water retention and microbial activity while gradually supplying nutrients. During decomposition, microorganisms produce organic compounds and acids that can modify nutrient retention and mobility. Organic amendments can particularly improve P availability by influencing P sorption reactions (von Wandruszka, 2006).

Practical Strategies for Unlocking Productivity

Managing calcareous soils does not mean fighting their natural chemistry. Instead, management should focus on improving nutrient-use efficiency.

1. Prefer placement over broadcasting: Banding P near the root zone reduces fertilizer–soil contact and can improve P availability. Similarly, N fertilizers should be incorporated rather than left exposed on the soil surface (FAO, 1973).

2. Use split nitrogen applications: Applying N in smaller doses according to crop demand can reduce losses and improve recovery by plants, particularly where surface-applied urea is vulnerable to ammonia volatilization (Motasim et al., 2024).

3. Build soil organic matter: Compost, farmyard manure, crop residues and green manures can improve soil physical and biological properties and influence nutrient availability, particularly P (von Wandruszka, 2006).

4. Correct micronutrient deficiencies strategically: Stable Fe chelates can be useful where Fe deficiency is severe because they maintain Fe in soluble forms under alkaline conditions. Foliar application can also bypass soil-related nutrient immobilization and provide rapid correction (Abadía et al., 2011).

5. Pay attention to zinc: Crops with high Zn requirements should be regularly monitored for deficiency. Soil or foliar Zn application can be incorporated into integrated nutrient management according to crop and soil conditions.

6. Encourage beneficial microorganisms: Nutrient-solubilizing microorganisms capable of producing organic acids, siderophores and other compounds can help mobilize nutrients in the rhizosphere. Phosphate- and zinc-solubilizing microorganisms therefore offer promising biological approaches, although their performance depends on soil, crop and environmental conditions.

7. Focus on the root zone: Because $CaCO_3$ strongly buffers soil pH, large-scale soil acidification is generally impractical. Localized acidification, fertigation, organic amendments, precision fertilizer placement and biological activity around roots provide more practical alternatives.

From "More Fertilizer" to "Better Fertilizer Management"

The most important lesson from calcareous soils is that more fertilizer does not necessarily mean more crop nutrition. Applying additional P when it is rapidly fixed, or additional urea when N is being lost as ammonia, can increase production costs without providing proportional yield benefits. The future of calcareous-soil management therefore lies in applying the right nutrient, at the right place, at the right time and in an appropriate form. Integrated strategies combining fertilizer management, organic matter and improved nutrient-use efficiency are increasingly important for sustainable P and overall nutrient management (Adnan et al., 2025).

Conclusion

Calcareous soils should not simply be considered difficult, high-pH soils. They are specialized soil environments governed by strong calcium carbonate–bicarbonate chemistry. Although nutrient fixation, precipitation, sorption and gaseous losses can restrict crop nutrition, these challenges can be managed effectively. Precision fertilizer placement, split N application, organic matter management, strategic micronutrient correction, biological nutrient mobilization and root-

zone-focused practices can improve nutrient availability and fertilizer-use efficiency. The key is not to fight the chemistry of calcareous soils, but to work with it. Understanding their hidden nutrient dynamics can help farmers reduce fertilizer losses, improve crop productivity and move towards more efficient and sustainable agriculture.

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Emerging Trends in Organic Fruit and Vegetable Production

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Abstract

Organic fruit and vegetable production is gaining increasing importance worldwide because of growing concerns regarding food safety, environmental degradation, soil health, biodiversity loss and the long-term sustainability of intensive agricultural systems. Organic horticulture emphasizes the use of natural and biological resources, recycling of farm wastes, and maintenance of soil fertility, conservation of beneficial organisms and reduction of dependence on synthetic agrochemicals. However, modern organic production is no longer limited to traditional practices. It is increasingly incorporating scientific innovations such as microbial bioinputs, biological pest management, precision irrigation, protected cultivation, climate-smart practices, improved varieties, digital traceability and efficient post-harvest technologies. The integration of these approaches is creating a new generation of organic production systems that are productive, resource-efficient and environmentally sustainable. In India, the large diversity of agro-climatic conditions, traditional knowledge and expanding consumer awareness provide considerable opportunities for organic fruit and vegetable production. Emerging concepts such as regenerative organic horticulture, smart organic farming, urban organic production, organic seed systems, farmer-producer organizations and direct marketing are further expanding the scope of the sector. At the same time, challenges related to productivity, certification, availability of organic inputs, pest and disease management, post-harvest losses and market access remain important. Future development therefore requires an integrated approach combining ecological principles with scientific research, farmer knowledge, modern technologies and market-oriented strategies. Organic fruit and vegetable production has the potential to contribute significantly to sustainable food systems, nutritional security, biodiversity conservation, climate resilience and improved livelihoods of horticultural farmers.

Keywords: Organic horticulture, organic fruits, organic vegetables, biofertilizers, biological control, regenerative agriculture, sustainable horticulture, precision farming

Introduction

Fruit and vegetable crops occupy a special position in agricultural systems because they provide vitamins, minerals, dietary fibre, antioxidants and numerous bioactive compounds essential for human health. They also generate substantial employment and income for farmers, particularly through intensive production, processing, marketing and value addition. However, increasing demand for horticultural commodities has encouraged intensive cultivation involving high external inputs, frequent irrigation, chemical fertilizers and pesticides. Although these practices have contributed to higher productivity, their excessive or inappropriate use may create concerns related to soil degradation, pesticide residues, water pollution, loss of beneficial organisms and declining ecological stability. These concerns have increased interest in alternative production systems capable of maintaining productivity while protecting natural resources.

Organic fruit and vegetable production has emerged as an important approach within sustainable horticulture. Organic production is based on ecological processes and emphasizes the use of organic matter, biological nutrient cycling, biodiversity, natural pest regulation and responsible management of natural resources. It attempts to maintain a productive relationship between soil, plants, microorganisms, animals and the surrounding environment. Unlike conventional production systems that may depend heavily on external synthetic inputs, organic horticulture attempts to strengthen the internal biological processes of the farm.

The concept of organic horticulture is also changing rapidly. Earlier, organic production was frequently associated with traditional farming methods and the avoidance of synthetic fertilizers and pesticides. Today, however, organic farming is increasingly connected with scientific research, microbial biotechnology, precision agriculture, protected cultivation, climate-smart farming and digital supply-chain management. This transformation has created the concept of modern or smart organic horticulture, in which ecological principles are supported by scientific and technological innovations.

The growing demand for safe and environmentally responsible food is also influencing consumer preferences. Consumers increasingly want information about the origin, production practices and quality of the food they purchase. This has increased the importance of certification, traceability and transparent supply chains. At the same time, farmers are searching for production systems that can reduce input costs, improve soil health and create better market opportunities.

India has considerable potential for organic fruit and vegetable production because of its diverse agro-climatic conditions, rich biodiversity and long history of traditional farming practices. The country possesses suitable conditions for producing a wide range of organic fruits and vegetables, from tropical and subtropical crops to temperate horticultural commodities. Consequently, the emerging organic horticulture sector can contribute not only to environmental sustainability but also to employment, rural development, export opportunities and nutritional security.

Transformation of Organic Fruit and Vegetable Production

The development of organic horticulture is closely associated with changing perceptions of agricultural productivity. Earlier agricultural development largely focused on achieving maximum production from a given area. Modern sustainable agriculture, however, increasingly considers productivity together with soil health, resource-use efficiency, biodiversity, food quality and long-term environmental sustainability. This broader perspective has encouraged the transformation of organic fruit and vegetable production from a low-input alternative into a knowledge-intensive production system.

One of the most important changes is the increasing emphasis on soil as a living biological system. Organic production recognizes that healthy soil contains a complex community of microorganisms, earthworms and other organisms that influence nutrient cycling, soil structure and plant health. Consequently, organic growers are increasingly emphasizing compost, farmyard manure, green manures, crop residues, mulches and other sources of organic matter. The objective is not simply to supply nutrients but to improve the physical, chemical and biological condition of the soil.

In fruit production, this approach is particularly important because orchards remain in the same location for many years. Continuous cultivation without adequate organic matter management can gradually reduce soil quality. Organic orchard management therefore increasingly includes mulching, cover crops, compost application, recycling of pruning residues and maintenance of vegetation between tree rows. These practices can contribute to improved soil structure, moisture conservation and biological activity.

In vegetable production, crop rotation and diversification are becoming increasingly important. Continuous cultivation of the same crop can encourage the buildup of soil-borne pathogens and pests and may lead to nutrient imbalance. Rotating vegetables with legumes, cereals, green-manure crops and cover crops can help diversify the biological environment and improve nutrient cycling.

Another important transformation is the increasing recognition of biodiversity as a production resource. Organic farms can be designed to provide habitats for pollinators, predators and other beneficial organisms. Flowering plants, hedgerows, cover crops and mixed cropping systems can support ecological interactions that contribute to natural pest regulation.

The concept of organic production is therefore gradually changing from an input-substitution approach to an ecological systems approach. Instead of simply replacing chemical fertilizers with organic fertilizers and chemical pesticides with botanical products, modern organic horticulture seeks to redesign the entire production system so that natural biological processes perform a greater proportion of nutrient and pest-management functions.

Another emerging trend is the integration of traditional knowledge with scientific research. Indian farmers have historically used compost, farmyard manure, crop residues, botanical preparations, mixed cropping and other ecological practices. Modern research is increasingly examining these practices scientifically to determine their effectiveness, standardize their use and integrate them with contemporary technologies.

Thus, the transformation of organic horticulture represents a movement from traditional low-input farming toward a scientifically supported, biologically integrated and market-oriented production system.

Emerging Biological and Ecological Approaches

One of the most significant trends in organic fruit and vegetable production is the growing importance of biological technologies. Biological approaches are particularly valuable because they can improve plant nutrition, suppress pests and diseases and enhance soil biological activity without relying heavily on synthetic chemicals.

Biofertilizers are becoming important components of organic nutrient management. Beneficial microorganisms such as nitrogen-fixing bacteria, phosphate-solubilizing microorganisms, potassium-solubilizing microorganisms and mycorrhizal fungi can contribute to nutrient availability and plant growth. Their importance is increasing because organic production requires efficient nutrient recycling and improved biological nutrient availability.

The future direction is likely to move beyond the use of individual microbial inoculants toward **microbial consortia**, where several microorganisms with complementary functions are used together. Such systems may support nutrient acquisition, root development and plant tolerance to environmental stresses. Research into plant growth-promoting microorganisms is also creating opportunities for improving crop performance under low-input conditions.

Biological management of pests and diseases is another rapidly developing area. Organic horticulture increasingly emphasizes natural enemies, microbial biocontrol agents, botanical extracts, pheromone traps, sticky traps and other non-chemical approaches. Beneficial organisms such as predators and parasitoids can help regulate insect pest populations, while microbial agents can suppress certain insect pests and plant pathogens.

The philosophy of pest management is also changing. Rather than attempting to eliminate every pest, modern organic systems aim to maintain pest populations below economically damaging levels by strengthening the ecological balance of the farm. Habitat management, crop diversification and conservation of natural enemies are therefore becoming increasingly important.

Botanical products are also receiving renewed attention. Plants such as neem contain naturally occurring compounds that can influence insect feeding, reproduction and development. Other botanicals are being investigated for insecticidal, fungicidal and repellent properties. However, the future development of botanical crop protection will require standardized formulations, consistent quality and scientifically validated application methods.

Another important ecological trend is the development of **regenerative organic horticulture**. Regenerative approaches attempt not only to maintain soil health but also to restore degraded soils and improve ecosystem functions. Practices such as cover cropping, mulching, compost application, reduced soil disturbance, crop diversification and biodiversity enhancement are central to this approach.

In perennial fruit orchards, regenerative management may involve maintaining vegetation between tree rows, incorporating organic residues into the soil, establishing flowering plants and reducing unnecessary soil disturbance. Such systems can support soil organisms, improve nutrient cycling and provide habitat for beneficial insects.

Organic horticulture is also increasingly connected with **agroecology**, which considers the farm as an ecological system. Agroecological production emphasizes diversity, recycling, efficiency, resilience and interaction between biological components. This approach is especially relevant to fruit and vegetable production because horticultural farms can accommodate diverse crops and supporting vegetation.

Smart, Climate-Resilient and Technology-Driven Organic Horticulture

A major emerging trend is the integration of modern technology into organic production. The idea that organic farming must remain completely disconnected from modern technology is gradually disappearing. Digital technologies can support organic principles by improving the accuracy and efficiency of resource management.

Precision agriculture is increasingly relevant to organic horticulture because organic inputs can also be wasted if applied without considering actual crop requirements. Soil moisture sensors, weather information, crop monitoring systems and digital farm-management tools can help farmers determine when irrigation or other interventions are required.

Precision irrigation is particularly important because water availability is becoming increasingly uncertain in many horticultural regions. Drip irrigation combined with soil-moisture monitoring can provide water directly to the root zone while reducing unnecessary losses. Organic mulches can further reduce evaporation and improve soil moisture conservation.

Remote sensing and drone technologies are also creating new possibilities. Aerial images can help identify variation in crop growth, water stress and plant health. In large orchards, such technologies can identify problem areas that require detailed field inspection. This makes organic management more targeted and efficient.

Artificial intelligence and machine learning are emerging as particularly promising technologies. Image-based systems can potentially identify insect pests and disease symptoms at an early stage. AI models can also analyse weather, crop and historical information to predict the probability of pest and disease outbreaks.

For organic farmers, early warning systems can be especially useful because biological control measures often require timely intervention. If a disease or pest is detected early, farmers may be able to use appropriate biological or botanical measures before the population reaches economically damaging levels.

The Internet of Things is another emerging area. IoT-based systems can connect field sensors with mobile devices and cloud-based platforms. Information about soil moisture, temperature, humidity and other environmental conditions can be continuously monitored. This creates the possibility of developing **smart organic farms** where decisions are increasingly based on real-time information.

Protected cultivation is also becoming an important component of modern organic horticulture. Greenhouses, polyhouses and insect-proof structures can provide greater control over temperature, humidity, irrigation and pest entry. Organic production under protected conditions may allow farmers to produce high-value vegetables with better quality and more consistent production.

Climate change makes these technologies even more important. Increasing temperatures, irregular rainfall, drought, flooding and changing pest patterns create significant risks for fruit and vegetable production. Climate-resilient organic systems therefore need to combine soil organic matter management, water conservation, crop diversification, stress-tolerant varieties and protected production.

The development of **climate-smart organic horticulture** represents an important future direction. Such systems aim to maintain productivity while increasing resilience to environmental stresses and reducing pressure on natural resources.

Quality, Certification, Traceability and Market-Oriented Organic Production

The future growth of organic fruit and vegetable production depends heavily on consumer confidence and market development. Organic production has little economic advantage for farmers if consumers cannot distinguish genuine organic products from conventional commodities marketed using vague environmental claims.

Certification therefore plays an important role in establishing credibility. Organic certification provides assurance that production and handling have followed specified standards. However, certification can sometimes be difficult for small farmers because of documentation requirements, inspection procedures and associated costs.

Participatory approaches and farmer groups can help address some of these challenges. Farmer Producer Organizations, cooperatives and organic clusters can enable farmers to share knowledge, organize certification, procure inputs and collectively market their produce.

Digital technologies are also transforming traceability. QR codes, digital records and electronic certification systems can potentially allow consumers to obtain information about the origin and production history of organic products. Blockchain technology is being explored for creating secure and transparent supply-chain records.

Traceability is particularly important for high-value organic fruits and vegetables because consumers may be willing to pay a premium for products with verified production histories. A digital traceability system could potentially provide information about the farm, certification status, harvesting date, processing, packaging and transportation.

Post-harvest management is another important area of emerging development. Fruits and vegetables are highly perishable, and poor handling can result in significant losses. Organic production therefore needs efficient systems for harvesting, grading, packaging, cooling, storage and transportation.

Modern cold-chain systems, improved packaging, controlled storage conditions and better transport infrastructure can extend the marketable life of organic produce. Proper segregation of organic and conventional products is also necessary to maintain organic integrity throughout the supply chain.

Value addition provides another major opportunity. Processing fruits and vegetables into juices, pulps, jams, dehydrated products, powders, pickles, sauces and other products can reduce post-harvest losses and increase farmer income. Small-scale processing units operated by farmer groups can provide employment and strengthen rural economies.

Direct marketing is also emerging as an important trend. Digital platforms, farmers' markets, community-supported agriculture and subscription-based vegetable boxes can shorten the distance between farmers and consumers. Such systems can provide farmers with better market access while allowing consumers to learn more about production practices.

Urban organic horticulture is further expanding the market. Rooftop gardens, community gardens, kitchen gardens and local vegetable production can supply fresh produce close to urban consumers. This can contribute to food awareness, nutritional security and environmental sustainability.

Challenges

Organic fruit and vegetable production faces several challenges, including variable productivity, inadequate availability of quality organic inputs, difficult certification procedures, nutrient management problems, pest and disease pressure, limited post-harvest infrastructure and insufficient access to remunerative markets. Small and marginal farmers may also face difficulties related to technical knowledge, certification costs and market linkages.

Future Prospects

The future of organic horticulture is promising with the integration of biofertilizers, microbial consortia, biopesticides, precision irrigation, artificial intelligence, IoT, remote sensing and protected cultivation. Regenerative farming, climate-resilient varieties, digital traceability, value addition, farmer-producer organizations and direct marketing can further improve sustainability, profitability and consumer confidence.

Conclusion

The future of organic fruit and vegetable production lies not merely in replacing synthetic inputs but in developing integrated systems based on soil health, biodiversity, biological processes and efficient resource management. With suitable research, farmer training, certification support, infrastructure and better markets, organic horticulture can contribute significantly to sustainable agriculture, nutritional security, environmental conservation and improved farmer livelihoods.

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Soil Carbon Dynamics: From Soil Health to Climate Security

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Abstract
Soil carbon is a key component of soil functioning which closely relates soil health with climate regulation. The dynamics of soil carbon is governed by the balance between carbon addition, transformation and losses that are further strongly influenced by interactions of climate, soil properties, vegetation, land use and management practices. Changes in soil carbon directly affects the physico-chemical properties of soil and the overall health. Beyond the role in soil health, carbon sequestration and stabilization in soils can contribute to atmospheric CO_2 regulation and climate-change mitigation. This article explores the major soil carbon pools and processes governing their dynamics and highlights their implications for soil health and climate resilience. Sustainable soil carbon management offers a pathway to simultaneously improve soil health, sustain productivity and strengthen the role of soils in climate-change mitigation.

Keywords: sustainability, resilience, soil properties, carbon sequestration.

Introduction
The ongoing armed conflicts along with rising global population are affecting the environment functioning substantially. The growing pressures coupled with global climate change is significantly contributing to increased land deterioration, vegetation loss, increase in energy consumption and greenhouse gas emissions (Bhatti et. al., 2024). The unintended conditions have not only accelerated the mere depletion but also has increased the degradation of natural resources. Consequently, agricultural productivity and food sustainability worldwide are in jeopardy with increase in the global hunger index (Abay et. al., 2023; Naja et. al., 2026). Albeit, the earlier studies have already highlighted that the excess use of inorganic fertilisers, high yielding exhaustive varieties are no longer enough for increasing and improving the yield (Penuelas et. al., 2023). Thus, this has shifted the focus towards maintaining sustainable balance between soil input and output involving soil health.

Soil health is a property of soil to act as a living and dynamic ecosystem to support agricultural sustainability (Ṭopa et. al., 2025) while, soil carbon is an important key indicator of soil health (Mesele et. al., 2026; Ngatia et. al., 2021). Soil carbon regulates various physico-chemical and microbial properties of soil. It is dynamic and is affected by interaction of various factors like climate, vegetation, land use and microbial population. Among these, climate is considered to be the most dominant factor in regulating the soil carbon pools and simultaneously the soil health (Kerketta et. al., 2026). The changing climatic conditions necessitate to study the soil carbon dynamics in soil and its effect on soil health. Furthermore, soil as a medium for the growth and development of plants and other biota is already well established (Hilgard et. al., 2025; Bhat et. al., 2024) but the recent studies also suggest it to be a source and sink for various greenhouse gases (Sonwani et. al., 2021). Since, soil can play multiple roles, this article highlights the potential of soil to simultaneously support soil health and contribute to climate-change mitigation through effective soil carbon management.

Soil Carbon Pools and Dynamics
Soil C is recognized as the largest storehouse of terrestrial carbon (Sharma et. al. 2023) and plays a key role in soil physico- chemical properties like CEC, water-holding capacity, nutrient storage and improving the overall soil structure. Apart from it, it also acts as habitat for multiple microorganism responsible for various nutrient transformations. It is further classified as soil organic carbon (SOC) and soil inorganic carbon (SIC) (Batjes, 1996).

Soil SOC is the major part of organic matter and is significantly affected by interaction of various factors like climate, time, soil texture and vegetation and land use management practices. It is further categorised as Labile/Active Carbon pool, intermediate/slow/partial stabilised carbon pool and recalcitrant/Stable/Passive/Inert/Resistant pool. A labile pool is the fraction that can easily and rapidly be transformed having higher turnover such as fresh plant residues, root exudates and microbial biomass (Sharma et. al., 2022). The intermediate /slow pool of soil carbon refers to the fraction of soil organic carbon containing partially decomposed plant residues and decompose more slowly than active/labile pool but more rapidly than passive/recalcitrant fraction. Conversely, recalcitrant pool refers to a fraction of organic matter that strongly resists microbial decomposition and remains stable with slow turnover (Khan et. al., 2025). Crop residues and root exudates contribute to the labile organic carbon pool, which undergoes microbial decomposition and mineralization, releasing plant-available nutrients (Wasikoyo et. al., 2026). A proportion of the carbon is subsequently transformed and stabilized within soil aggregates and mineral associations, contributing to the formation of relatively stable organic carbon pools (Even et. al. 2025).

Albeit, SOC is widely recognized for its role in soil health and climate regulation, soil inorganic carbon (SIC) constitutes a relatively stable carbon reservoir. It mainly involves carbonates (CO3−2) and bicarbonates (HCO3−) of Ca2+, Mg2+ in the form of calcite (CaCO3) or dolomite. It is the major component of carbon cycle in arid and semi- arid regions (Shi et. al., 2025) as carbonate formation potentially decreases CO2 from the atmosphere while, carbonate dissolution releases CO2 (Batool et. al., 2024; Shao et. al., 2022). Hence SIC pool is usually used for evaluating the climate-mitigation potential of soils.

Role of Soil Carbon in Soil Health

Soil health is defined as the capacity of soil to function as a vital living system to sustain biological productivity, maintain environment quality and promote plant, animal and human health as whole (Doran and Zeiss, 2000). Soil carbon is a key indicator of soil health as it is involved in the formation and stabilization of soil aggregates, improving soil structure, porosity, aeration, infiltration and resistance to erosion. The carbon-rich soils also enhance water-holding capacity and water availability to plants (Song et. al., 2023), which is particularly important under abiotic stress conditions such as drought and irregular rainfall conditions. Soil carbon further serves as an important reservoir of nutrients and an energy source for soil microorganisms, thereby regulating the decomposition of organic matter, nutrient mineralization and cycling of essential elements. In addition, organic carbon contributes to cation exchange capacity and buffering capacity, enhancing nutrient retention and maintaining a favourable chemical environment for plant growth. Through these interconnected effects, soil carbon supports sustained crop productivity while simultaneously increases the soil resilience towards environmental stresses.

However, the influence of carbon on soil health depends not only on the quantity of carbon present but also on its quality, turnover, distribution and stabilization within different soil as discussed above.

Role of Soil Carbon in Climate Security

Soils represent one of the largest terrestrial carbon reservoirs and their ability to sequester and stabilize carbon can influence the atmospheric concentration of CO_2 (Anjum et. al., 2022; Rodrigues et al., 2022). Through the incorporation of plant residues, root-derived carbon and organic amendments, atmospheric carbon can be transferred into soil organic matter and subsequently stabilized through aggregation and mineral association (Tou et. al., 2025). This process contributes to long-term carbon storage and climate-change mitigation. Beyond carbon sequestration, soil carbon also enhances the resilience of soil ecosystems to climatic variability (Dutta et. al.2024).

However, the contribution of soil carbon to climatic security depends on the balance between carbon inputs and losses (Moinet et. al. 2023). Agricultural practices such as intensive tillage, residue removal, deforestation, intensive land use can accelerate carbon decomposition and release CO_2, ultimately reducing the carbon-storage potential of the agricultural soils (Kamyab et. al., 2025; Imran et. al., 2025). Conversely, conservation agriculture, residue retention, cover cropping, agroforestry, organic amendments and reduced soil disturbance can promote carbon accumulation and stabilization (Bhattacharya et. al., 2025).

Agricultural Practices to Increase Carbon Storage

Agricultural practices such as conservation tillage, cover cropping, crop rotation, crop-residue retention, organic manure application and agroforestry play a vital role in enhancing soil carbon storage by increasing organic carbon inputs, minimizing soil disturbance and reducing carbon losses through decomposition and erosion. The incorporation of crop residues, compost and farmyard manure provides additional carbon substrates for soil microorganisms, thereby promoting soil organic matter formation and nutrient cycling. Cover crops and diversified cropping systems enhance below-ground carbon inputs through root biomass while maintaining continuous soil cover protects the soil surface from erosion and reduces the loss of carbon-rich topsoil. Conservation tillage minimizes the physical disruption of soil aggregates, which can protect organic matter from rapid microbial decomposition. Furthermore, agroforestry systems contribute to carbon sequestration through the accumulation of carbon in tree biomass, roots and soil, while legume-based rotations can improve soil fertility and support biomass production. The effectiveness of these practices, however, depends on soil type, climatic conditions, crop productivity, management duration and the balance between carbon inputs and losses. In addition, the integration of legumes, diversified cropping systems and sustainable nutrient management can improve soil structure, microbial activity and long-term soil organic carbon stabilization (Lal, 2004; Paustian et. al., 2016). These practices not only improve soil fertility, water-holding capacity and overall soil health but also strengthen the resilience of agricultural systems to climate variability and extreme weather events.

Conclusion

Soil carbon dynamics provide a fundamental link between soil health and climate security, highlighting the role of soil in sustaining agricultural productivity and regulating the global carbon cycle. Understanding the interactions among various carbon pools, environmental factors and land management practices is essential for improving carbon stabilization and minimizing carbon losses. The adoption of sustainable agricultural practices can enhance soil carbon storage, restore degraded soils and strengthen ecosystem resilience to climate variability. However, achieving these

benefits requires a comprehensive approach that considers both soil organic and inorganic carbon pools, their long-term stability and their responses to changing climatic conditions. Integrating soil carbon management into sustainable agricultural practices and climate policies is therefore essential for safeguarding soil health, ensuring food security and advancing long-term climate-change mitigation.

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The Berry That Fooled My Tongue - A Small Red Fruit from West Africa can Make a Lemon Taste Like Lemonade. This is the Story of Miracle Fruit—Nature's Most Surprising Flavour Magician.

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It began with a lemon. A visitor at a small fruit garden in Kerala picked up a bright red berry, chewed it slowly, and waited for a minute. Then, with a mischievous smile, she took a slice of lemon and bit into it. Everyone around expected her face to twist with sourness. Instead, her eyes widened. "This tastes like sweet lemonade!" she exclaimed. The lemon had not changed. No sugar had been added. Yet, to her tongue, the sharp acidity had almost disappeared, replaced by a pleasant sweetness. The little berry responsible for this trick is called **miracle fruit** (*Synsepalum dulcificum syn. Richadella dulcifica*) and it truly lives up to its name.

A Fruit from the African Forests

Miracle fruit is native to the humid forests of West and Central Africa, belonging to the family Sapotaceae, where it grows as a small evergreen shrub. Its berries are tiny about the size of coffee cherries and turn from green to a glossy red when ripe. For generations, communities in parts of West Africa used the berry before eating sour or less palatable foods. A small miracle fruit could make difficult foods easier to enjoy. Long before food scientists understood the reason, local knowledge had already discovered its secret. Today, the plant is grown in tropical regions across the world, including parts of Asia, Africa, and the Americas. It is still rare in Indian gardens, but its unusual ability is attracting the attention of farmers, chefs, food technologists, and health-conscious consumers.

The Moment the Tongue Changes

The magic begins the moment the berry is chewed. Inside miracle fruit is a special protein called **miraculin,** present only in the pulp (4.44%) in the range of 0.07 to 1.03 mg/g. On its own, miraculin does not taste sweet, it is neutral in nature. But when it meets acidic foods such as lemon, tamarind, vinegar, or unsweetened curd, it binds to the taste bud receptors, namely hT1R2 and hT1R3, it changes the way our sweet taste receptors respond. In simple words, miraculin waits quietly on the tongue. When sour food arrives, the acid activates it. Suddenly, the brain receives a stronger "sweet" signal, while the sharp sourness seems softened. That is why, after eating miracle fruit, a lemon can taste like lemonade, raw tamarind may seem sweet, and even a spoonful of vinegar may become surprisingly pleasant. The effect usually lasts for a short time (1/2 hr) often up to about two hours until the protein is washed away or broken down. Miracle fruit does not add sugar. It does not change the chemistry of the lemon. It simply changes the story our brain hears from the tongue.

A Party Trick That Became Serious Science

For many years, miracle fruit was known mainly as a curiosity. People organized "flavour-tripping" parties, where guests tasted miracle berries and then tried lemons, limes, strawberries, cheese, and even bitter vegetables. Every bite became a surprise. But scientists began asking a more important question: **Could this berry help people eat less sugar?**

If naturally sour foods can taste sweet without added sugar, miracle fruit, similar to *Gymnema sylvestrae* and *Thamautococcus danielli* may help reduce our dependence on sugar and artificial sweeteners. Researchers are exploring its possible use in low-sugar beverages, desserts, and foods for people who need to limit sugar intake. There is also interest in using miracle fruit for people whose sense of taste changes during illness or medical treatment, especially cancer patients. A fruit that makes food more enjoyable could improve appetite and quality of life. However, scientists caution that more clinical research is needed before miracle fruit can be recommended as a treatment.

More Than a Sweet Illusion

Miracle fruit is not only a taste modifier. The plant contains nutritional and phytochemical compounds, and traditional medicine systems have used different parts of the plant for various purposes. Modern studies are examining its antioxidant, anti-inflammatory, antidiabetic, and antimicrobial potential, though many findings are still preliminary. The fruit also offers opportunities for **waste-to-wealth** thinking. Fresh berries can be sold in niche markets, valued for its vitamin C (40mg/100g) while processed products such as tablets, freeze-dried powders, flavour-modifying cubes, and frozen pulp can extend shelf life and increase value. Even leaves, seeds, and processing residues may have future uses

in nutraceuticals, cosmetics, or bio-based products. For a small farmer, this means miracle fruit need not remain just a novelty fruit. With proper processing and branding, it could become part of a high-value specialty crop system.

Can it Grow in Indian Gardens?

Miracle fruit enjoys warm, humid tropical conditions much like many parts of southern India. It prefers partial shade, especially when young, and grows best in well-drained, slightly acidic soil rich in organic matter.

A few simple practices can help:

a. Plant it in partial shade and protect young plants from harsh afternoon sun.
b. Use loose, well-drained soil; avoid waterlogging.
c. Maintain regular moisture, particularly during flowering and fruiting.
d. Apply organic manure or compost to support slow, steady growth.
e. Protect the plant from strong winds and long dry spells.

Because the plant grows slowly and the market is still niche, it is best suited for home gardens, nurseries, agri-tourism farms, and small-scale specialty growers rather than immediate large-scale cultivation.

A Berry That Teaches Us to Look Closer

Miracle fruit reminds us that nature does not always reveal its wonders in large, flashy forms. Sometimes, the most astonishing discoveries come from a berry no bigger than a coffee cherry. It cannot turn a lemon into sugar. It cannot replace a balanced diet or cure disease. But it can change the way we experience food and perhaps, one day, help us enjoy healthy, low-sugar foods with greater pleasure. The next time you bite into a lemon and wince, remember: somewhere in a tropical garden, a tiny red berry is waiting to rewrite that story.

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When a Bumper Becomes a Disaster: Krishnagiri's Mango Glut, Cold Chain Crisis and Farmer Distress

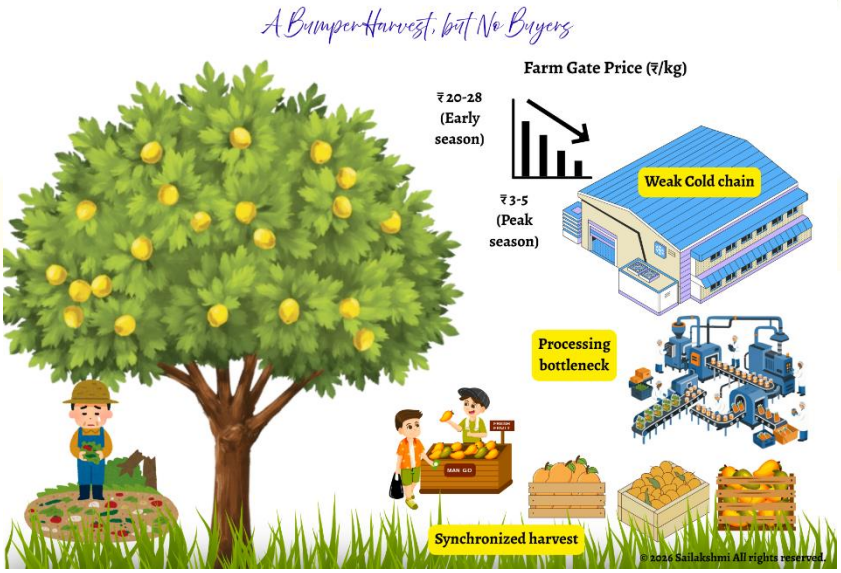
Article ID: 74624

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Abstract
Krishnagiri does not just grow mangoes, it grows identity. The district with 33,000 hectares area under mango cultivation dominated by the pulp-friendly cv. Totapuri (locally called Kilimooku or Kallamai), feed India's beverage, ice-cream and other processing industries, supports thousands of rural livelihoods. For decades, a good flowering on season has meant celebration with extra wages for farm labourers, advance payments from traders and merchants and a sense that the orchard will once again "pay the bills." But in 2025, the script flipped. A near-perfect monsoon and warm spell triggered heavy, synchronized flowering across blocks. Trees bowed under fruit. Trucks lined up at farm gates. Yet, within weeks, the mood shifted from pride to panic. Pulp factories slowed procurement, export orders faltered, and prices collapsed from an early-season ₹20-28/kg to distress levels of ₹3-5/kg, sometimes not even covering plucking and transport. In some villages, farmers stopped harvesting altogether; in others, they cut down trees rather than pour more money into a loss-making crop. What should have been a bumper year became a textbook case of how abundance, without infrastructure and market coordination, can turn into waste and misery.

Keywords: Export, Mangoes, Pulp, Post-harvest losses, Totapuri.

Introduction - Price Crash: From ₹28/kg to ₹4/kg
At the start of the season, expectations were high. Many farmers recalled previous years when Totapuri fetched ₹18-22/kg on average, with occasional spikes higher. Traders initially quoted ₹20-28/kg for early, well-graded lots, feeding hopes of a profitable year. Then came the slide. As harvests peaked simultaneously, pulp units citing sluggish export demand and unsold inventory from earlier seasons began cutting back purchases. Beverage companies, under cost pressure, reduced the proportion of real mango pulp in drinks, further softening demand. Within weeks, farm-gate prices in Krishnagiri and neighbouring belts fell to ₹4-5/kg. In Madurai, Dindigul, and parts of Dharmapuri, rates dipped to ₹3/kg, with some traders offering as low as ₹1-2/kg for overripe or slightly damaged fruit. The economics turned cruel. Harvesting, grading, packing, and transporting a kilogram of mango often costs ₹6-8/kg. Selling at ₹4/kg meant a loss on every crate. For smallholders with 2-5 acres and tight cash flows, that arithmetic was devastating.



Why "Excess" Production Becomes "Losses"
On paper, "bumper harvest" sounds like success. In perishable horticulture, it can be a trap. Three interlocking factors turned Krishnagiri's abundance into distress:

1. Synchronized Arrivals: Everyone Ripens at Once: A favourable weather window advanced flowering and fruit maturity across large areas. Instead of a staggered flow of fruit over 6-8 weeks, markets were flooded within 3-4 weeks.

Mandis and collection centres were overwhelmed. Trucks waited for hours. Fruits softened in the sun. The moment supply outpaces handling capacity, quality drops and so do prices.

2. Processing Bottleneck: Factories Full, Orders Slow: Totapuri's main destiny is the pulp vat, not the retail basket. But in 2025, many processors were sitting on carry-over stock from previous seasons. Export pipelines to West Asia and other regions had slowed due to geopolitical tensions and quality/consistency concerns. With cold storage limited and working capital tied up, factories delayed new purchases or quoted rock-bottom rates.

3. Weak Demand Signals: Less Pulp, More Substitutes: Industry reports point to another quiet shock: beverage manufacturers reducing real-pulp content in mango drinks to manage costs. When large buyers use less pulp per litre, the total volume needed shrinks—even if sales volumes look stable. Combine that with global market fluctuations, and the demand curve bends downwards just as supply peaks. In such a scenario, "excess" does not mean "more income." It means more fruit chasing fewer buyers, faster spoilage, and weaker bargaining power for farmers.

The Cold Chain Gap in Numbers

If there is one phrase that recurs in every post-mortem of Tamil Nadu's mango crises, it is "cold chain gap." Field interactions and local surveys in Krishnagiri and nearby districts consistently highlight: Around 70% of stakeholders, farmers, traders, and small processors, report inadequate cold storage and packhouse facilities near orchards. Transport delays of even 12–24 hours in summer heat can push Totapuri from "ripe" to "reject," especially when fruits travel without pre-cooling. Limited reefer (refrigerated) transport means most trucks carry warm fruit, accelerating softening, respiration, and pulp breakdown.

The consequence is a vicious cycle: without cold chain, farmers must sell immediately; immediate sales during a glut mean lower prices; low prices discourage investment in cold infrastructure; and the cycle continues. Add to this the lack of standardized grading and ripening protocols. A crate of uniformly graded, pre-cooled Totapuri can fetch a premium from processors and exporters. A mixed lot, warm and uneven, gets discounted or rejected.

Human Cost: Dumped Fruit, Felled Trees

Statistics tell part of the story; people tell the rest. In villages around Krishnagiri, Salem, Dharmapuri, Dindigul, and Madurai, the 2025 season left deep scars: Unharvested orchards: Many farmers simply stopped plucking. When the market pays ₹3–4/kg and harvesting costs ₹6–8/kg, leaving fruit on the tree becomes a rational, if heartbreaking, choice. Felled trees: Some growers, especially those with aging orchards and high debt, began cutting down Totapuri trees to prevent further losses and reduce maintenance costs. Debt and distress: Short-term loans taken for labour, fertilizers, and spraying became hard to repay as incomes evaporated. Labour hit: Women and daily wage workers who depend on harvest work saw fewer employment days as farmers scaled back operations or abandoned blocks. One image kept appearing in reports: heaps of ripe mangoes rotting by the roadside, while farmers watched, helpless. For a community that measures pride in full crates and busy trucks, it was a humbling, painful season.

A Berry That Teaches Us to Look Closer

Krishnagiri's Totapuri is not just a local crop; it is a node in a national and global value chain. Yet that chain has weak links:

1. Export Disruptions: Orders to West Asia and other traditional markets faltered amid geopolitical tensions, currency fluctuations, and quality complaints. Without reliable export offtake, domestic processors bear the entire glut.

2. Pulp Inventory Overhang: Many units entered the season with unsold pulp stock from previous years. With beverage demand soft and competition from other fruit bases, they delayed new purchases or demanded steep discounts.

3. Quality and Compliance Gaps: Inconsistent grading, lack of standardized ripening, and limited traceability reduce competitiveness. Buyers in high-value markets want uniform Brix (sugar content), firmness, and pulp recovery parameters that are hard to guarantee when fruit arrives warm, mixed, and rushed.

4. Coordination Failure: Farmers, traders, processors, and exporters often operate in silos. Without pre-season contracts or coordinated harvest calendars, everyone reacts to the same price signals at the same time, amplifying the boom–bust cycle.

Policy and Industry Responses

As distress mounted, responses came from multiple quarters some swift, some symbolic, some too late for the 2025 season.

1. Government Procurement and MSP: In neighbouring Karnataka, the Centre and state announced procurement of distressed Totapuri at a Minimum Support Price (MSP) of ₹1,616 per quintal, sharing losses 50:50 under a Market Intervention Scheme (MIS). Similar demands rose in Tamil Nadu, with farmer groups urging the state to adopt comparable measures.

2. Political Pressure and Protests: Farmer associations and opposition parties staged protests and hunger strikes in Krishnagiri, demanding at least ₹13/kg and compensation for losses. Headlines spoke of "mango stir" and "juicy mess," capturing both the irony and the anger.

3. Committee Findings and Reform Talks: A Union-level committee identified delayed factory purchases, low real-pulp content in beverages, and global market swings as key drivers of the crash. It recommended better coordination between processors, exporters, and farmer groups, along with measures to stabilize arrivals and prices. Yet, on the ground, many farmers felt these measures arrived late or bypassed smallholders without strong trader linkages. For a family that invested lakhs in an orchard, a committee report does not pay the bank EMI.

What It Will Take to Fix This

Turning the next bumper into a blessing needs system-level fixes, not just sympathy. The solutions are known; what is needed is scale, speed, and coordination.

1. Staggered Harvest and Market Arrivals: Promote canopy management, growth regulators, and block-wise harvesting calendars to avoid synchronized peaks. Encourage varietal diversification within and across farms so that not all trees ripen in the same window.

2. Cold Chain at the Farm Gate: Expand packhouses with pre-cooling near major clusters in Krishnagiri, Dharmapuri, and Salem. Incentivize mobile cold rooms and reefer transport corridors from orchards to processing hubs and ports. Link cold-chain subsidies to FPOs and cooperatives so smallholders can access shared infrastructure.

3. Contract Farming and Forward Linkages: Tie Farmer Producer Organizations (FPOs) directly with processors and exporters through pre-season contracts with floor prices. Use model agreements that specify quality parameters, delivery schedules, and price bands to reduce opportunistic behaviour.

4. Diversify Products and Markets: Encourage small-scale units for frozen pulp, puree, dried mango, and ready-to-drink formats. Explore new export destinations with consistent quality protocols, and support units to meet international food-safety standards.

5. Real-Time Market Intelligence: Use SMS/WhatsApp advisories on mandi prices, factory intake schedules, and ripening windows so farmers can time sales better. Create a dashboard for arrivals, prices, and cold-storage availability at district and block levels.

6. Policy Continuity and Swift Intervention: Make market intervention swift and transparent; link it to quality grading so that better produce fetches better rates even in glut years. Align MSP/MIS triggers with local cost structures so that support prices are truly protective, not symbolic.

A Roadmap from Crisis to Confidence

Krishnagiri's mango story need not be a cautionary tale. The district has the soil, the climate, the varieties, and the human capital to lead India's mango economy. What it needs now is a coordinated push on infrastructure, market design, and farmer empowerment.

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From Geographical Indication Tag to Income Enhancement: A Farmer-Owned Business Model for Lakadong Turmeric

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Abstract

Lakadong turmeric grown by over 17,500 households in Meghalaya's Jaintia Hills is prized for its 7–12% curcumin content nearly three times that of ordinary turmeric. Despite receiving a Geographical Indication (GI) tag in March 2024, farmers capture only about 2% of the final retail value. Five problems hold them back: distress selling, lack of curing infrastructure, culinary rather than curcumin-based pricing, unused GI registration and fragmented markets. This article proposes "The Golden Root," a farmer-owned three-tier business model in which village SHGs feed into 15 FPOs federated under an apex producer company holding the GI licence and brand. Supported by existing schemes such as Mission Golden Spice and warehouse-receipt finance, the model targets four market channels with batch-level traceability. Full participation is projected to triple household income, offering a replicable pathway for other GI crops of North-East India.

Introduction - Price Crash: From ₹28/kg to ₹4/kg

Lakadong turmeric *(Curcuma longa)*, grown across the West and East Jaintia Hills District of Meghalaya, is prized worldwide for a curcumin content of 7–12 percent, nearly three times that of ordinary culinary turmeric grown elsewhere in India. In March 2024, this distinctiveness earned it a Geographical Indication (GI) tag, a legal recognition meant to protect its identity and unlock premium markets (GI Registry, Govt. of India 2024). More than 17,500 farm households across these districts produce upward of 18,000 tonnes of the rhizome every year. Yet a GI tag on paper does not automatically put money in a farmer's pocket. Today, adulterated turmeric from other states is routinely sold under the "Lakadong" name while the authentic growers who bear every agronomic and weather risk receive barely a fraction of what the product eventually fetches in retail shelves or pharmaceutical extracts. This article summarises a proposed farmer-owned business model "The Golden Root" that shows exactly how the GI tag can be converted from a certificate into a functioning income-multiplying engine.

Market Value Status of Lakadong Turmeric

The Table 1 traces one kilogram-equivalent of Lakadong turmeric as it moves from the farmgate to four different market destinations. The gap between what a farmer earns and what the final product sells for is undefined and it is precisely this gap that authorised-user registration under the GI tag is designed to help farmers capture. The farmer's share of the final retail rupee is estimated at just around 2 percent.

Table 1. Indicative 2025-26 price ladder for Lakadong turmeric:

Value-chain stage	Price realised (₹ per kg equivalent)	Who captures it today
Farmer - raw rhizome at farmgate	30 – 40	Grower
Trader/aggregator - dried, graded	120 – 180	Middlemen
Brand - retail powder pouch (Direct to consumer {D2C})	800 – 1,500	Outside brands
Curcumin extract - pharma/nutraceutical	4,000 – 5,000	Extraction companies

Why Alone Has the GI Tag Not Worked?

A GI tag protects a name, not automatically the income of the people who grow the crop behind that name. Five linked bottlenecks explain why Lakadong farmers have not benefited from GI recognition so far:

1. Distress selling - Harvest peaks in November - December. Cash needs for school fees and the next sowing force farmers to sell wet rhizome immediately, exactly when prices are at their lowest.

2. No curing or drying capacity - Wet turmeric cannot be stored. Without boiling, drying and polishing units near the village farmers have no way to hold stock until the lean season when prices recover.

3. Sold as culinary, not as curcumin - Processed and sold as an ordinary kitchen spice, the very trait that makes Lakadong special i.e., its 7–12 percent curcumin content remains invisible to buyers and unpaid for.

4. GI is registered but unused - Without authorised-user enrolment and batch-level traceability the GI tag protects no one as a result adulterated turmeric from other states is still sold under the Lakadong name (Biam *et al* 2026)

5. Fragmented, oligopsonistic buying - A handful of traders' face thousands of scattered smallholders, so negotiating power sits entirely with the buying side.

Against these constraints a farmer-owned three-tire value chain business model is proposed.

Farmer-Owned Three-Tier Value Chain Business Model

The proposed model keeps ownership of processing and the brand with the producers themselves, so that each tier moves the farmer one step closer to the consumer's rupee, instead of handing that margin to an outside trader or company.

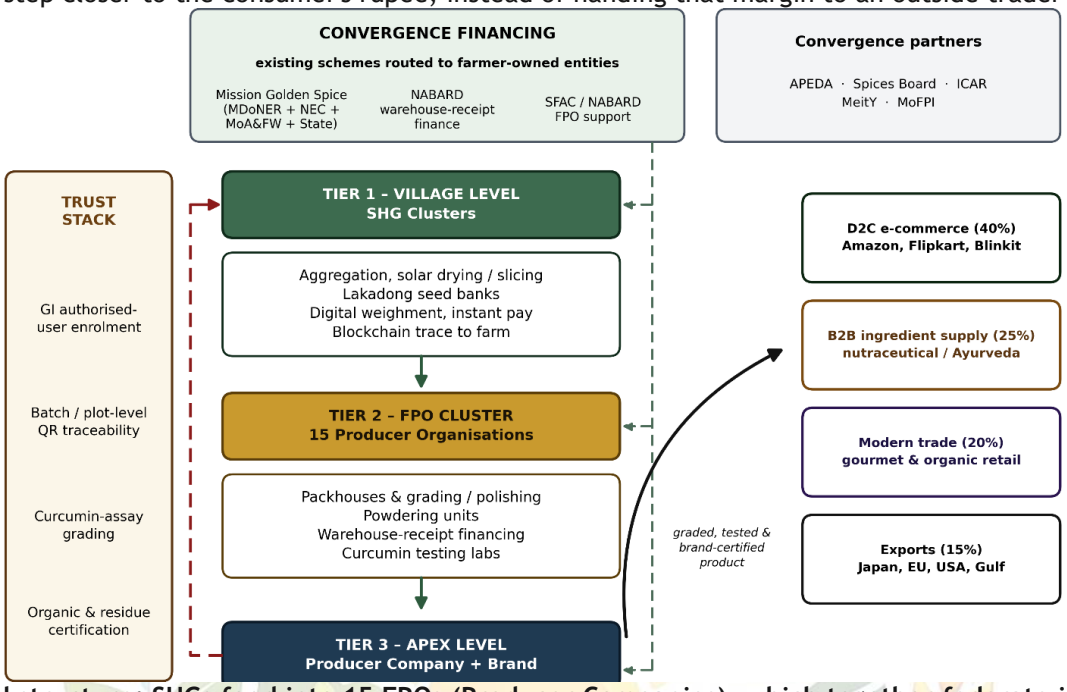


Table 2. Legal structure: SHGs feed into 15 FPOs (Producer Companies), which together federate into one Apex body holding the GI licence and brand equity. Farmers hold shares at every tier

Tier	Institution	Key functions
Tier 1 - Village level	SHG clusters	Aggregation, solar drying & slicing, Lakadong seed banks, digital weighment with instant payment, blockchain trace to farm
Tier 2 - FPO cluster	15 Farmer Producer Organisations	Owned packhouses, grading/polishing/powdering, warehouse-receipt financing, curcumin testing labs
Tier 3 - Apex level	Producer company + brand	Owns the GI-licensed brand, D2C/modern trade/export sales, curcumin extraction unit

Through this model moving the same tonne of raw rhizome through each successive tier of the model rather than selling it wet at the farmgate nearly triples what a household earns, as shown in Figure 2.

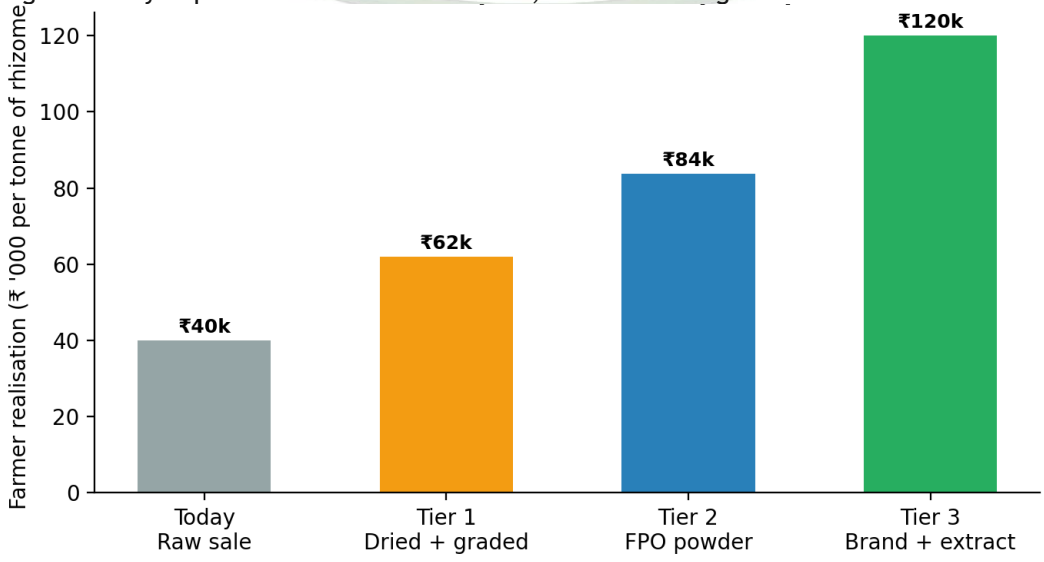


Figure 2. Farmer realisation per tonne of rhizome at each stage of participation. Full Tier-3 participation delivers a 3x income multiple over today's raw farmgate sale.

The gain comes from four sources acting together: curing and storage remove the distress-sale discount; grading by curcumin percentage earns a tested premium; the FPO's own processing margin returns to members as a patronage bonus and extract sales from the apex company lift the pool price paid to every contributing farmer.

Market Channel of the Business Model

A GI tag earns a premium only when buyers can trust it. The model routes Lakadong turmeric to four market channels each requiring a different proof of authenticity and layers a "trust stack" underneath all of them.

Table 3. Planned market access mix by volume:

Market channel	Share of volume	What it needs from the GI tag
D2C e-commerce (own site, Amazon, Flipkart, BigBasket, Blinkit)	40%	Story-led listing with lab report on every pack
Business to Business (B2B) ingredient supply (nutraceutical/Ayurveda manufacturers)	25%	Curcumin assay, not appearance-based pricing
Modern trade (gourmet retail, organic chains, hotels)	20%	Consistent grading and organic certification
Exports (Japan, USA, EU, Gulf via APEDA/Spices Board)	15%	Organic + GI certification as the entry ticket

Financing: Using Existing Schemes

The financing strategy avoids seeking fresh capital and instead channels existing central, state and institutional schemes directly to farmer-owned entities like FPOs, cutting out contractor intermediaries who typically capture these funds. This convergence approach layers infrastructure grants, credit facilities, and technical support from multiple agencies into a single coordinated financing stack (Government of Meghalaya 2026).

Table 4. Financing and institutional support architecture:

Scheme / partner	Role
Mission Golden Spice (₹175.45 cr, 2026–30)	Ministry of Development of North Eastern Region (MDoNER) and North Eastern Council (NEC) (₹87.62 cr) for infrastructure; Ministry of Agriculture and Farmers Welfare (MoA&FW) (₹58.10 cr) for production and organic certification; State (₹29.73 cr) for branding, FPO working capital and traceability
Warehouse receipt finance	National Bank for Agriculture and Rural Development (NABARD) backed pledge loans against stored dried turmeric, the single intervention that ends distress selling
Small Farmers' Agri-Business Consortium (SFAC) / NABARD Farmers Producer Organization (FPO) support	Equity grant matching, credit guarantee cover, and a professional CEO subsidy for each FPO's first three years
Convergence partners	Agricultural and Processed Food Products Export Development Authority (APEDA) and Spices Board (exports), National Turmeric Board (standards), Indian Council of Agricultural Research (ICAR) (agronomy), Ministry of Electronics and Information Technology (MeitY) for traceability layer, Ministry of Food Processing Industries (MoFPI) for processing units

Five-Year Roadmap of the Business Model

This roadmap unfolds in two phases: Years 1–3 focus on organizing farmers and building the core value chain (GI enrolment, processing infrastructure, and branding) while Years 4–5 shift toward high-value expansion through curcumin extraction and export-grade certification.

Table 5. Phase 1 (Years 1–3) builds and strengthens the value chain; Phase 2 (Years 4–5) drives expansion and scale-up:

Year	Focus	Key milestones
Year 1	Organise	Enrol farmers as GI authorised users; form and register FPOs; install solar dryers and slicing units in pilot clusters
Year 2	Process	Set up cluster warehouses and curcumin testing labs; begin warehouse-receipt lending against stored stock
Year 3	Brand	Launch the farmer-owned retail brand; go live on D2C and quick-commerce; deploy QR traceability to plot level
Year 4	Extract	Commission the curcumin extraction facility; sign first nutraceutical offtake contracts on assay-based pricing

Year 5	Export	Secure organic and residue certification for Japan, EU, USA and the Gulf; scale acreage

The Outcome: When the Hills Own the Brand

The larger point of this model is not simply a better price for turmeric. It is farmer ownership of everything that happens to the crop after harvest — the drying, the grading, the brand, and ultimately the GI tag itself. A Geographical Indication is only as valuable as the institutions that stand behind it: authorised users who are enrolled, traceability that is real, and a brand that farmers themselves control. When those three pieces are in place, Meghalaya's "golden root" can finally deliver a golden return to the households who grow it.

Table 6. Target outcomes of the farmer-owned Lakadong turmeric model:

Indicator	Target
Effective farmer realisation	₹40/kg → ₹80/kg
Household income multiple	3x, from the same land and harvest
Production target by 2030	60,000 MT across 7,000 hectares
Women's share of processing & institutional roles	>80%

Conclusion

Registering a GI is the first step, not the last. Converting recognition into rural income requires deliberate, sequenced investment in on-farm drying and grading infrastructure, farmer-owned processing (FPOs), authorised-user enrolment with batch-level traceability, and direct market linkages that reward quality (curcumin %) rather than mere appearance. Extension functionaries and FPO promoters working with other GI-tagged crops in the North-East can adapt this same four-part sequence.

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Fermented Foods of Tradition: Nature's Key to Sustainable Health

Article ID: 74626

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Summary
Fermentation is one of humanity's oldest and most natural food preservation techniques, yet its relevance today is greater than ever. This article explores the rich tradition of fermented foods across India, examining how these microbial marvels support digestive health, boost immunity, and enhance nutrition. The process utilizes beneficial microorganisms—bacteria, yeast, and mold—to break down sugars and starches, transforming ordinary ingredients into probiotic powerhouses. From everyday staples like curd, idli, and dosa to regional treasures like Hawaijar, Ngari, and Soibum, fermented foods represent a perfect blend of ancient wisdom and modern nutritional science. This review provides an in-depth analysis of traditional fermented foods, their preparation methods, nutritional profiles, health benefits, and their potential role in addressing modern lifestyle diseases. It also discusses the challenges and future prospects of integrating these traditional foods into contemporary diets.

Introduction
Modern consumers are increasingly inclined toward minimally processed, natural, and health-promoting foods. However, contemporary diets often lack adequate nutrients and beneficial microbes essential for gut health and overall well-being. This has fueled a renewed interest in traditional foods that have sustained generations. Fermented foods have emerged as one of the most promising categories of functional foods. They operate through natural biological processes and do not require synthetic additives, thus aligning with the growing consumer demand for clean-label products. Fermentation, often described as a "living process," is driven by beneficial microorganisms that create a symbiotic relationship with the human body. In India, fermented foods have been prepared since ancient times, with each region developing its own unique preparations based on local ingredients, climate, and cultural practices (Tamang, 2022).

Principles of Fermentation Technology
Fermentation is typically initiated by lactic acid bacteria (LAB), yeasts, and molds that are naturally present or intentionally added to food substrates. When these microorganisms metabolize sugars and starches, they produce organic acids (primarily lactic acid), alcohol, carbon dioxide, and various bioactive compounds. This creates an environment that inhibits harmful pathogens while enhancing the nutritional profile of the food. The key microorganisms involved in traditional fermentation include Lactobacillus, Leuconostoc, Pediococcus, Streptococcus, Saccharomyces, and various species of Bacillus and Rhizopus. The specific microbial consortia depend on the substrate, environmental conditions, and traditional practices followed in each region (Doo et al., 2024).

These beneficial microbes interact with food components, causing biochemical changes that improve digestibility, increase vitamin content, and produce antimicrobial compounds. The intensity, type of substrate, microbial load, and fermentation time can be tailored depending on the specific product and desired characteristics.

Applications in Food Preservation and Nutrition
1. Dairy-Based Fermented Foods: India's dairy-based fermented foods include **curd (dahi), buttermilk (chaas), kefir, cheese, and lassi**. These products are excellent sources of calcium, vitamin B12, and protein. The probiotic bacteria in these foods improve digestion, boost immunity, and help reduce inflammation in the body. Curd is perhaps the most widely consumed fermented food in India, served with meals and used in countless preparations. Fermentation reduces lactose content, making these foods suitable for lactose-intolerant individuals while retaining essential nutrients.

2. Grain and Pulse-Based Fermented Foods: Fermented foods made from grains and pulses—**idli, dosa, appam, dhokla, handvo**, and various traditional breads—are staples across India. The lactic acid bacteria in fermentation break down complex carbohydrates and phytic acid, making these foods easier to digest and improving mineral absorption. They provide sustained energy and their high fiber content keeps the digestive system running smoothly. Idli and dosa, in particular, have gained global recognition as healthy, fermented breakfast options (Kabui et al., 2025).

3. Vegetable-Based Fermented Foods: Vegetable-based fermented foods such as **kimchi, sauerkraut, pickles (achaar)**, and mixed vegetable-pulse preparations are rich in **antioxidants**. These compounds protect the body from harmful free radicals and promote healthy skin and hair. Fermented vegetables also contain **phytonutrients** that offer protection

against infections, inflammation, and certain cancers. In India, traditional pickles made from mango, lemon, and various vegetables are prepared using salt, oil, and spices that facilitate natural fermentation and preservation.

4. Fermented Fruit Products: Fermented products made from fruits include **apple cider vinegar, wine**, and naturally fermented juices. These support digestive health, improve nutrient absorption, and help maintain the body's pH balance. Apple cider vinegar contains acetic acid, which is beneficial for managing cholesterol levels and blood sugar. Traditional fermented fruit beverages are also prepared in various parts of India during harvest seasons.

5. Traditional Meat and Fish Ferments: In Northeast India, traditional fermented meat and fish products are prepared using indigenous knowledge passed down through generations. In Manipur, commonly consumed fermented foods include fermented bean (**Hawaijar**), fermented fish (**Ngari, Hentak**), and fermented bamboo shoots (**Soibum, Soidon**). These foods have distinct microflora that improve gut health, boost immunity, and enhance the flavor, aroma, and digestibility of food. Similar products like **Shidal** and **Tungrymbai** are prepared in other Northeastern states (Kabui et al., 2025).

6. Fermented Beverages: Fermented beverages include **kombucha, rice beer (like Apong and Handia)**, and naturally fermented fruit wines. Kombucha—a unique tea fermented with yeast and bacteria—helps eliminate toxic substances from the body, improves liver function, and boosts immunity. Traditional rice beers are integral to the cultural and social fabric of many Northeastern communities.

Effects on Food Quality Attributes

One of the major advantages of fermentation is its ability to retain and even enhance the quality attributes of food products. Studies have shown that fermented foods maintain their original color, texture, flavor, and nutritional content better than many processed alternatives. For instance, fermented dairy products retain calcium and protein while gaining probiotics. In grains and pulses, fermentation increases B-vitamin content, particularly B12, which is otherwise rare in plant-based foods. The absence of thermal stress allows preservation of bioactive compounds, antioxidants, and essential nutrients. Furthermore, fermentation produces volatile compounds that contribute to characteristic flavors and aromas, which are crucial for consumer acceptability (Doo et al., 2024)

Mechanisms of Health Benefits

The health benefits of fermented foods are multifactorial. Key mechanisms include:

Probiotic Effect: Live beneficial bacteria colonize the gut, improving microbial balance and digestive function.

Enhanced Nutrient Bioavailability: Fermentation breaks down anti-nutrients like phytic acid and tannins, increasing the absorption of minerals and vitamins.

Production of Bioactive Compounds: Fermentation generates organic acids, bacteriocins, and bioactive peptides that have antimicrobial, antioxidant, and immunomodulatory properties.

Immune System Modulation: Probiotics interact with the gut-associated lymphoid tissue, strengthening both innate and adaptive immunity.

Gut-Brain Axis Support: Beneficial microbes influence neurotransmitter production and may positively affect mental health (Alvanoudi et al., 2025).

The degree of health benefits depends on the type of fermented food, microbial strains present, fermentation conditions, and individual gut microbiota composition.

Advantages and Challenges

Advantages:

a. **Natural and Chemical-Free:** No need for synthetic preservatives or additives.
b. **Enhanced Nutrition:** Increases vitamin content, improves mineral absorption, and provides probiotics.
c. **Improved Digestion:** Breaks down complex compounds, making food easier to digest.
d. **Extended Shelf Life:** Natural preservation through organic acids and antimicrobial compounds.
e. **Cultural and Economic Value:** Supports local food traditions and small-scale producers.

Challenges:

a. **Standardization:** Traditional fermentation relies on natural microflora, leading to variability in quality and safety.
b. **Hygiene and Safety:** Improper fermentation can lead to contamination or production of harmful compounds.
c. **Seasonal Availability:** Many traditional fermented foods are prepared seasonally and may not be available year-round.
d. **Consumer Awareness:** Modern consumers may be unfamiliar with traditional fermented foods and their benefits.
e. **Regulatory Framework:** Need for validated protocols and safety standards for commercial production (Tamang, 2022).

Combination with Modern Food Technologies (Hurdle Technology)

Traditional fermentation can be effectively integrated with modern preservation methods in a hurdle approach to enhance overall efficacy and safety. Synergistic effects have been observed when fermentation is combined with:

1. Refrigeration and Cold Storage
2. Vacuum Packaging and Modified Atmosphere Packaging (MAP)
3. Mild Heat Treatment
4. Natural Antimicrobials (essential oils, plant extracts)

These combinations help reduce microbial risks more effectively while preserving food quality and safety. They also allow for extended shelf life and wider distribution of traditional fermented products (Doo et al., 2024).

Regulatory and Safety Considerations

The regulatory status of traditional fermented foods varies globally. While there is growing scientific consensus on their health benefits, regulatory bodies are carefully evaluating safety standards for commercial production. Preliminary studies suggest that traditionally fermented foods are generally safe when prepared hygienically. However, risk assessment studies on microbial safety, biogenic amines, and consumer perception are necessary for wider acceptance. Standardization of traditional recipes and processes is essential for commercial viability.

Future Directions

To fully realize the potential of traditional fermented foods in the modern food industry, future research and development should focus on:

Documentation and Preservation: Systematic documentation of traditional fermentation practices before they are lost.

Strain Identification and Characterization: Identifying and characterizing beneficial microbial strains for starter culture development.

Optimization of Fermentation Parameters: Standardizing time, temperature, and substrate ratios for consistent quality.

Scale-Up and Commercialization: Developing pilot-scale and industrial processes for traditional fermented foods.

Clinical Studies: Conducting human trials to validate health benefits and establish recommended intake.

Integration into Modern Diets: Developing convenient, ready-to-eat fermented food products.

Consumer Education: Raising awareness about the health benefits of traditional fermented foods.

Regulatory Harmonization: Developing standards for traditional fermented foods at national and international levels (Alvanoudi et al., 2025).

Conclusion

Traditional fermented foods represent a transformative treasure in the field of nutrition and food preservation, offering a sustainable, chemical-free, and natural solution for ensuring food safety, enhancing nutrition, and promoting health. Their ability to provide probiotics, improve digestion, boost immunity, and preserve food without compromising sensory and nutritional quality makes them an ideal tool for modern food processing and public health. Despite current challenges such as standardization, hygiene, and limited regulatory clarity, continuous research, innovation, and interdisciplinary collaboration are likely to make traditional fermented foods a mainstream component of modern diets in the near future. India's rich heritage of fermented foods offers a valuable foundation for developing functional foods that address contemporary health challenges. It is time we recognize, preserve, and celebrate this **eternal treasure of health** for generations to come.

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From Runners to Revenue: Potential of Strawberry Planting Material Production in Bihar

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Introduction

Strawberry (*Fragaria x ananassa*) is a high-value fruit crop with considerable potential for commercial cultivation in Bihar. The development of a reliable, healthy and locally available supply of quality planting material can become an important component of strawberry-based horticultural diversification in the state.

Strawberry is propagated by runners. Runners are horizontal, above-ground stem that grow outward from a parent strawberry plant and produce new genetically identical "daughter" clone plants. Planting materials contribute to major share of cost of cultivation of strawberry in Bihar. This is due to almost nil availability of planting materials in Bihar. Due to high temperature during March- April in Bihar, the runners start drying out and it becomes challenging to save runners for next season. In view of this, the planting materials need to be procured every year from Maharashtra, Himachal Pradesh, Haryana, etc. The procurement and transportation cost of planting materials (runners) of strawberry is a big hurdle in the strawberry cultivation in Bihar. As per Department of Horticulture, Government of Bihar has released demand of good quality planting materials of strawberry cultivars (Chandler and Sweet Charlie, 60 and 36 lakhs, respectively) during financial year 2025-26 and 2026-27. Establishing a systematic strawberry planting material production programme may help reduce dependence on plants transported from other states, improve timely availability and create additional income and employment opportunities for farmers, entrepreneurs and horticultural institutions in Bihar.

Factors Affecting Runner Production in Bihar

Mulching Material: Black polythene mulch often promotes higher vegetative growth and runner initiation compared to organic mulches like paddy straw or grass.

Sub-tropical Climate: Because strawberries are temperate crops grown in Bihar's winter sub-tropical window (November to March), high temperature shifts and day-length variations influence whether the plant diverts energy into runner generation.

Suitable Production Models for Bihar

Production model	Main opportunity	Essential requirement
Runner nursery	Conventional multiplication from mother plants	Healthy, true-to-type mother stock
Plug-plant nursery	Rooted plants for commercial growers	Trays, clean growing medium and irrigation
Protected nursery	More controlled multiplication and plant health management	Net house, sanitation and monitoring
Tissue culture	Large-scale multiplication of selected cultivars	Laboratory, trained staff and acclimatization facility
Contract production	Supply against farmers' or institutional demand	Confirmed orders and quality compliance

Propagation Techniques

1. Select healthy runners: Choose strong, vigorous runners that have formed small leaves and tiny root bumps (nodes) at the joints.

2. Prepare a small pot or bed: Fill a small nursery pot with cocopeat: perlite (1:1) or cocopeat: sand (1:1).

3. Anchor the node: Press the leaf node of the runner onto the surface of the soil. Secure it in place using a U pin or a bent tie so that it stays in firm contact with the dirt.

4. Water the soil regularly to keep it moist but not soggy, allowing adventitious roots to sprout from the node.

5. Check for root growth: Roots get well established in 3-4 weeks.

6. Snip and transplant: Use clean, sharp pruners to cut the connecting stem from the mother plant.

		
Runners produced from mother plant	**Snipping of runners produced**	**Securing runners to encourage rooting**

Major Opportunities in Bihar

1. Commercial production of strawberry runners: Mother plants can be maintained under suitable nursery conditions to produce daughter plants through stolons (runners). This is a practical opportunity for small and medium-scale nurseries, especially where irrigation, well-drained growing media and healthy mother stock are available.

2. Plug plant and tray-based nursery production: Rooted runner plants can be established in plug trays or small containers filled with a clean, well-aerated growing medium. This approach improves handling, grading, transportation and establishment after transplanting.

3. Protected mother-stock multiplication: Insect-proof net houses and other suitable protected structures can help maintain mother plants, manage environmental stress and reduce exposure to some pests and diseases. Proper sanitation and disease monitoring remain essential.

4. Tissue-culture-based planting material: Laboratory multiplication offers the potential to generate large numbers of uniform plants from selected mother stock. Acclimatization facilities and appropriate quality testing are necessary before supplying plants to growers.

Roadmap to Revenue Generation

1. Establishment of a healthy mother block by selecting authentic disease-free cultivars.

2. Development of nursery infrastructure with provision of raised beds or containers, plug trays, reliable irrigation, suitable growing media and protected structures.

3. Standardization of propagation methods by maintaining time of collection of runners, planting of runners and their maintenance.

4. Building of a marketing network by coordination with farmers, FPOs, nurseries and the Bihar Directorate of Horticulture.

Conclusion

Strawberry planting-material generation represents a promising nursery enterprise and research opportunity in Bihar. Government procurement requirements, the expansion of strawberry cultivation and existing research on runner production and tissue culture provide a foundation for developing local production capacity. The most practical approach is to begin with a healthy mother block and conventional runner or plug-plant production, while developing tissue-culture-based multiplication through an appropriately equipped laboratory or institutional partnership. Commercial success will depend on reliable demand, timely delivery, cultivar authenticity, plant health and competitive production costs.

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Prospects of Dragon Fruit Cultivation in Bihar

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Introduction

Dragon fruit (*Selenicereus undatus*) also known as Kamalam, is an emerging high-value fruit crop with considerable potential for diversification of horticulture in Bihar. It belongs to family Cactaceae. Two variants of dragon fruit (Red fleshed and white fleshed) are being successfully grown in agroclimatic conditions of Bihar. This crop has gained popularity due to its distinctive appearance, consumer appeal and potential for commercial cultivation. It is cultivated commercially in several Asian countries and has gained popularity in India, particularly in Gujarat, Maharashtra, Karnataka and other states.

Dragon fruit cultivation in Bihar has strong commercial prospects, backed by the state's Dragon Fruit Vikas Yojana under the Mukhyamantri Bagwani Mission. The scheme provides direct financial subsidies across 21 districts of Bihar.

Neutraceutical Properties

This fruit may be considered as super fruit because of its richness in minerals, vitamins and antioxidants content. On the basis of 100g fresh fruit weight, it contains 80–85% water, 4.5–7.5 g total sugars, 4–10 mg vitamin C, 0.2–0.3 mg acidity in the form of lactic acid, 2.5–3.0% dietary fiber, 10–13 g carbohydrate, 1.0–1.2 g protein, 270–400 mg potassium, 27.0–39.0 mg magnesium, 0.7–1.0 mg iron and 18 mg calcium and 19.0–36.0 mg phosphorus, 59 IU of vitamin A, 0.1 mg riboflavin, 150 µg vitamin E, Vitamin B1 (0.04 mg), Vitamin B3 (0.16 mg). Red fleshed fruits have higher phenolics and flavonoids content (40–60 mg GAE and 20–40 mg CE, respectively), whereas, white fleshed fruits contain 15– 20 mg GAE and 10–20mg CE, respectively. It provides 60–66 kcal calories of energy. This fruit is an immune booster, digestion helper and minimizes risk of diabetes, heart ailment and cancer.

Scientific Cultivation Practices

Selection of cultivars: The commercially cultivated types include red-skinned, white-fleshed dragon fruit and red-skinned, red- or purple-fleshed types. Yellow-skinned types are also cultivated in some regions.

Propagation and planting: Dragon fruit is generally propagated through healthy stem cuttings. Rooted or properly prepared cuttings from healthy, true-to-type mother plants are preferred for establishing commercial plantations. Planting is undertaken with permanent support structures, such as reinforced concrete or suitably designed poles. Generally, four plants are planted per pole from four directions at a distance of 30 cm from the base of the pole.

Nutrient management: Dragon fruit plants are heavy feeder and fertilizer along with organic manure should be applied in split doses at various growth stages. A standardized INM schedule comprises bioagents such as VAM formulation (50g/plant) and Azotobactor formulation @50 g/plant, which is applied at the time of planting in the pit along with FYM and vermicompost.

Intercropping: It is always advisable to utilize the interspaces by growing short duration low height annual crops in the initial year before the start of fruiting stage. Suitable crops are French bean, green peas, spinach, leafy coriander, onion and marigold in winter season; and cowpeas, amaranthus and any other location specific crops fulfilling the intercropping criteria.

Irrigation management: Soil water conservation by mulching is very useful for better plant growth and fruit quality. Black polyethylene (30–40 micron) or weed mat mulching along the row with provision of ease of fertilizer application at the basin is generally good for conserving soil moisture, soil temperature and enhance microbial activities.

Pollination: Flowers are hermaphrodite but heterostyly (distyle) in nature with androecium part remains at the base of the flower and gynoecium part overgrows and come out of the flower. As a result, pollens of the same flower do not reach the stigma surface. The anthesis time is 7-9 pm. Only bats are reported to act as pollinator in the night. Therefore, to ensure better pollination, hand pollination is done for higher fruit set. Pollens may be collected separately and are placed on the stigma surface by fine brash. In the next day pollinated flowers remain closed and gradually fruit set occurs and fruit development starts. Appropriate time for pollinations 7–9 pm in the night.

Fruit bearing: Fruiting takes place in 3–4 flushes from June to October. Fruit shape is oblong to oval, unripe fruits are deep green which turns into reddish pink in case of red skinned varieties. Fruits mature in 35–40 days after flowering and right harvest stage of fruit is when fruit skin including bracts turned full red. Individual fruit weight is 300–400 g TSS of 13–14° Brix. The fruit is non-climacteric in nature. The approximate shelf life varies from 7–20 days.

Training and pruning: The single strong, central main stem is tied straight up to support pole. The lower growth is removed by cutting off all side shoots and lower branches along the bottom two-thirds of the main stem to send energy upward. Tipping is done once the main stem grows about 4 to 6 inches past the top of the trellis. This forces the plant to branch out into 3 to 5 main sub-branches that cascade down like an umbrella. The structural pruning is done during the post-harvest season. The dead, diseased, yellowing, or ground-touching stems are discarded keeping only 3 to 4 healthy sub-branches per main arm.

Pest and disease management: Important production risks include fungal stem diseases, anthracnose, stem rot and sunburn injury. Excessive moisture, poor drainage, wounds and dense canopies can increase disease problems.

An integrated management programme should include healthy planting material, good drainage, balanced nutrition, sanitation, appropriate pruning and regular field inspection. Any pesticide or fungicide should be used only when required and in accordance with approved recommendations and label instructions.

Agroclimatic suitability of Bihar: Bihar has a predominantly subtropical climate, characterized by hot summers, a monsoon season and relatively cool winters. These conditions may support dragon fruit cultivation, provided that the crop is established in suitable locations and protected against major environmental stresses. The crop thrives well in temperature range of 18–35° C. Warm conditions favor vegetative growth and flowering. However, prolonged extreme heat and intense solar radiation can cause sunburn, yellowing and damage to the green stems, known as cladodes. Excess rainfall and waterlogged conditions may prove detrimental for its growth. The plant is sensitive to sub zero temperature. Well-drained sandy loam or loam soils with adequate organic matter are preferable.

Major Opportunities for Dragon Fruit Cultivation in Bihar

Diversification of horticulture: Bihar is known for commercially important fruits such as mango, litchi, banana, guava and pineapple. Dragon fruit can complement these crops by providing farmers with an alternative high-value fruit.

Potential for income generation: Its perennial nature offers the possibility of repeated harvests over several years.

Employment generation: The crop requires labor for planting, training, pruning, pollination, harvesting, grading, packaging and marketing. Local nurseries can also generate income through the production of healthy rooted cuttings.

Scope for value addition: Dragon fruit can be marketed as fresh fruit or processed into juice blends, beverages, jams, jellies, frozen pulp and other products. Such activities could support rural enterprises and improve market opportunities for growers.

Conclusion

Different areas offer bright prospects of dragon fruit cultivation in Bihar such as establishment of reliable nursery, training of growers in scientific cultivation technologies, encourage farmer producer organizations, collective marketing and direct relationships with retailers and institutional buyers. The fruit may give boost to explore small-scale processing and cold-chain solutions.

		
Planting materials of dragon fruit	**Planting materials planted in poly bags**	**Training system in dragon fruit**

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Vermiwash: Turning Organic Waste into a Powerful Liquid Bio-Input

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Introduction

Sustainable agriculture increasingly requires nutrient sources and crop-management inputs that can improve productivity while reducing dependence on externally manufactured agricultural chemicals. Recycling biodegradable organic residues through biological processes is one important approach. Vermicomposting, in which earthworms and associated microorganisms transform organic materials into stabilized vermicompost, is particularly relevant because it produces both a solid organic amendment and liquid fractions or extracts that can be used as agricultural inputs. Vermiwash is generally described as a liquid extract obtained from a vermicomposting system containing earthworms and decomposing organic materials. It contains soluble mineral nutrients, organic compounds, earthworm-derived secretions, microorganisms and biologically active substances. The agricultural interest in vermiwash arises from its potential dual function as a liquid nutrient and plant-growth-promoting input. Research has reported effects on seed germination, seedling vigour, vegetative growth, flowering, yield, nutrient uptake and certain pest or disease-management parameters. However, the response is strongly dependent on crop, concentration and production method. Therefore, vermiwash should be considered a variable biological input rather than a chemically standardized fertilizer.

What is Vermiwash?

Vermiwash is a liquid product associated with vermicomposting in which water passes through a biologically active bed containing earthworms, decomposing organic matter and microbial communities. The resulting liquid contains water-soluble constituents released from the organic substrate together with materials associated with earthworm activity. Earthworms contribute mucus, excretory products and other biological substances, while microorganisms participate in decomposition and nutrient transformation. Consequently, vermiwash can contain a mixture of mineral nutrients, soluble organic compounds, microbial populations and biologically active substances. The term "vermiwash" has sometimes been used inconsistently for several different earthworm-derived liquids. This distinction is important because laboratory-prepared earthworm exudates, vermicompost extracts and liquids collected from a vermiwash unit are not necessarily chemically identical.

Vermiwash, Vermicompost and Vermicast

Parameter	Vermiwash	Vermicompost	Vermicast
Basic definition	Liquid collected from a vermicomposting system	Stable organic material produced by earthworms and microorganisms	Earthworm droppings (casts) produced after digestion
Origin	Liquid that passes through an earthworm-based system	Breakdown of organic materials by earthworms and microorganisms	Directly produced by earthworms after digestion
Primary biological process	Water extracts soluble nutrients and other compounds	Organic matter is broken down and converted into stable compost	Organic matter is eaten, digested and excreted as casts
Earthworm role	Help create the biological conditions from which the liquid is collected	Major role in breaking down organic matter along with microorganisms	Directly produce the material as their casts
Typical application	Foliar spray or soil application	Used as an organic fertilizer/soil amendment	Added to soil or used in growing media

Formation and Production of Vermiwash

The collection of Vermiwash can commence after a period of 30 days. During this time, the organic waste undergoes decomposition facilitated by earthworms, which enhances the microbial richness and nutrient composition, as well as the enzymes generated by these organisms. Following the 30-day decomposition period, the liquid formula may be collected every 7 to 10 days. Additionally, daily watering is necessary during the collection process to replenish the extracted water and to help regulate the temperature.



Figure 1. Diagrammatic representation of typical vermiwash set up

Mechanism of Action

The effects of vermiwash are probably produced by several interacting mechanisms rather than by one single component.

Nutrient supply: Soluble N, P, K and other nutrients can contribute to plant nutrition. Because vermiwash is liquid, soluble constituents may become available relatively rapidly. However, nutrient concentration is generally much lower and more variable than concentrated mineral fertilizers. Chemical composition of vermiwash given in Table 1.

Parameter	Heat-stress	Cold-stress	Field-produced
pH	7.98	7.40	7.52
EC (dS m^{-1})	0.56	0.42	1.10
Organic carbon (%)	0.042	0.036	0.009
Total N (mg L^{-1})	55.0	52.0	61.02
Total P (mg L^{-1})	19.15	17.80	18.20
Total K (mg L^{-1})	46.24	45.20	55.20
Na (mg L^{-1})	119.40	110.80	120.10
Ca (mg L^{-1})	181.08	175.25	178.60
Mg (mg L^{-1})	196.34	186.90	198.00
IAA (mg L^{-1})	16.08	15.05	15.02

Table 1. Chemical composition of vermiwash produced by different methods

Microbial activity: Beneficial microorganisms may contribute to nutrient transformation, phosphate solubilization, biological nitrogen inputs and interactions around the root zone.

Root development: Plant-growth-regulating substances such as IAA may stimulate root initiation and development.

Nutrient uptake and physiological activity: Improved root development, soluble nutrient availability and microbial interactions may collectively improve nutrient acquisition and plant physiological performance.

Plant defence and disease suppression: Earthworm-derived materials contain biological substances that may interact with plant defence and soil microbial communities. Antimicrobial compounds and competitive microbial populations have been proposed as possible contributors to pathogen suppression. This does not justify treating vermiwash as a universal substitute for registered pesticides or fungicides.

Research Evidence on Vermiwash in Crop Production

Vermiwash has been investigated in several crops for its potential effects on seed germination, vegetative growth, flowering, yield and selected quality parameters. Studies have also explored its use in seed treatment, foliar spraying and soil or root-zone application. However, responses vary with crop, vermiwash preparation, concentration and

application stage. The crop-specific evidence is summarized in Table 2. Experimental rates are presented as research treatments and should not be interpreted as universal recommendations.

Crop	Application method	Rate	Timing	Major response
Green mung (*Vigna radiata*)	Seed/germination	1:5 dilution	Germination	100% germination; highest vigour index
Fenugreek (*Trigonella foenum*)	Vermiwash	3,000–12,000 ppm	Field	Growth, yield and biochemical responses
Urdbean (*Vigna mungo*)	Foliar spray	15%	Flower initiation	Improved growth and yield
Cluster bean (*Cyamopsis tetragonoloba*)	Foliar spray	5%	Field	Improved growth and yield attributes
Brinjal (*Solanum melongena*)	Foliar spray	Experimental	Field	Increased growth, flowering and fruiting
Wheat (*Triticum aestivum*)	Foliar + FYM/vermicompost	10%	25, 50, 75 DAS	3,756 kg ha^{-1} seed yield in pooled analysis
Greengram (*Vigna radiata*)	Foliar + RDF	3%	Pre-flowering/pod formation	Higher leaf-area index

Table 2. Crop-wise applications and reported responses

Disease and Pest Suppression

Vermiwash contains microorganisms, earthworm mucus, coelomic-fluid components and antimicrobial compounds associated with disease-suppressive activity. These components can inhibit or compete with plant pathogens through antimicrobial activity, microbial competition and other biological interactions. Studies have reported suppression of fungal pathogens, bacterial pathogens, nematodes and certain insect pests following vermiwash or related earthworm-product applications. Vermiwash therefore has potential as a complementary component of integrated pest and disease management, rather than a replacement for registered pesticides. Its effectiveness depends on earthworm species, feedstock, preparation method, composition, concentration and target crop or pathogen.

Conclusion

Vermiwash is a biologically derived liquid with potential applications in sustainable agriculture. It contains soluble nutrients, organic compounds, earthworm-derived substances, microorganisms, enzymes and plant-growth-regulating compounds. Research has reported improvements in seed germination, seedling vigour, vegetative growth, flowering, fruiting and yield in several crops. However, its composition and effectiveness vary with raw materials, earthworm species, production conditions, concentration and application method. Higher concentrations do not necessarily produce better results. Vermiwash is therefore a useful supplementary biological input in sustainable crop production, but standardized production, quality assessment, crop-specific dose validation and long-term field research are needed. It cannot be considered a universal replacement for chemical fertilizers, pesticides or fungicides.

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Enablers and Disablers of Blockchain Technology in Agriculture - An Overview

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Abstract
Blockchain technology (BCT) has the potential to transform Indian agriculture by resolving supply chain inefficiencies, but severe infrastructural and literacy barriers inhibit its widespread adoption. This article outlines the drivers (enablers) and barriers (disablers) in broad reference to the Indian socio-economic and agricultural scenario.

Introduction
Indian agriculture faces persistent challenges from supply chain opacity, high transaction costs, systemic leaks in subsidy distribution, and frequent export rejections due to missing origin data. While blockchain technology (BCT) offers a decentralized, tamper-proof solution to these inefficiencies, its deployment across India's unique socio-economic landscape is highly complex.

Blockchain technology is primarily a shared database that stores records on a distributed and decentralized ledger. Once the data is recorded and stored on the blockchain network, one cannot change or modify it, thereby making it transparent and trustworthy. Initially born out of a need for a more decentralized financial system this technology is finding innovative uses in a wide range of sectors including agriculture. Exploring the studies made on the potential upsides and downsides of BCT in agriculture can provide insights on best management practices.

What is BCT?
Blockchain Technology (BCT) is a decentralized, digital ledger system that securely records information across a peer-to-peer network. Unlike traditional databases managed by a central administrator, blockchain distributes data authority among all participants i.e., they enable a community of users to record transactions in a shared ledger within that community, such that under normal operation of the blockchain network, no transaction can be changed once published (Yaga et al., 2019). One of the most popular blockchain technologies is Bitcoin which hosts a digital ledger. Bitcoin provides the platform to mine, store and trade bitcoins via a complex computer algorithm which is tied to a distributed network (Sarmah, 2018).

BCT in Agriculture
Blockchain technology (BCT) is fundamentally reshaping global industries by providing a decentralized, immutable ledger that eliminates traditional intermediaries and fosters unprecedented data transparency. Across diverse domains like finance, healthcare, and supply chain management, BCT streamlines operations by establishing a single, tamper-proof source of truth. This transformative capability is particularly revolutionary in the agriculture sector, where blockchain is deployed to track food provenance from seed to shelf, optimize supply chains, secure land registries, and facilitate fair, instantaneous peer-to-peer payments for farmers. By turning opaque transactional networks into open, verifiable ecosystems, BCT enhances operational efficiency while restoring consumer trust in the products they buy. Especially with the cases of spurious seeds impacting the yields of small-scale farmers, BCT has the potential to trace such counterfeit seeds or falsely branded seeds and ensures the accountability of all stakeholders involved throughout the journey of such seeds. By assigning a unique digital identity such as a QR code to every authorized seed batch, every transfer of ownership and quality certification is permanently recorded on a decentralized ledger. This tamper-proof transparency prevents unauthorized third parties from introducing fake or low-quality seeds into the supply chain. Ultimately, it allows farmers to instantly verify the authenticity and origin of their purchase with a simple smartphone scan, securing crop yields and protecting agricultural livelihoods.

However, the applicability of BCT in agriculture has its drivers and barriers. Unlike traditional application software and Operating Systems, blockchains suffer from severe technology challenges (Biswas and Gupta, 2019). The literature states the drivers at one hand that strengthen BCT such as stakeholder collaboration, enhance customer trust, and democratization, and, on the other hand, barriers such as lack of global standards, industry level best practices and policies for blockchain adoption in the agrifood sector (Akella *et al.*, 2023). The discussion below highlights core enablers and disablers in the context of Indian Agriculture.

Core Enablers of BCT in Indian Agriculture

1. End-to-End Traceability and Food Safety: Traceability was most shouted application of blockchain in agriculture field (Yadav and Singh, 2019). BCT provides an unalterable record of an agricultural product's journey from the farm gate to the urban consumer.

2. Leakage Control in Subsidy & Seed Distribution: Integrating BCT into fertilizer subsidies prevents diversion to non-agricultural sectors. It also ensures that genuine, quality-certified seeds reach small farmers without unauthorized duplication.

3. Disintermediation and Equitable Pricing: Smart contracts bypass traditional rural brokers enabling automated payments directly to farmers' bank accounts upon verified delivery. This enforces fair pricing models and mitigates cash-flow delays.

4. Synergy with Agri-IoT Ecosystems: Integrating distributed ledgers with IoT edge devices (soil sensors, automated weather stations) turns real-time data into a secure trigger for crop insurance payouts. This end-to-end digitisation removes operational friction and provides clear benchmarks for crop insurance scenarios.

Core Disablers of BCT in Indian Agriculture

1. Absence of Clear Regulatory Frameworks: A major systemic roadblock is the lack of specific guidelines from agencies regarding smart contracts and tokenised assets. This legal ambiguity deters institutional investments.

2. Severe Digital Literacy Deficits: The majority of the Indian farming community consists of smallholders who face language barriers and limited experience with digital apps. Complex cryptographic workflows generate high operational anxiety.

3. High Infrastructure Setup Costs: Deploying enterprise-grade blockchain infrastructure alongside the required IoT nodes requires significant capital. Smallholder cooperatives struggle to afford these costs without government backing.

4. The integrity risk: Blockchain secures data against tampering but cannot verify if original data entered at the farm level was accurate. Deliberate or accidental mislabelling by manual actors degrades network integrity.

Interplay of Enablers

The primary enablers discussed above do not work in isolation. Instead, they form a self-reinforcing loop that builds institutional trust. For a long time, Indian agricultural exports have faced frequent rejections in strict regulatory markets like the EU and US due to chemical residue limits and missing origin data. The current reviews show that when blockchain is paired with cryptographic tags (like QR codes or RFID), it creates an unchangeable audit trail that ensures data immutability and product auditability (Mohammed, A *et al.*, 2023). This transparency shifts blockchain from an expensive IT project to an economic necessity for high-value export crops.

Another aspect in Indian context is how blockchain can improve public governance. Currently, systems like the *Pradhan Mantri Kisan Samman Nidhi* (PM-KISAN) rely on centralized databases to send direct benefit transfers (DBT) to farmers. Integrating a hybrid consortium blockchain helps different government bodies—like state land records, banks, and fertilizer cooperatives share verified data securely. This automates validation processes, eliminates duplicate identities, and ensures that input subsidies reach smallholders without leaks.

Deconstructing the Disablers

Despite clear operational benefits, the practical adoption of blockchain faces severe challenges from entrenched structural, social, and economic factors across rural India. A recurring criticism across the literature is the vulnerability of the data-entry layer. Blockchain guarantees that data cannot be altered once uploaded, but it cannot verify if that data was accurate in the first place. In a typical Indian village, data about seed quality, pesticide application, and harvesting dates is still logged manually by farmers or local aggregators. Without automated IoT sensors, there is a constant risk of human error or deliberate mislabelling, which compromises the integrity of the entire ledger. This manual dependence adds to the perceived technical complexity for on-ground operators.

The operational promise of smart contracts relies heavily on cutting out intermediaries to ensure farmers get fair prices However there are still reports that emphasize on brokers operating at mandis to not just facilitate trades but also acting as vital informal moneylenders for smallholders during lean seasons. Attempting to completely replace them with cold, automated smart contracts often triggers significant pushback from local market networks.

Furthermore, there still exists a severe digital divide. Unreliable 4G/5G mobile internet in remote areas makes real-time blockchain synchronization incredibly difficult, compounding existing workforce education deficits.

Conclusion

The integration of blockchain technology (BCT) into Indian agriculture presents a profound structural paradox. On one hand, its enablers such as unalterable end-to-end traceability, automated smart-contract disintermediation, and leak-

proof subsidy distribution offer a powerful cure for the supply chain opacity, systemic inefficiencies, and trust deficits that have historically plagued the sector. On the other hand, its disablers are deeply entrenched in the Indian socio-economic fabric, characterized by fragmented landholdings, severe rural digital literacy gaps, high infrastructure costs, and a lack of regulatory clarity.

Ultimately, blockchain cannot succeed as an isolated technology plug-in. Its future in India depends on a shift away from complex, public networks toward hybrid, localized consortium models that place community institutions like Farmer Producer Organisations (FPOs) at the center. By hiding technical complexities behind simple, everyday mobile interfaces, India can transform its agricultural supply chain from a vulnerable, middleman-driven system into a resilient, transparent ecosystem capable of protecting smallholder livelihoods and competing globally. Setting up a blockchain sandbox controlled and managed by governments will create a safe harbor for supply chains to inexpensively demonstrate this technology and provide the opportunity for governments to support change, rather than to react and match to systems established by others (Kouhizadeh *et al*.,2021).

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Bioremediation of Xenobiotics in Contaminated Soil

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Abstract

Soils worldwide are increasingly burdened by synthetic chemicals to which natural ecosystems have not historically been exposed. Common examples include pesticides, petroleum products, industrial solvents, dyes, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons. Many of these compounds are resistant to degradation, allowing them to persist in soils, leach into groundwater, and accumulate within food chains. Bioremediation addresses this challenge through the use of living organisms, primarily bacteria and fungi, as well as plants to transform pollutants into less harmful or harmless forms. This article examines the nature of xenobiotics, the factors contributing to their persistence in soils, the mechanisms through which microorganisms degrade them, field-based remediation approaches, and the constraints affecting their effectiveness. It also considers how modern omics technologies and genetic engineering may improve the speed and predictability of remediation.

Introduction

Soil is far more than a layer of mineral particles. It is a living system that hosts an enormous variety of microorganisms, and these communities drive nutrient cycling, organic matter turnover, and the natural purification of the land. When industrial and agricultural activity introduces chemicals that the system has not encountered before, this purification capacity can be overwhelmed. The word xenobiotic comes from the Greek for "foreign to life". It refers to chemical substances that are not naturally produced by, or normally expected within, an organism or an ecosystem. In soil science, the term mostly applies to pollutants such as pesticides, fertilizer residues, synthetic dyes, dioxins, PCBs, and PAHs. At high concentrations, they disrupt the soil's biological balance, contaminate surface and groundwater, and interfere with plants by binding to enzymes, nutrient transport systems, and other biologically important molecules. Physical and chemical clean-up methods such as excavation, incineration and chemical oxidation can work, but they are costly, energy-hungry and often disturb the soil structure. Bioremediation has therefore gained wide acceptance as a cleaner alternative that aims to degrade xenobiotics without creating harmful by-products.

Major Classes of Soil Xenobiotics

Xenobiotics enter soil through farming, manufacturing, waste disposal, fuel spills and atmospheric deposition. The table below summarises the groups that receive the most attention.

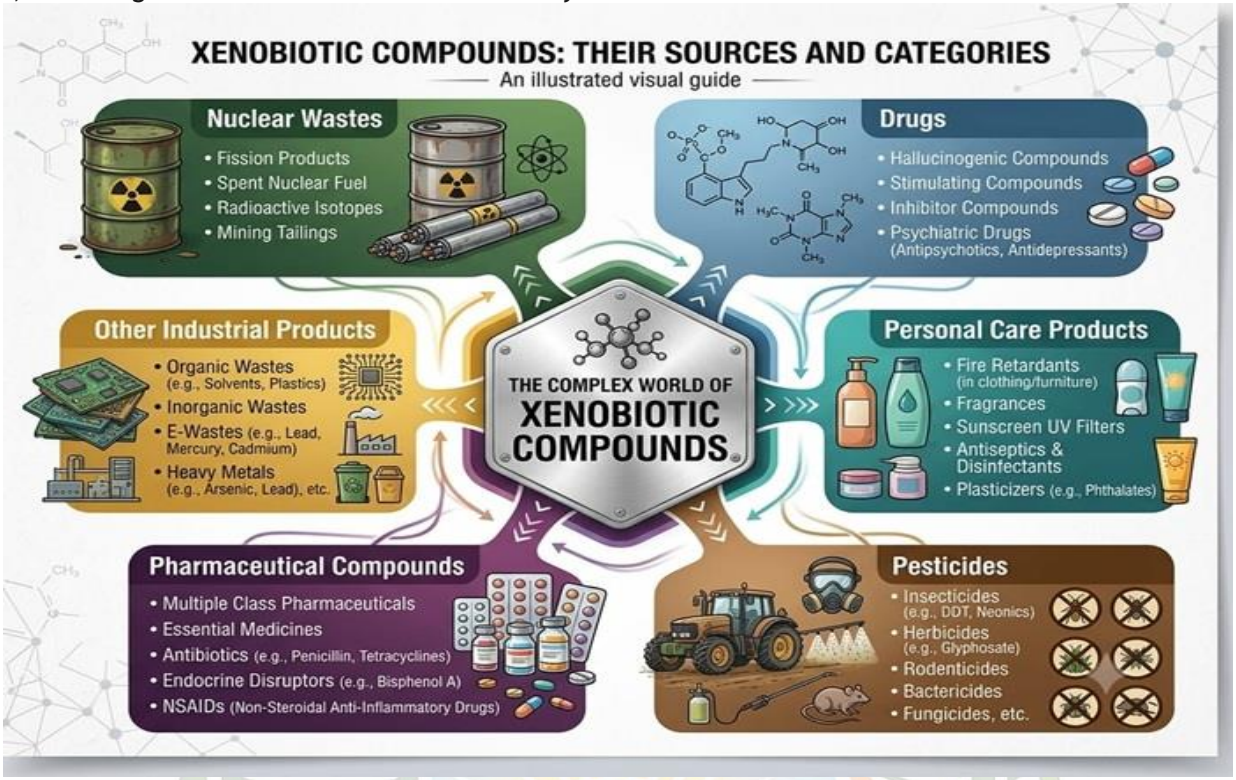
Class	Typical examples	Main concern
Pesticides	Organochlorines (DDT), organophosphates (chlorpyrifos), triazines (atrazine)	Persistence, toxicity to non-target organisms, leaching
Petroleum hydrocarbons	Diesel, crude oil, benzene, toluene, xylene	Oxygen depletion, toxicity, groundwater contamination
PAHs	Naphthalene, phenanthrene, pyrene, benzopyrene	Strong sorption to soil, carcinogenic potential
Halogenated compounds	PCBs, trichloroethylene, dioxins	Chemical stability, bioaccumulation
Dyes and phenolics	Azo dyes, chlorophenols, nitrophenols	Colour, toxicity, formation of toxic intermediates

(Common groups of xenobiotic pollutants found in soil)

Why Xenobiotics Persist?

Several characteristics render these compounds challenging for natural degradation. Many of these compounds incorporate halogen atoms, nitro groups, or stable aromatic rings, which are infrequently encountered by microbial enzymes in natural substrates, potentially resulting in the absence of established catabolic pathways. Additionally, some compounds exhibit hydrophobic properties, adhering strongly to organic matter and clay, thereby reducing their bioavailability to microbes. Furthermore, certain compounds possess sufficient toxicity to inhibit the microbial

communities capable of degrading them. Over time, the situation deteriorates as the contaminants migrate into minute soil pores, rendering them inaccessible to cells and enzymes.



Mechanisms of Microbial Degradation

Microorganisms exhibit significant catabolic capabilities, supported by a diverse set of genes, enzymes, and metabolic pathways dedicated to the degradation of organic compounds. Ideally, a pollutant undergoes mineralization, which involves its conversion into carbon dioxide, water, and inorganic ions, with a portion of the carbon being utilized for the synthesis of new biomass.

Aerobic degradation: In environments with abundant oxygen, bacteria initiate the degradation process through the action of oxygenase enzymes. These enzymes, specifically monooxygenases and dioxygenases, introduce oxygen atoms into aromatic rings, destabilizing them. The destabilized rings are subsequently cleaved via ortho- or meta-pathways, and the resulting fragments are integrated into central metabolic pathways, such as the tricarboxylic acid cycle. Metagenomic studies focusing on soils associated with crops have revealed that pathways like benzoate degradation, the meta-cleavage pathway, and the catabolism of salicylate, gentisate, and phenylacetyl-CoA are particularly prevalent.

Anaerobic degradation: Where oxygen is absent, such as in waterlogged or compacted soil, other electron acceptors take over. Nitrate, sulfate, iron (III), and even carbon dioxide can support degradation. A key process here is reductive dehalogenation, in which halogen atoms on compounds like PCBs and chlorinated solvents are removed and replaced with hydrogen. Anaerobic routes are usually slower but are essential for highly chlorinated pollutants.

Co-metabolism: Some xenobiotics cannot serve as a sole carbon or energy source. In co-metabolism, an organism growing on another substrate produces enzymes that fortuitously transform the pollutant. Trichloroethylene breakdown by methane- or toluene-oxidising bacteria is a well-known example.

The role of fungi: White-rot fungi release extracellular oxidative enzymes, including laccases and lignin and manganese peroxidases. Because these enzymes act outside the cell with low specificity, they can attack bulky, poorly soluble compounds such as high-molecular-weight PAHs and dyes. Fungal hyphae also grow through soil pores and can reach contaminants that bacteria cannot.

Microbial partnerships: In practice, complete degradation is rarely carried out by one species. Consortia share the work: one member converts the parent compound to an intermediate and another consumes that intermediate, which prevents the build-up of toxic products. Biosurfactant-producing microbes add a further benefit by releasing sorbed hydrophobic pollutants from soil particles.

Bioremediation Strategies: Techniques fall into two broad groups. In situ treatments are applied directly in the contaminated ground, while ex situ treatments involve removing the soil for processing elsewhere.

Approach	Principle	Typical use
Natural attenuation	Relies on existing microbes with monitoring only	Low-risk, low-concentration sites

Biostimulation	Adds nutrients, oxygen or moisture to boost native degraders	Hydrocarbon spills with nutrient-poor soil
Bioaugmentation	Introduces selected or engineered microbes	Soils lacking capable degraders
Bioventing and biosparging	Supplies air to the subsurface to support aerobic breakdown	Volatile and semi-volatile fuel components
Landfarming and biopiles	Excavated soil is tilled or piled and aerated	Large volumes of oil-contaminated soil
Composting and bioreactors	Controlled conditions in piles or slurry tanks	Pesticides, explosives, highly contaminated soil
Phytoremediation	Plants and their root microbes take up, transform, or stabilise pollutants	Large, shallow, moderately contaminated areas

(Table: Common bioremediation approaches for contaminated soil)

Phytoremediation deserves particular mention. Roots release exudates that feed microbial populations in the rhizosphere, and this plant-microbe interaction, often called rhizoremediation, can raise degradation rates considerably compared with unplanted soil.

Factors Controlling Success

1. Contaminant properties. Chemical structure, concentration, solubility and toxicity decide whether microbes can attack the compound and whether they survive the exposure.

2. Bioavailability. Strong sorption and ageing reduce the fraction of pollutant that microbes can reach, often making this the main bottleneck.

3. Soil conditions. pH (near neutral is generally favourable), temperature, moisture, oxygen supply, organic matter and clay content all influence microbial activity.

4. Nutrient balance. Carbon, nitrogen and phosphorus must be available in workable proportions; otherwise, growth stalls.

5. Microbial community. The presence, abundance, and adaptability of degrading populations, along with competition from other organisms, shape the outcome.

6. Co-contaminants. Heavy metals can inhibit degraders, so mixed contamination often needs a combined strategy.

Modern Tools: Omics and Genetic Engineering

A long-standing limitation is that only a small fraction of soil microorganisms can be grown in the laboratory, and culture-based studies are biased towards fast-growing species. Culture-independent methods have changed this picture. Metagenomics, metatranscriptomics, metaproteomics and metabolomics reveal which organisms are present, which genes they carry and which are actually switched-on during degradation. Molecular techniques also allow researchers to track catabolic genes and monitor microbial community shifts during treatment.

These data feed bioinformatics resources. For instance, an analysis of 105 metagenomic and metatranscriptomic samples from the soils of seven crops identified more than 25,000 genes and enzymes linked to xenobiotic degradation and produced an online database, XenMetaDB, to support further work.

With this knowledge, genetic and metabolic engineering can be used to build strains with broader substrate range, higher enzyme activity or better stress tolerance. Extremophiles, which tolerate heat, cold, salinity or extreme pH, are also being explored because they can function at sites where ordinary microbes fail. Releasing engineered organisms, however, raises regulatory and ecological questions that must be handled carefully.

Advantages and Limitations

Advantages

a. Lower cost and energy demand than excavation or thermal treatment.
b. Pollutants are often destroyed rather than merely moved to another medium.
c. Minimal disturbance to the site and its soil structure, with public acceptance generally high.

Limitations:

a. Treatment can be slow, taking months to years.
b. Results vary with site conditions and are difficult to predict without pilot trials.
c. Intermediate metabolites are sometimes more toxic than the parent compound, so monitoring is essential.
d. Very high concentrations or mixed contamination may inhibit microbial activity.

Future Prospects

Advancements are expected to arise from integrating multiple approaches rather than depending on a singular method. Notable examples include the design of microbial consortia guided by omics, the pairing of plants with specific rhizosphere bacteria, the addition of biochar or biosurfactants to enhance bioavailability, and the use of nanomaterials in conjunction with microbes. To transition promising laboratory findings into standard practice, long-term field validation, standardized monitoring protocols, and clear regulations for engineered organisms are essential.

Conclusion

Xenobiotic contamination represents a pervasive and enduring issue; however, the metabolic adaptability of soil organisms provides a viable solution. Effective bioremediation necessitates a comprehensive understanding of the contaminant, the soil environment, and the microbial capacity available. Progress in molecular biology is gradually transforming the field from a trial-and-error approach to a design-based strategy, which is anticipated to enhance the reliability of land restoration efforts in the coming years.

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Farmer Digital Registry in Telangana: Progress and Prospects

Article ID: 74632

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Introduction

Digitalisation is transforming agricultural governance by improving farmer identification, information management and the delivery of public services. The Farmer Digital Registry, implemented under the Government of India's AgriStack initiative, aims to establish a unique digital identity for farmers and facilitate the integration of relevant agricultural records. For Telangana, this initiative offers opportunities to simplify access to agricultural schemes, improve transparency and strengthen evidence-based agricultural planning.

What is the Farmer Digital Registry?

The Farmer Digital Registry is a digital database that assigns a unique Farmer ID and links relevant farmer information with digitised land records. It is a key component of AgriStack, alongside geo-referenced village maps and the Crop Sown Registry. Together, these components are intended to improve the availability of reliable information on farmers, agricultural land and seasonal cropping patterns.

The Digital Agriculture Mission, approved by the Union Cabinet in September 2024 with an outlay of ₹2,817 crore, seeks to establish digital public infrastructure for agriculture and facilitate farmer-centric digital services. The registry is intended to support the verification of farmers for eligible schemes and improve the coordination of agricultural services.

Progress of the Farmer Digital Registry in Telangana

Telangana has made substantial progress in farmer enrolment. The state's Farmer Registry portal reports the following figures.

Indicator	Number
PM-Kisan beneficiaries	39,77,791
Total farmer enrolment	54,41,334
Approved Farmer IDs	53,91,755
Enrolment as a percentage of PM-Kisan beneficiaries	136.84%
Approved Farmer IDs as a percentage of PM-Kisan beneficiaries	136.79%
Cases pending Farmer ID generation and approval	76
Enrolments recorded for the day through the specified name-matching process	59

Source: Government of Telangana, Farmer Registry portal

The reported 54.41 lakh enrolments and 53.92 lakh approved Farmer IDs indicate substantial progress in building the state's digital agricultural database. The enrolment total exceeds the number of PM-Kisan beneficiaries, suggesting that the registry and PM-Kisan datasets differ in coverage. Consequently, the enrolment percentage should not be interpreted as the proportion of all eligible farmers in Telangana who have registered.

The state facilitates registration through Common Service Centres (CSCs), MeeSeva centres, operator-assisted enrolment and self-enrolment. The figures indicate that operator-assisted registration is the predominant mode, highlighting the importance of accessible support for farmers who may face digital literacy or connectivity constraints.

District-wise patterns identify Nalgonda, Wanaparthy, Kamareddy, Jagtial and Medak among the leading districts by enrolment. Rajanna Sircilla, Hanumakonda, Medchal-Malkajgiri, Mulugu and Jayashankar Bhupalpally appear among the districts with lower enrolment. These differences warrant further examination using district-wise eligible farmer populations and registration completion rates.

Potential Benefits to Farmers

Simplified access to agricultural schemes: A verified Farmer ID can facilitate identification and eligibility verification for applicable government programmes, potentially reducing repetitive documentation and administrative delays.

Improved access to credit and insurance: Reliable farmer and land information can support eligible agricultural credit applications and crop insurance administration. The Government of India has identified credit delivery, insurance, procurement and direct benefit transfer as important applications of AgriStack.

Better agricultural planning: The Digital Crop Survey records information on crops cultivated and irrigation practices. Telangana's official portal identifies its objective as developing a verified source of farmer and crop information that

can be used by relevant departments, banks and insurance agencies. Such information can support crop planning, input distribution, irrigation management and agricultural research.

Strengthened procurement and marketing: Reliable farmer and crop records can support the administration of eligible procurement programmes. Farmer Producer Organisations may also benefit from authorised, aggregated information to plan collective input purchases, production and marketing.

Targeted extension services: Integrating agricultural information with weather forecasts, pest surveillance and advisory systems can facilitate more location-specific recommendations. These services could help farmers make better-informed decisions about crop management and resource use.

Challenges and Policy Considerations

Despite its potential, the effectiveness of the registry depends on data accuracy, inclusion and institutional coordination.

Land-record discrepancies, inheritance-related changes and differences between recorded ownership and actual cultivation may complicate registration.

Tenant farmers and sharecroppers may face difficulties if procedures rely heavily on recorded land ownership. Women who actively cultivate land may also be underrepresented when records do not adequately reflect their role in agricultural production.

Digital literacy, internet connectivity and access to registration facilities are additional concerns. Assisted registration, village-level awareness programmes and accessible grievance-redressal mechanisms are essential to minimise exclusion.

Data privacy and security also require careful attention. The Government of India states that AgriStack follows a federated model in which states retain ownership of their registry data, with safeguards governing consent and access by authorised entities. Transparent data-use practices and secure information management are necessary to maintain farmers' confidence.

The Way Forward

Telangana should strengthen registration support through agricultural extension personnel, Common Service Centres and MeeSeva centres. Timely correction of inaccurate records and appropriate procedures for recognising women cultivators and tenant farmers should be prioritised in accordance with applicable rules.

The state should also assess the registry using indicators such as coverage relative to the eligible farming population, approval rates, processing time, grievance resolution and successful access to agricultural services. District-level comparisons should account for differences in eligible farmer populations rather than relying solely on absolute enrolment figures.

Agricultural universities, Krishi Vigyan Kendras, extension agencies and Farmer Producer Organisations can contribute through farmer awareness, digital literacy and systematic evaluation of the initiative's outcomes.

Conclusion

The Farmer Digital Registry represents an important step towards digital transformation of agriculture in Telangana. The reported enrolment of more than 54 lakh farmers and approval of nearly 54 lakh Farmer IDs indicate considerable progress in developing digital agricultural infrastructure.

However, registration is only the first step. Accurate records, inclusive registration, effective institutional coordination and strong data protection are essential to translate digital identification into tangible benefits.

The ultimate success of the Farmer Digital Registry will depend on its ability to improve farmers' access to agricultural services, strengthen transparency and contribute to better livelihoods.

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Artificial Intelligence Assisted Crop Improvement for Sustainable Agriculture

Article ID: 74633

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To meet the growing demands for food in the era of climate change and limited arable land for agriculture, there great need of developing climate resilient and smart varieties/hybrids by utilizing advanced technologies like artificial intelligence and machine learning. Plant breeding played vital role in modern agriculture and it has undergone significant changes in terms of application of genetic principles and utilization of modern tools for increasing the productivity and development of high quality, biotic and abiotic stress tolerant varieties. The major eras of evolution of crop breeding are categorized into five phases are as follows.

Crop Breeding 1.0: Traditional breeding and selection based on natural variability, phenotypic selection and domestication.

Crop Breeding 2.0: During 20th century scientific efforts initiated based on Mendelian genetics, hybridization, heterosis and field testing.

Crop Breeding 3.0: late in the 20th century, emergence of molecular markers, sequencing platforms, transgenics, QTL mapping and marker assisted selection

Crop Breeding 4.0: Employment of precision allele combinations using available sequenced data, multiomic profiling, high throughput phenotyping, environmental sensing, genome editing and deep learning for varietal development

Crop Breeding 5.0: Deployment of Artificial intelligence in the core of breeding cycle optimization, smart phenotyping, genotyping, hyper dimensional multimodal data integration and intelligent breeding support and decision systems.

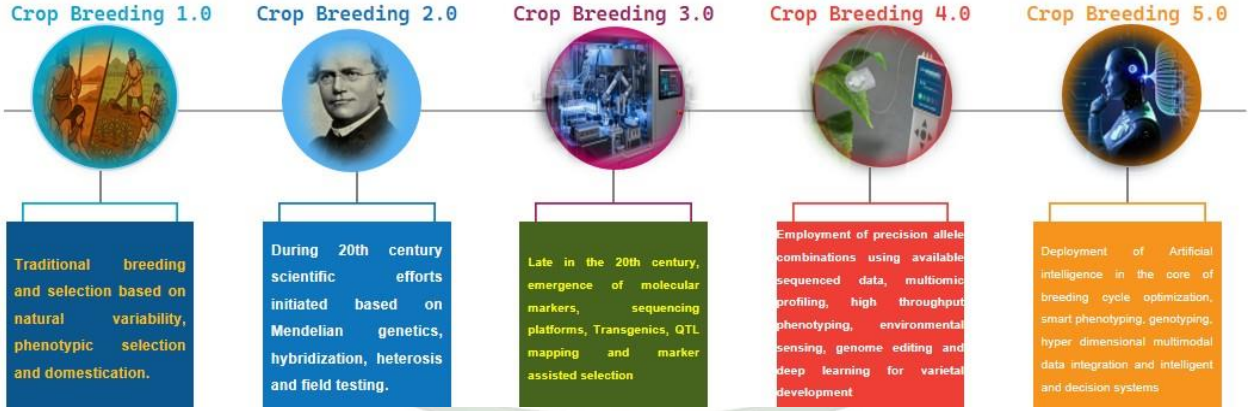


Figure 1: The major eras of evolution of crop breeding

Artificial intelligence (AI) is plays key role in transforming modern breeding and crop improvement by utilizing cutting edge AI technologies viz., machine learning (ML), computer vision, and deep learning for acceleration of high yielding and climate resilient cultivars. The major applications are described below.

Major Applications

Labour intensive and time consuming traditional data recording and phenotyping is replaced by intelligent robotic systems, sensors and digitalization. Employment of UAV and Satellite Monitoring for measurement of weather parameters like temperature, relative humidity, soil properties and plant traits like biomass volume and photosynthetic efficiency. Machine learning models along with sensors are used for root distribution for identification of drought tolerant and waterlogging tolerant varieties.

Table 1: Application of AIML tools in modern plant breeding:

Core Breeding Area	AI/ML Applications	Specific tools/ Models Used	Functional Purpose	Expected Breeding Outcome
Germplasm management and trait discovery	Automation, multiomic data fusion and smart diversity mapping	Self-Organizing Maps(SOM), Unsupervised Clustering, High-speed Computer Vision, Near-	Identification of hidden genetic traits, integration of transcriptomic, proteomic, and	Identification of novel genes of climate resilience. Discovery of complex biological

		Infrared Spectroscopy (NIRS), Graph Neural Networks (GNNs).	metabolic data into a interconnected biological network.	networks governing novel traits
High-Throughput Phenotyping	Micro-Phenotyping, 3D Canopy Architecture Reconstruction	LiDAR processing algorithms, Point cloud deep learning Transfer learning, Instance segmentation (YOLOv8)	precise 3D digital model to evaluate spatial leaf layouts and light intercept patterns.	Identification of elite lines with novel traits like drought tolerance and quality etc.
Genomic Selection	Decoding of genome, generation of synthetic haplotype	Convolutional Neural Networks (CNNs), Deep learning, Generative adversarial networks (GANs)	Model for non-additive gene interactions, generates synthetic, highly viable plant genetic sequences	Improvement of trait prediction accuracy for highly complex polyploid crops
Speed Breeding & Tissue Culture	Automated Embryo Screening	Image Classification, Edge AI	Monitoring of *in vitro* tissue cultures and somatic embryos inside growth chambers.	rapid regeneration, accelerating the speed breeding clock.
Genome Editing	Prime & Base Editing Optimization	Natural Language Processing (NLP) / Transformer models	Analysis of DNA sequences and predict the best layout for complex prime editing guide RNAs (pegRNAs).	Enables highly precise, single-nucleotide corrections to instantly repair defect genes without breaking the DNA strand.
Enviromics	Climate-Stress Spatial Mapping	Random Forests, Gradient Boosting (XGBoost), GIS Integration	satellite weather patterns, soil topography, and moisture dynamics.	Generation of map showing suitability of which variety/ high yield in specific zone
Biotic Stress Screening	Early Asymptomatic Disease Detection	Thermal Imaging Analysis, Support Vector Machines (SVM)	Detects microscopic temperature	Detects infections days before visible physical spots

Advanced genomic prediction and selection models are uses for trait association mapping, genomic selection, candidate gene identification and dissecting the complex biological networks are helpful for ideal and potential parent's identification and utilization in best heterotic crosses. AI based genome editing systems are utilized for designing custom CRISPR proteins, off target minimization and optimization of guide RNA designing with great accuracy for enhancing trait modification. Deep learning models analyzes accessibility chromatin and utilizing multi-omics data and forecast on-target efficiency, which will be utilized for design superior gRNAs.

Limitations

The major limitation for employment of AIML technologies includes the phenotypic bottleneck and low trained datasets and poor trained models, high environmental noise due to GxE interaction complexity leading to poor performance in unusual weather situations, the block box problems, high set up costs and biological barriers in polyploidy crops because of complex genomes.

Future Prospects

The future status of Artificial intelligence and machine learning in plant breeding is transitioning from predictive modeling to autonomous, generative crop design for sustainable global agriculture. Artificial intelligence and machine learning tools will play critical role in revolutionizing modern plant breeding for a highly precise, data-driven biological engineering science for understanding the complex traits and rapidly identify elite genes and predict crop performance across volatile environments for sustainable plant breeding systems.

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Beyond Parasite Killing: Pharmacological Selectivity, Sublethal Effects, and Environmental Safety of Antiparasitic Drugs in Aquaculture

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Abstract
Antiparasitic drugs in aquaculture are usually evaluated based on their ability to eliminate parasites, but efficacy does not establish safety. This article compares the selectivity of major drug classes, summarises sublethal effects in fish, and shows that crustacean non-target species are often harmed far below treatment concentrations. An integrated parasite–host–environment assessment is proposed.

Keywords: antiparasitic chemotherapeutants, therapeutic index, sublethal toxicity, non-target crustaceans, environmental risk assessment, *Argulus*.

Introduction
Parasites such as *Ichthyophthirius multifiliis*, monogeneans, *Argulus* and sea lice reduce growth, damage gills and skin, and invite secondary infection in crowded culture systems. Chemical treatment is the quickest means of control, typically evaluated solely based on the removal of parasites. However, a drug can clear a parasite and still injure the fish, and once bath water is discharged or medicated feed settles, the same molecule meets organisms that were never its target. This article investigates the effective concentration lies from the concentrations that harm the host and its neighbours.

Where Pharmacological Selectivity Comes From
Selectivity rests first on the drug target (Table 1). Avermectins act on glutamate-gated chloride channels, which vertebrates lack (Wolstenholme, 2012), and praziquantel activates a flatworm ion channel ($TRPM_{PZQ}$) that admits calcium (Norbury et al., 2022). Fish often lack the benzoylurea target; however, chitin synthase genes occur in many fishes and chitin is present in the zebrafish gut and in fish scales (Tang et al., 2015). They tolerate benzoylureas mainly because they do not moult a cuticle. Organophosphates and pyrethroids act on targets shared by the parasite, the fish and wild crustaceans, therefore, their selectivity is only a matter of degree. Trichlorfon kills adult zebrafish at a 96 h LC_{50} of 28.8 mg/L but *Daphnia magna* at a 48 h LC_{50} of 0.29 µg/L, a difference of approximately 100,000-fold (Coelho et al., 2011).

Table 1: Pharmacological Basis of Selectivity in Major Antiparasitic Drug Classes Used in Aquaculture:

Drug class (examples)	Target in the parasite	Basis of selectivity over fish	Principal non-target concern
Organophosphates (azamethiphos, trichlorfon)	Acetylcholinesterase inhibition	Weak, target shared with fish and crustaceans	Cladocerans affected below 1 µg/L (Coelho et al., 2011)
Pyrethroids (deltamethrin, cypermethrin)	Delayed closure of voltage-gated Na^+ channels	Weak, fish also highly sensitive	Shrimp killed at 2 ng/L (Arnberg et al., 2023)
Avermectins (emamectin, ivermectin)	Activation of glutamate-gated Cl^- channels	Target absent in vertebrates (Wolstenholme, 2012)	Benthic organisms near farms (Horsberg, 2012)
Benzoylureas (lufenuron, teflubenzuron)	Inhibition of chitin synthesis at moulting	Fish do not moult a cuticle (Tang et al., 2015)	Moult failure in crustaceans (Macken et al., 2015)
Praziquantel	Activation of flatworm $TRPM_{PZQ}$ channel, Ca^{2+} influx	Flatworm-specific target	Flatworms and snails, few data (Norbury et al., 2022)
Formalin, H_2O_2, $CuSO_4$	Protein cross-linking, oxidation, membrane damage	None, gill is a co-target	Copper builds up in sediment (Tavares-Dias, 2021)

Note. Compiled for this article from the studies cited in each row.

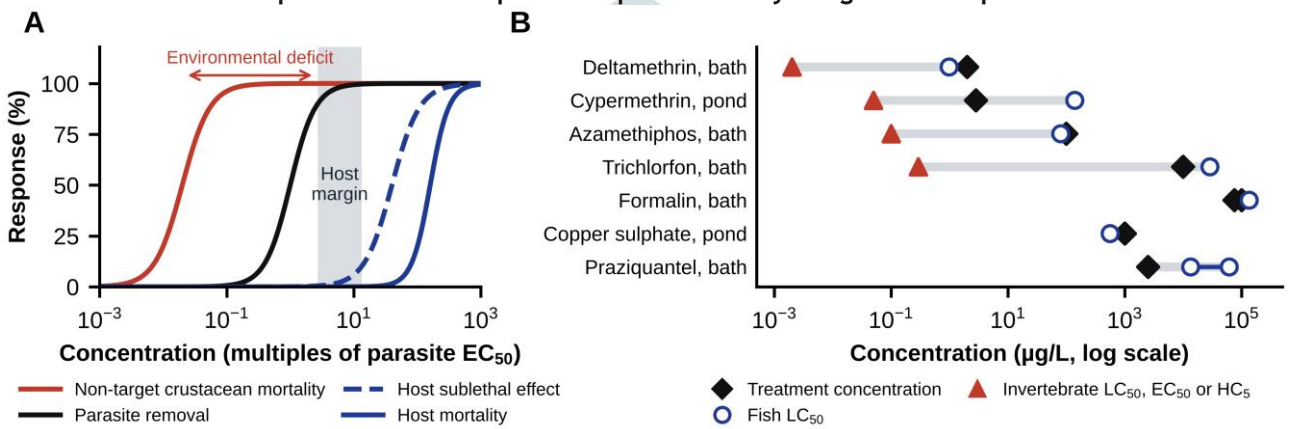
The Therapeutic Window and Its Limits
The therapeutic index (TI), usually host LC_{50} divided by parasite EC_{50}, is the usual safety measure (Figure 1B). Praziquantel baths can carry a margin above 30-fold (Norbury et al., 2022). Formalin gave a TI of only 1.15 to 2.05 in koi carp (Tancredo et al., 2019), and the 96 h LC_{50} of copper sulphate for *Labeo rohita* fingerlings (0.56 mg/L) is lower than the dose of approximately 1 mg/L advised at 100 mg/L alkalinity (Tavares-Dias, 2021). The index also hides the trade-

off between cure and harm. In pirarucu, trichlorfon at 10 mg/L for 96 h removed 96.9% of gill monogeneans but caused anaemia and leukopenia, whereas regimens that spared the fish removed only about half (de Oliveira-Lima et al., 2025). A more protective margin would compare a sublethal host EC_{10} with the parasite EC_{90} (Figure 1A).

Sublethal Effects: Harm Without Mortality

Survival is not proof of safety. *L. rohita* exposed for 45 days to 2.8 µg/L cypermethrin, one-fiftieth of its LC_{50} and close to the dose used against *Argulus*, showed lower brain acetylcholinesterase, haemoglobin and erythrocyte counts (Das & Mukherjee, 2003). Lufenuron fed to Nile tilapia at the recommended 5 mg/kg biomass/day raised plasma aminotransferases, increased malondialdehyde and induced erythrocyte micronuclei, although the changes reversed after withdrawal (Ghorai et al., 2026). Pink salmon fry lost olfactory response to food at 100 ng/L deltamethrin, far below bath strength (Sahota et al., 2022). A brief antioxidant response may be adaptive, whereas persistent lipid peroxidation or tissue lesions signal injury, and infected untreated controls are needed to separate drug and parasite effects.

Figure 1: Concentration-Response Relationships and Reported Safety Margins of Antiparasitic Treatments:



Note. (A) Illustrative curves, not fitted to data. (B) Values from Arnberg et al. (2023) and Sahota et al. (2022) for deltamethrin, Bera et al. (2022), Das and Mukherjee (2003) and Soares et al. (2017) for cypermethrin, Kaur et al. (2015), Sahota et al. (2022) and Hamoutene et al. (2023) for azamethiphos, de Oliveira-Lima et al. (2025) and Coelho et al. (2011) for trichlorfon, Tancredo et al. (2019) for formalin, Tavares-Dias (2021) for copper sulphate and Norbury et al. (2022) for praziquantel. Exposure times differ (1 to 96 h), so margins are indicative.

Environmental Safety Beyond the Treated Fish

Bath water is released after treatment, and in-feed drugs settle with uneaten feed and faeces. Because sea lice are copepods, drugs chosen to kill them also act on other crustaceans. Northern shrimp died after 1 h at 2 ng/L deltamethrin, a 1000-fold dilution of the treatment dose, and lethal concentrations were predicted up to 4 to 5 km from release (Arnberg et al., 2023). Sediment is the likely reservoir for benzoylureas, and ng/L concentrations stopped copepod nauplii from moulting although adults tolerated mg/L levels (Macken et al., 2015). The cypermethrin dose of 2.84 µg/L used against *Argulus* in Odisha (Bera et al., 2022) exceeds the 96 h LC_{50} of a freshwater prawn more than 50-fold (Soares et al., 2017).

Towards a Parasite-Host-Environment Assessment

A wide host margin does not ensure environmental safety (Table 2), and resistance links the three domains. The Phe362Tyr mutation in the acetylcholinesterase of *Lepeophtheirus salmonis* lowers sensitivity to azamethiphos (Kaur et al., 2015) and invites higher or repeated doses. Assessments should therefore use sublethal endpoints in the cultured species, compare predicted environmental concentrations with thresholds such as the azamethiphos HC_5 of 0.10 µg/L (Hamoutene et al., 2023), and report evidence gaps openly.

Table 2: Parasite-Host-Environment Evidence Matrix for Selected Antiparasitic Drugs:

Drug (route)	Parasite efficacy	Host safety margin	Environmental concern	Main evidence gap
Lufenuron, teflubenzuron (feed)	Strong, larval and pre-adult stages (Macken et al., 2015)	Adequate, reversible liver changes (Ghorai et al., 2026)	High, sediment reservoir, moult failure (Macken et al., 2015)	No peer-reviewed data in Indian major carps
Azamethiphos (bath)	Variable, lowered by Phe362Tyr (Kaur et al., 2015)	Narrow, fry LC_{50} below bath level (Sahota et al., 2022)	High, HC_5 of 0.10 µg/L (Hamoutene et al., 2023)	Effects of repeated baths

Cypermethrin (pond, *Argulus*)	Moderate, 87.2% kill (Bera et al., 2022)	Limited, sublethal effects at 2.8 µg/L (Das & Mukherjee, 2003)	High, prawn LC_{50} 0.05 µg/L (Soares et al., 2017)	Pond effluent levels
Praziquantel (bath, feed)	Strong, feed use limited by taste (Norbury et al., 2022)	Wide, bath margin above 30-fold (Norbury et al., 2022)	Insufficient evidence	Fate in pond systems

Note. Ratings are a qualitative tool proposed in this article, not a regulatory classification.

Conclusion

Parasite removal is necessary but not sufficient. Parasite-specific targets protect the fish but not the wider invertebrate community. Sublethal harm appears at or below therapeutic exposure, and crustaceans may be harmed at 50 to more than 1000 times below treatment strength. Drug choice should consider parasite identity, host margin and environmental exposure.

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Soil Testing: It's Importance and Benefits

Article ID: 74635

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In modern agriculture, soil testing is the most important practise to manage fertiliser application and crop production. Without soil testing, it is very difficult to ensure the right application of fertilisers for the crop and get the optimum yield.

What is Soil Testing?

The process by which elements such as phosphorus, potassium, calcium, magnesium, sodium, sulphur, manganese, copper and zinc are chemically removed from the soil and measured for their available content within the sample of soil is called Soil Testing. This is an important diagnostic tool for determining the nutrient for plants.



"Healthy soil is the foundation of a healthy crop and healthy farm."



कृषी महाविद्याय • जागतिक मृदा दिनानिमित्त शाश्वत शेतीवर मार्गदर्शन

नाशिक | मविप्रच्या कृषि महाविद्यालयात मृद विज्ञान विभाग यांच्या माध्यमातून जागतिक मृदा दिन कार्यक्रम साजरा करण्यात आला. मातीचे महत्त्व, तिचे संवर्धन आणि शाश्वत शेतीबद्दल जनजागृती तसेच निरोगी शहरांसाठी निरोगी माती हा या दिनाचा मुख्य उद्देश होता. अध्यक्षीय भाषणात महाविद्यालय प्राचार्य डॉ.बापूसाहेब भाकरे यांनी मातीची सुपिकता व जमीन आरोग्य व्यवस्थापन यावर मार्गदर्शन केले.

What are the Objectives of Soil Testing?

The Objectives of Soil Testing are:

1. To evaluate the fertility and nutrient status of soil for providing an index of nutrient availability or supply in a given soil.

2. Determination of acidity, salinity and alkalinity problems.

3. To provide a recommendation on the amount of manure and fertilizer based on soil test value and according to crop.

4. To avoid excess use of fertilizer and to ensure environmental safety.

5. When crops are harvested, a considerable amount of nutrients are removed from the soil and causes loss of fertility in soil over a long period of time. So, the soil should be tested.

6. Evaluation of the suitability of the soil for the crop.

7. Restoration of soil fertility is a key factor for crop productivity, profitability and sustainability.

8. Fertilization programme must consider crop needs, soil supply, fertilizer use efficiency, the contribution from manures etc.

9. Time to time evaluation of the inherent soil fertility status is essential for arriving at the crop and site-specific balanced fertilization program to sustain productivity.

10. To predict the probability of obtaining a profitable response to and fertilizers.

What are the Benefits of Soil Testing?

1. Soil Analysis leads to more informed fertiliser decisions, reducing risks in the soil such as soil erosion, soil infertility and degraded lands and increasing farm profitability in the long-term.

2. Reveals the amount of plant-available macro-nutrients in the soil and where soil nutrients are in the soil profile

3. Identifies nutrients that could be yield-limiting

4. Monitors soil health properties such as pH, EC and OC, which affect nutrient availability to crops and thereby yields and profitability

5. Provides a basis for variable rate application (VRT) depending upon soil and crop.

6. Supports decisions about fertiliser rate, timing, placement and product.

7. Improved knowledge of the soil types within the farm to maximise management options.

8. Maximises in-season responsiveness.

9. Consequently, it also provides a farm management tool with a potential benefit to the farmer of increased yields, reduced operating costs and superior environmental risk management and it also includes improved crop maturity and quality, higher tolerance to disease and pest damage, and increased growth.

Why should Farmers Get their Soil Tested?

1. It informs the farmer of the current health of the farm's soil and how to improve it Soil fertility is determined by the soil biological, chemical, and physical properties. Properties such as structure, soil texture, and colour are visible to the eye. However, it is hard to see the chemical composition of the soil. Therefore, there is a need for soil diagnosis and that's why soil sampling is critical. Soil tests are used to determine the soil's nutrient level and pH content. Armed with this information, farmers can define the quantity of fertiliser and the exact type that is needed for application to improve the soil on your farm. This is essential because fertile soils are necessary to grow healthy crops.

2. Soil test leads to minimisation of fertiliser expenditure knowing the exact deficiency of soil is experiencing will result in zero wastage of such farm inputs. The quantity and type of fertilisers of crops and soil need prevent farmers from wasting money on unnecessary extra fertiliser application. Moreover, nutrients such as potassium and phosphorus that are part of inorganic fertilisers are very limited resources. Their supply is limited or rather finite; implying that there is a need to be cautious in the usage to prevent a future shortage of such limited resources.

3. Soil testing results in limited over-fertilisation Applying fertiliser to the soil without knowing the exact and actual nutrient that it needs will lead to over-fertilisation Overuse of fertiliser may be harmful not only to the environment but also it might cause fertiliser burn to the crops. Testing soil prior and receiving informed fertiliser recommendation prevents farmers from applying an excessive amount of fertilisers and minimising the related environmental damages. Over-fertilisation might result in water pollution, nutrient leaching, and irreversible harm to the aquatic life. Just a simple soil test can prevent all these negative environmental effects.

4. Farmers can easily avoid soil degradation It is estimated from research that each year more than 24 billion tonnes of fertile soil is lost because of erosion which is caused by unbalanced soil management. Furthermore, land degradation directly affects the livelihoods and health of an estimated 1.5 billion people. Soil restoration is a costly, difficult, and

time-consuming process. Therefore, better soil management through soil testing is an easier route to take, and application of the right amounts of fertilisers is efficient and financially justified.

5. Farmers with fertile soils can contribute to feeding the world's growing population the importance of soil testing has been in existence since the early years. Different types of soils and variation in soil properties are important factors to note in farming. Soil texture, soil moisture, and soil chemistry are determinants of what crops can be grown and how much yield the farm can produce. The current generation puts more pressure on the soil than ever before. There is a need for fertile soils to produce yields that will feed the world's ever-growing population. Improved soil health implies more crops, potentially closing the world's food security issues. This will eventually bring a better life to millions of people. Soil testing is the first step in soil management. The activity gives farmers valuable information that helps them improve the soil's health; healthy soils eventually imply healthy crops.

What are the Soil Testing benefits for Farmers?

Soil testing provides plenty of benefits for farmers. Healthy soil improves crop growth. Farmers can begin testing their soil before harvest season to get a jump on how they can improve their soil. These benefits can help farmers by:

1. Improving yields and profitability because you are providing necessary nutrients to your crops.

2. Increasing consistency of nutrient availability across a field.

3. More uniform crop growth. This also helps individual plants stronger against weeds and simplifies other processes like cultivation and spraying.

4. More uniform plant maturity. This can help simplify crop harvesting and drying along with improving market quality.

5. Allowing fine-tuning of which nutrients are most needed. Helping you allocate your fertilizer dollars to those nutrients that will give you the greatest profit increase.

What are the Environmental Benefits of Soil Testing?

Soil sampling can also help the environment. Regular usage can wear out the land on which you grow your crops. The biggest impact soil testing has on environmental benefits mean:

1. More efficient use of plant nutrients means fewer losses from leaching or runoff into waterways.

2. Poorly nourished crops leave less plant residue to hold soil in place. Plant residue helps build soil and saves it from wind and water erosion.

3. Providing the right levels of nutrients helps increase yields and may help reduce the need for intensively farming marginal land.

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Microgreens: Nutritional Powerhouses and Innovative Cultivation Techniques

Article ID: 74636

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Abstract

Microgreens are nutrient-dense specialty crops generally harvested 7–14 days after germination at the cotyledon stage. Their short production cycle and rich phytochemical composition, including vitamins, minerals, polyphenols, flavonoids, carotenoids and glucosinolates, have attracted growing interest in commercial agriculture, research and space farming. They may also offer antiproliferative and antidiabetic benefits through the regulation of reactive oxygen species (ROS) and metabolic pathways. However, bioactive compound accumulation depends on species, growth stage and environmental conditions. Cultivation methods include soilless substrates, hydroponics, aeroponics and aquaponics, each presenting challenges related to oxygenation, lighting and resource management. Optimizing red and blue LED light ratios may improve biomass production and antioxidant accumulation. Therefore, the present study investigates the effects of different blue-to-red LED ratios on fresh yield, ascorbic acid, total phenolic content and antioxidant activity in hydroponically grown red cabbage (*Brassica oleracea* var. *capitata* f. *rubra*) microgreens.

Introduction

Microgreens are edible young seedlings harvested 7–14 days after germination, typically when their cotyledons are fully expanded and the first true leaves begin to emerge. Their short production cycle, attractive colors, distinctive flavors and high nutritional value have increased their commercial and scientific importance in controlled-environment agriculture (CEA). They are rich in vitamins, essential minerals and bioactive compounds, including polyphenols, flavonoids, carotenoids and glucosinolates, which may provide antioxidant, antiproliferative and antidiabetic benefits. However, their nutritional composition varies with species and growing conditions, making precise cultivation management essential. In CEA systems, light-emitting diodes (LEDs) offer opportunities to regulate plant growth and phytochemical synthesis through specific wavelengths. Blue light (430–460 nm) can promote antioxidant and phenolic compound accumulation, whereas red light (630–660 nm) supports photosynthesis and biomass production. However, an appropriate balance is required because excessive blue light may restrict growth, while excessive red light may affect seedling morphology and nutritional quality. Therefore, the present study evaluates the effects of different blue-to-red LED light ratios on fresh biomass yield, ascorbic acid content, total phenolics and antioxidant activity in hydroponically grown red cabbage (*Brassica oleracea* var. *capitata* f. *rubra*) microgreens.

Species	Nutrients / Indices	Findings
Parsley	Minerals, carotenoids, TPC	Microgreens have more P and K, less Ca, Mg, S, and Na than baby greens; microgreens have more lutein and carotenoid but fewer phenolics than baby greens
Beet	Ascorbic acid, TPC, betalains	The pigment betalains unique to Caryophyllales are the primary contributors to antioxidant ability
Choy sum	Amino acids, sugars, minerals, vitamins, glucosinolates	Amino acids, carotenoids, vitamin K, folate, and most minerals, except Na, are more concentrated in microgreens than in adult plants
Hemp	Minerals, cannabinoids, TPC, and delta-8 THC	Good source of P and Mg; low levels of THC; cannabinoids accumulate over time; slightly more phenolics and antioxidants than other microgreens
Wild leafy species (Sanguisorba minor Scop., Sinapis arvensis L. and Taraxacum officinale Weber ex F.H.Wigg.)	Macronutrients, vitamins, anthocyanins, carotenoids, nitrate	Competitive yield; high levels of anthocyanins and carotenoids; nitrate level is concerning

Kose and Kirik wheat landraces	Macronutrients, phenolics, flavonoids, carotenoids, total antioxidant ability	Wheat landraces have significantly higher total antioxidant ability than wheat cultivars, barley, and oat, but the nitrogen balance index is low
Borage and purslane	Yield, minerals, TPC, carotenoids	Purslane has high TPC and ascorbic acid and potential good beta-carotene bioavailability; borage microgreens have a high fresh yield and a more balanced phenolic profile
Lettuce (microgreens, baby leaves, and mature plants), various landraces and cultivars	TPC, ascorbic acid and minerals	Microgreens have 42% more ascorbic acid, 79% more phenolics, and more Ca, K, and Fe than adult lettuce; red-leaf varieties show the greatest variation between growth stages
Chinese basil microgreens and mature plants	VOCs and TPC	Fragrance does not correlate to phenolics; microgreen basil has higher content of VOCs but lower TPC than mature plants
Beetroot, radish, kale, amaranth, green peas, in comparison to sprouts	Phenols, antioxidants, pigments, organic acids, sugars, pectin, antioxidant activity	Microgreens are higher in carotenoids, chlorophylls, and organic acid; sprouts are higher in amino acids, pectin, and sugars; overall, sprouts show stronger antioxidant capacities than microgreens
Amaranthus, bottle gourd, cucumber, jute, palak, poi, pumpkin, radish, water spinach, in comparison to mature plants	TPC, total flavonoids, ascorbic acid, antioxidant activity	Microgreens have higher Zn and K content; mature plants have higher TPC and antioxidant activity; no specific trend in ascorbic acid, Fe, Cu, or Mn
Fourteen species from Brassicaceae, Fabaceae, Pedaliaceae, Polygonaceae, Convolvulaceae, and Malvaceae	Macronutrients, vitamins, TPC, anthocyanins	Lentil has most proteins, ascorbic acid, and carotenoids; buckwheat shows highest TPC; anthocyanins found only in purple radish and red cabbage
Carrot, fennel, fenugreek, French basil, mustard, onion, radish, roselle, spinach, sunflower	Phytochemicals, OPCI, APCI	Roselle and fennel microgreens have highest APCI; other species have greater or similar APCI and OPCI compared to mature spinach leaves

Emerging Cultivation Systems for Microgreen

Soilless substrate-based farming utilizes porous media such as peat moss, coconut coir, hemp mats or rockwool, with water delivered through top-down dripping or bottom-up wicking. A distinguishing feature of this method is that nutrient solutions are optional, enabling substrates to function as both physical support and an active nutrient reservoir, which makes them ideal for low-cost, non-commercial and home-scale cultivation kits. In contrast, hydroponic systems such as deep-water culture (DWC) and the nutrient film technique (NFT) feature higher water-use efficiency and excellent root oxygenation. In DWC systems, seeds float on an inert medium above an actively aerated nutrient reservoir, whereas NFT continuously recirculates a shallow nutrient stream over an inclined tray. While these hydroponic methods target yield enhancements in commercial and household vertical farming, DWC requires careful aeration calibration to avoid root hypoxia or physical damage and NFT remains vulnerable to pump failure and rapid root dehydration.

Aeroponic systems deliver nutrients directly to suspended roots via atomized aerosol droplets ranging from 10 to 100 μm. Providing the highest water efficiency and optimal root-zone oxygenation among all methods, aeroponics demands complex instrumentation and higher capital costs while remaining vulnerable to power interruptions or nutrient misformulations, making them well-suited for high-tech, large-scale commercial facilities like AeroFarms and vertical growth towers. Finally, aquaponic systems combine aquaculture with hydroponics by using beneficial nitrifying bacteria to convert fish waste into plant-available nutrients. These systems offer high circular water and nutrient efficiency along with beneficial organic microbiota, though they require continuous balancing of the differing biological nutrient requirements among fish, nitrifying microbes, and microgreen crops as emerging sustainable, circular closed-loop production options.





Figure: 1A home-friendly microgreen growth kit. (*a*) A proprietary germination mat with seeded pockets. (*b*) Placing the germination mat after one-time watering. (*c*) Seedlings emerging from the pockets. (*d*) Harvesting the microgreens. Photos courtesy of Hamama, Inc

System	Delivery Mechanism	Water Efficiency	System Complexity	Primary Operational Challenge
Soilless Substrate	Drip, spray, or capillary wicking	Moderate	Low	Substrate disposal and physical uniformity
WC Hydroponics	Floating raft on aerated solution	High	Moderate	Root hypoxia vs. root agitation damage
NFT Hydroponics	Shallow recirculating film	High	Moderate	Rapid desiccation if pumps fail
Aeroponics	Atomized aerosol mist (10-100μm)	Highest	High	Power failure risk and technical sensitivity
Aquaponics	Nitrified aquaculture effluent	High	High	Multi-organism nutrient balancing

Micro Green for Space Farming

Microgreens have emerged as an attractive crop for bioregenerative life support systems in extended human spaceflight, serving as a versatile supplement to the leafy greens tested by NASA on the International Space Station. Their rapid 7 to 14 day cultivation cycle and minimal maintenance requirements enable crew members to produce fresh, ready-to-eat food with minimal labor while conserving tight spacecraft volume, electrical power and water resources. The dense nutritional profiles of microgreens rich in essential vitamins, minerals, and bioactive phytonutrients provide critical antioxidant and potential antiproliferative activities that can counteract the oxidative stress and cellular damage induced by space radiation. Furthermore, their vibrant coloration and intense flavors enhance food presentation and stimulate crew appetite. However, their operational integration involves distinct trade-offs, particularly the large net consumption of seed stock resulting from their inability to produce seed progeny in orbit, as well as lower overall biomass accumulation and oxygen generation compared to mature crops.



Figure 2: Microgreen tests performed by NASA. (*Left*) Radish microgreens on a parabolic flight simulating temporary microgravity. (*Right*) Radish microgreens on the random positioning machine simulating chronic microgravity. Photos provided by R. M. Wheeler and C.M. Johnson from the NASA Kennedy Space Centre.

Deploying microgreens in extraterrestrial settings presents physical challenges unique to reduced gravity and microgravity environments. The absence of buoyancy-driven natural air convection restricts heat dissipation, moisture transpiration and boundary-layer gas exchange, requiring forced-air circulation via electric fans to prevent plant metabolic disorders.

Root-zone fluid dynamics are equally challenging, as the lack of gravitational drainage causes substrate liquid accumulation, poor aeration and root hypoxia. To overcome this, space cultivation systems utilize particulate media such as arcillite calcined clay chips with embedded porous tubes, passive capillary-driven watering units like the NASA Veggie chamber and recirculating aeroponics. In addition, because microgravity disrupts conventional root gravitropism, plant shoots rely on phototropic cues, meaning directed artificial lighting can successfully guide shoot orientation, cotyledon expansion and true-leaf development in weightless habitats.

Nutritional Profile and Bioactive Potential of Microgreens

Microgreens are nutrient-rich sources of essential minerals, vitamins and bioactive compounds, particularly phenolics and glucosinolates. Their nutritional composition varies with species and developmental stage; for example, lettuce microgreens may contain higher ascorbic acid and total phenolic content than mature lettuce, while other species accumulate more phenolics at maturity. Mineral concentrations also differ between growth stages. Beyond their nutritional value, certain microgreens exhibit potential antiproliferative and antidiabetic effects. Brassicaceae microgreens may inhibit cancer cell proliferation by modulating reactive oxygen species (ROS) and inducing apoptosis. Similarly, barley and broccoli microgreens have shown potential in regulating blood glucose, improving insulin sensitivity, reducing inflammation and supporting healthy gut microbiota. These findings highlight the importance of species-specific evaluation of microgreens for nutritional and functional benefits.

Conclusion

Microgreens are young plants with great potential. These versatile, nutrient-dense crops may play a beneficial role in the health of consumers, food and nutrient security and bioregenerative support in outer space. The utilization of unconventional species, emerging growth platforms, innovative physical and chemical treatments and the IoT all have had a profound influence on the development of the microgreen industry. Holistic nutritional evaluation, produce safety and space farming remain great opportunities for future research. Finally, it is envisioned that AI and nanotechnology may greatly enhance the productivity, quality, value and pleasure of microgreen production in the future.

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Microgreen Cultivation: An Innovative Approach of Nutritious Vegetable Production

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Microgreens, young and tender edible plants harvested during the early stages of growth, offer an array of flavours, colours and nutrients that enhance culinary experiences. These miniature plants, grown in soil or similar mediums, develop their first true leaves before harvest, distinguishing them from sprouts and baby greens. Their small size, intense flavours, vibrant colours and nutrient density make microgreens a popular superfood choice. Packed with vitamins, minerals, antioxidants and phytonutrients, they contribute to overall health and wellbeing. In the culinary realm, microgreens are celebrated for their creativity, enhancing plate presentation, infusing flavours and serving as healthy garnishes. This chapter explores popular vegetable crops for microgreen cultivation, the importance of high-quality seeds, factors influencing crop selection, suitable growing mediums and container options. Drainage and aeration are emphasized as key elements for successful microgreen cultivation. The chapter concludes by highlighting the potential of microgreens for space missions and the need for ongoing research to enhance their post-harvest quality and production technology.

Keywords: Microgreens, Culinary trends, Nutrient density, Superfood Vegetable crops.

Introduction

Microgreens are young, tender and edible plants that are harvested at an early stage of growth, usually within 7 to 21 days after germination, depending on the crop. They are distinct from sprouts and baby greens, as they are grown in soil or a soil-like medium and develop their first true leaves before harvest. These young seedlings are packed with essential nutrients and offer a concentrated burst of flavors, colors and textures that can elevate the culinary experience of any dish.



Characteristics of Microgreens

1. Small Size: Microgreens are typically 1 to 3 inches tall at harvest, making them easy to handle and ideal for garnishing.

2. Intense Flavors: Despite their small size, microgreens boast intense and diverse flavors, ranging from spicy and peppery (e.g., radish and mustard) to mild and nutty (e.g., sunflower and beet).

3. Vibrant Colors: Microgreens exhibit a vibrant palette of colors, with hues ranging from deep red (beets) to bright green (pea shoots) and purple (purple basil).

4. Nutrient Density: These young plants are packed with essential vitamins, minerals and antioxidants. Studies have shown that microgreens often contain higher nutrient levels than their mature counterparts, making them a nutritional powerhouse.

Nutritional Benefits and Health Attributes

Microgreens are gaining popularity as a superfood due to their impressive nutrient profile. While the nutrient content can vary depending on the crop, in general, microgreens are rich in:

1. Vitamins: Microgreens are excellent sources of vitamins such as vitamin C, vitamin K, vitamin E and various B-vitamins, which are essential for overall health and wellbeing.

2. Minerals: They contain essential minerals like iron, calcium, magnesium and zinc, which play vital roles in various physiological functions.

3. Antioxidants: Microgreens are known for their high antioxidant content, which helps combat oxidative stress and reduce the risk of chronic diseases.

4. Phytonutrients: These young plants contain various phytonutrients like carotenoids, flavonoids and polyphenols, which have been associated with health benefits and disease prevention.

5. Dietary Fiber: Microgreens provide dietary fiber, promoting healthy digestion and aiding in weight management

Culinary and Culinary Trends

Microgreens have not only captured the attention of health-conscious individuals but have also become increasingly popular in the culinary world. Chefs and home cooks alike appreciate microgreens for their exceptional taste, delicate texture and vibrant colors. Some of the culinary trends associated with microgreens include:

1. Culinary creativity: Microgreens offer a canvas for culinary experimentation, allowing chefs to add unique flavors and aesthetics to their dishes.

2. Plate presentation: With their visually appealing colors and shapes, microgreens are used to enhance the presentation of various dishes, from salads to main courses.

3. Flavor infusion: Adding microgreens to dishes provides a burst of fresh, concentrated flavors that complement and elevate the overall taste.

4. Healthy garnishes: Microgreens serve as healthier alternatives to traditional garnishes like fried onions or bacon, providing nutrition without compromising taste.

5. Farm-to-table movement: Microgreens are a staple in the farm-to-table movement, as they can be easily cultivated in local settings and offer a sustainable source of fresh produce.

Selection of Vegetable Crops for Microgreen Cultivation

Microgreens can be grown from a wide variety of vegetable crops, each offering its unique flavors, colors and nutrient profiles. Here is some popular vegetable crops commonly cultivated as microgreens:

1. Broccoli: Broccoli microgreens have a mild, slightly peppery flavor with a hint of sweetness. It is rich in vitamins A, C and K, as well as minerals like calcium and iron.

2. Radish: Radish microgreens are known for their spicy and peppery taste. It adds a pop of red or purple color to dishes and contains vitamins E and K, along with various antioxidants.

3. Kale: Kale microgreens have a milder taste compared to mature kale leaves. It is an excellent source of vitamins C, K and A, as well as minerals like potassium and calcium.

4. Cabbage: Cabbage microgreens offer a sweet and crunchy flavor, adding a delicate texture to dishes. It contains vitamins C, K and E, as well as folate and fiber.

5. Beet: Beet microgreens have a slightly earthy taste and vibrant red color. It is rich in antioxidants, including betalains, as well as vitamins A and C.

6. Mustard: Mustard microgreens have a tangy and spicy flavor that adds a zesty kick to dishes. Rich in vitamins A, C and K and contain calcium, iron and magnesium.

7. Arugula: Arugula microgreens have a nutty, peppery flavor that complements a wide range of dishes. Good source of vitamins A, C and K, as well as calcium and iron.

8. Spinach: Spinach microgreens are tender and mild in taste, making them a versatile addition to salads and sandwiches. Rich in vitamins A, C and K, as well as iron and magnesium.

9. Sunflower: Sunflower microgreens have a mild, nutty flavor and a crunchy texture. Good source of vitamin E, essential fatty acids and minerals like selenium and zinc.

10. Pea shoots: Pea shoot microgreens have a fresh, sweet taste reminiscent of peas. Rich in vitamins C and A, as well as iron and fiber.

Factors Affecting Crop Selection

The choice of vegetable crops for microgreen cultivation can be influenced by several factors:

1. Growing conditions: Consider the growing conditions available to you. Some crops may perform better in specific environmental conditions, such as light intensity, temperature and humidity.

2. Market demand: Research the market demand for microgreens in your area or target market. Choose crops that are popular and in demand to ensure a profitable venture.

3. Cultivation cycle: Different vegetable crops have varying growth rates and time to harvest. Consider the cultivation cycle and the turnaround time for each crop to plan your production schedule efficiently.

4. Nutritional value: Take into account the nutritional value of the microgreens. Select crops that offer a diverse range of essential nutrients and health benefits.

5. Flavor and culinary appeal: Consider the flavor and culinary appeal of the microgreens. Some crops may have more versatile applications in different dishes and cuisines.

6. Availability of seeds: Ensure that the selected seeds are readily available and accessible from reliable suppliers.

By carefully considering these factors and choosing high-quality seeds, you can cultivate a diverse and appealing array of microgreens, offering a wide selection of flavors and nutritional benefits to your consumers.

Conclusion

Microgreens are a promising food product of the future. Besides catering to the daily needs of layman, these foods can even be taken up in space missions to be cultivated as fresh food sources for astronauts. Rigorous research in the fields of post-harvest management and care as well as substrate and seed biofortification are required so that the visual quality, concentration of bioactive compounds, shelf life and post-harvest quality of microgreens can be improved for the year-round production and availability of these functional foods. Effect of various growth conditions (light quality, temperature, humidity and irrigation scheduling) along with the suitable stage for harvesting so as to harness maximum nutrition from the available and yet to be exploited microgreen varieties may be studied for further improvement in the production technology of microgreens.

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Microplastics in Soil: Effect on Structure, Microbes, and Crops

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Introduction

Soil is frequently regarded as the cornerstone of agriculture; however, it is increasingly becoming a repository for plastic waste. Microplastics, defined as plastic particles smaller than 5 millimetres, are now found in agricultural lands, forests, gardens, and even remote areas. Some researchers suggest that terrestrial soils may contain significantly more microplastics than oceans, although measurements vary considerably across different regions and methodologies. The significance of this issue lies in the fact that soil is not an inert medium; it is a dynamic, structured system where physical architecture, microbial communities, and plant roots are in constant interaction. Plastic particles can disrupt each of these components. This article examines how soil microplastics form and how they affect soil structure, microbial communities, and crop growth.

Sources and Pathways of Microplastics in Soil

Microplastics reach soil through several routes:

1. Agricultural plastic film and mulch: Polyethylene mulch films, greenhouse covers, and irrigation tubing fragment under sunlight and mechanical stress, leaving residues in the field.

2. Sewage sludge and biosolids: Treatment plants capture microplastics from laundry fibres and personal care products. When the resulting sludge is applied as fertiliser, those particles move onto farmland.

3. Compost and organic amendments: Compost made from municipal waste may contain plastic fragments that were not fully removed.

4. Irrigation with wastewater: Treated or untreated wastewater can carry fibres and fragments into fields.

5. Atmospheric deposition and tyre wear: Wind and rain deposit airborne particles, and road runoff carries tyre and paint particles to roadside soils.

6. Coated fertilisers and seeds: Polymer coatings used for slow-release fertilisers or seed treatments can leave behind residues.

Plastics decompose at a slow rate once they are introduced into the soil. Processes such as tillage, the activity of earthworms, and freeze-thaw cycles contribute to their movement and fragmentation, resulting in the accumulation of plastic particles over time.

Effects on Soil Structure

Healthy soil depends on aggregates, which are clusters of mineral particles, organic matter, and microbial glues that create pore space for air and water. Microplastics can interfere with this architecture in several ways.

Bulk Density and Porosity: The incorporation of plastics, which are significantly lighter than mineral particles, can reduce soil bulk density. Specifically, fibres have the potential to create or enlarge pores; however, they may also obstruct the narrow channels essential for water movement.

Aggregate Stability: Research presents varied findings. Some studies indicate that fibres and films may weaken soil aggregates by introducing fracture points, whereas others suggest that certain particles can be integrated into aggregates. The effects are contingent upon the polymer's type, shape, size, and concentration.

Water Retention and Evaporation: Plastic fibres can induce the formation of channels and cracks, thereby accelerating water loss and leading to faster soil drying. In coarse soils, this phenomenon may exacerbate drought stress for crops.

Soil Chemistry: Microplastics have the capacity to adsorb pesticides, heavy metals, and other pollutants, and they may release additives such as plasticisers and stabilisers. This can influence the mobility of contaminants within the soil and their bioavailability to organisms.

Effects on Soil Microbes

Soil Microorganisms: encompassing bacteria, fungi, and archaea, play a crucial role in nutrient cycling, organic matter decomposition, and disease suppression. The introduction of microplastics into their environment presents a novel surface and a distinct set of chemicals.

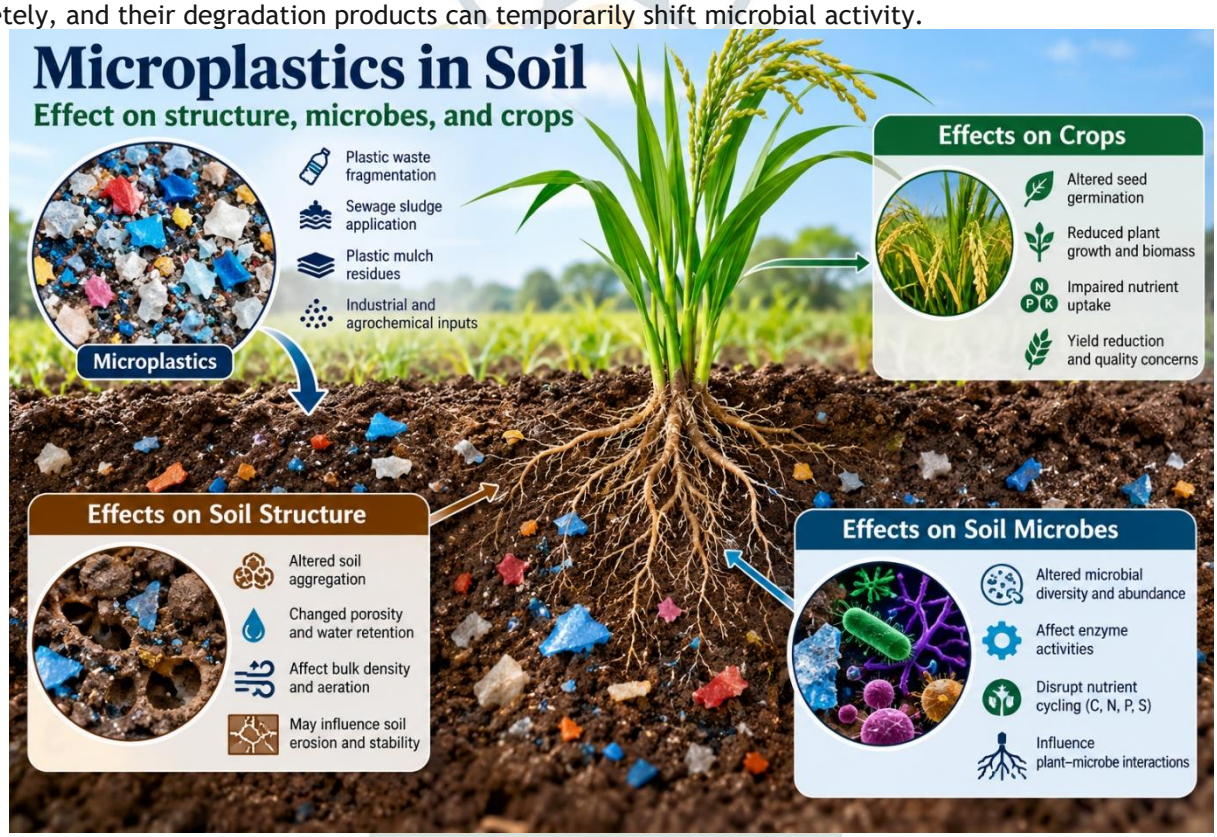
The plastisphere: Microorganisms colonize plastic surfaces, forming biofilms that are distinct from the surrounding soil community. These biofilms may include organisms capable of partially degrading plastic, as well as opportunistic or resistant strains.

Community composition and diversity: Numerous studies have documented shifts in the dominance of microbial groups in the presence of plastics, with diversity either increasing or decreasing depending on specific conditions. Of particular concern are changes in the balance between fungi and bacteria, given the role of fungi in aggregate formation.

Enzyme activity and nutrient cycling: Microplastics have been associated with alterations in enzymes involved in the cycling of carbon, nitrogen, and phosphorus. Such changes in nitrification and denitrification processes can influence nitrogen availability and greenhouse gas emissions.

Soil fauna: Earthworms, springtails, and nematodes ingest or move plastic particles. Reported effects include reduced growth, gut damage, and altered burrowing, which in turn changes soil mixing and aeration.

Biodegradable plastics: These are not automatically safer. Depending on conditions, they may break down slowly or incompletely, and their degradation products can temporarily shift microbial activity.



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Effects on Crops

Crop responses exhibit considerable variability, with outcomes ranging from positive to neutral or negative.

Germination and Early Growth: Elevated concentrations of specific particles can impede or diminish germination and seedling vigor, particularly when these particles contain toxic additives.

Root Development: The presence of fibers and fragments can modify the soil environment surrounding roots, influencing root length, branching, and soil contact. Alterations in water availability may exacerbate these effects.

Nutrient Uptake and Photosynthesis: Microplastics can disrupt microbial nutrient cycling and soil moisture, potentially reducing nutrient availability. Some laboratory studies have also documented decreased chlorophyll content and biomass.

Uptake of Particles: Controlled experiments have demonstrated that very small particles, particularly nanoplastics, can penetrate plant roots and ascend within certain species. The implications for food safety in real-world contexts remain under investigation.

Yield and quality: Field-scale results are mixed, and some effects depend on soil type, crop species, and climate. Contaminants carried by plastics may add risk beyond the particles themselves.

Mitigation and Management

The most effective solution is to prevent plastic from entering soil in the first place:

1. Use mulch films that are thicker, reusable, or properly collected after the season, and consider alternatives such as straw or other organic mulches.
2. Improve screening and quality standards for sewage sludge and compost.
3. Reduce plastic waste at source and strengthen waste collection in rural areas.
4. Upgrade wastewater treatment and limit the use of untreated effluent for irrigation.
5. Support research and monitoring, including standardised methods, so that policy rests on solid evidence.
6. Encourage practices that keep soil biologically active, such as adding organic matter and reducing disturbance, which supports resilience to stress.

Conclusion

Microplastics in soil are a growing concern because they affect every layer of the soil system. They can alter how soil aggregates and retains water, reshape the microbial communities that support plant growth, and influence how crops grow and take up nutrients and contaminants. Evidence shows that effects depend heavily on the type, size, shape, and amount of plastic, as well as on soil and crop conditions. While uncertainty remains, the direction is clear enough to justify action: reducing plastic inputs now is far easier than removing particles from soil later.

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Flower Gardening for Wellness: Mental and Emotional Benefits of Floral Therapy

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Abstract
Floral therapy, which involves flower gardening and interaction with flowering plants, is gaining attention as a complementary approach to promoting mental and emotional well-being. In the context of increasing urbanisation, demanding lifestyles, and growing mental health concerns, flower gardening provides an accessible opportunity to reconnect with nature and improve quality of life. Activities such as planting, watering, pruning, and nurturing flowers may help reduce stress, encourage relaxation, enhance mindfulness, and promote positive emotions. The colours, fragrances, and textures of flowers offer sensory stimulation, while gardening activities encourage physical movement, creativity, patience, and a sense of accomplishment. Furthermore, community gardening can strengthen social relationships, reduce feelings of isolation, and foster a sense of belonging. Floral gardening can be incorporated into daily routines through home gardens, balconies, container cultivation, community spaces, educational institutions, and suitable healthcare programmes. Despite challenges related to space, time, knowledge, and maintenance, sustainable gardening practices and digital technologies can improve accessibility. Further scientific research is required to establish its therapeutic effectiveness and develop evidence-based applications. Overall, floral therapy represents a promising complementary approach to supporting psychological well-being, emotional resilience, and a healthier connection with nature.

Keywords: Floral, gardening, Mental health, Emotional well-being, Horticultural therapy.

Introduction
In today's rapidly developing world, characterized by technological progress and increasing urbanization, mental health concerns such as stress, anxiety, and depression are becoming increasingly common. Although medical treatment and professional counselling remain essential for managing these conditions, complementary approaches that promote overall well-being are also receiving growing attention. Among these approaches, floral therapy, which involves gaining psychological and emotional benefits through flower gardening, offers a simple and accessible way to support mental health. The process of growing, nurturing, and caring for flowers provides individuals with an opportunity to connect with nature, reduce everyday tensions, experience happiness, and develop a renewed sense of purpose and emotional well-being.

Stress Reduction and Relaxation
Flower gardening offers a natural and refreshing way to escape the pressures and demands of everyday life. Activities such as preparing the soil, sowing seeds, planting flowers, and caring for developing plants can promote a feeling of peace and relaxation. Spending time in green environments has been associated with reduced levels of cortisol, a hormone linked to stress, while also supporting the release of endorphins that can enhance mood and emotional well-being. In addition, the attractive colours, soothing fragrances, and varied textures of flowers provide a rich sensory experience that helps calm the mind, ease tension, and promote overall psychological relaxation.

Strengthening Mindfulness and Attention
Gardening naturally encourages concentration, patience, and careful observation, making it closely associated with the principles of mindfulness. When people become involved in activities such as planting, watering, pruning, and removing weeds, their attention is directed toward the task at hand and the present moment. This focused interaction with plants can reduce the distraction caused by persistent or stressful thoughts and create a calm, meditative state of mind. Therefore, flower gardening can serve as a simple and practical means of incorporating mindfulness into everyday routines while supporting greater mental clarity, inner calm, and emotional stability.

Enhancing Mood and Emotional Health
Caring for flowers can have a positive influence on mood and contribute to improved emotional well-being. Observing plants develop from small seedlings into healthy, blooming flowers can create feelings of satisfaction, achievement, and

happiness. The appealing colours, fragrances, and natural beauty of flowers may further encourage positive emotions and help reduce feelings of sadness, tiredness, and emotional stress. Because of these potential benefits, flower gardening is frequently incorporated into horticultural therapy programmes designed to support individuals experiencing emotional difficulties, including depression and anxiety.

Fostering Social Relationships

Flower gardening is not merely an individual activity; it can also serve as an effective means of promoting social interaction and community engagement. Community gardens, gardening clubs, and shared horticultural spaces encourage people to work together, exchange ideas, and establish meaningful relationships. For individuals experiencing loneliness or social isolation, participating in group gardening activities offers valuable opportunities to interact with others, develop friendships, and strengthen their sense of social connection and belonging. Thus, flower gardening can contribute not only to personal well-being but also to the development of supportive and socially connected communities.

The Psychological Principles Underlying Floral Therapy

Biophilia: The Innate Human Connection with Nature: The biophilia hypothesis suggests that humans possess an inherent tendency to connect with nature and other living organisms. Interacting with flowers through gardening and plant care fulfils this natural inclination, potentially helping to alleviate stress, promote emotional balance, and improve overall psychological well-being.

The Role of Sensory Perception in Floral Therapy: The diverse colours, textures, and fragrances of flowers provide a stimulating sensory experience that may activate the brain's reward systems. This interaction with the natural beauty of flowers can promote feelings of pleasure, encourage relaxation, and contribute to improved mood and emotional well-being.

The Relationship Between Mental and Physical Well-Being: Gardening activities, including digging, planting, watering, and caring for flowers, provide moderate physical exercise that can help improve both physical and mental well-being. Such activities may promote the release of endorphins, which are associated with improved mood, while also helping to relieve muscle tension and physical discomfort. The combination of gentle physical activity and interaction with nature can encourage relaxation, reduce everyday stress, and support overall health and well-being.

Creative Expression: Designing floral arrangements and planning garden layouts provide individuals with opportunities to explore their imagination and express their creativity. These artistic gardening activities can encourage self-expression, enhance feelings of satisfaction, and promote emotional well-being. Engaging in creative pursuits through flower gardening may also help individuals cope with everyday stress, strengthen emotional resilience, and develop a more positive outlook on life.

Restorative Environments: Gardens serve as peaceful and restorative environments, offering a refreshing escape from the noise, congestion, and pressures of urban life. Spending time among flowers and green vegetation can help restore mental energy, improve concentration, and alleviate cognitive fatigue. The natural surroundings of a garden provide an opportunity to relax, refresh the mind, and support psychological well-being.

Integrating Floral Gardening into Everyday Activities

Establishing Home-Based Flower Gardens: Even limited spaces, such as balconies, windowsills, and small terraces, can be converted into attractive and productive floral gardens. Container gardening offers a convenient way to cultivate ornamental flowers in urban homes where open garden areas are unavailable. Colourful flowering plants, including marigolds, petunias, and geraniums, can enhance the visual appeal of these spaces, create a pleasant atmosphere, and bring a refreshing touch of nature into everyday living environments.

Encouraging Participation in Shared Gardens: Participating in a local community garden enables individuals to experience the benefits of gardening while strengthening social relationships and community engagement. These shared spaces provide opportunities to exchange gardening knowledge, learn new cultivation techniques, and collaborate with others who share similar interests. Such interactions can promote a sense of belonging, encourage mutual support, and contribute to improved social and emotional well-being.

Practising Flower Gardening Throughout the Seasons: Adjusting gardening activities according to seasonal changes helps individuals remain connected with nature throughout the year. During spring and summer, gardeners can focus on cultivating colourful flowering plants, while autumn and winter provide opportunities to grow seasonally suitable, hardy plants or maintain indoor gardens. Adopting season-specific gardening practices ensures continuous involvement in horticultural activities, enhances gardening skills, and allows individuals to enjoy the aesthetic and psychological benefits of plants in different seasons.

The Role of Flower Gardening in Healthcare Settings: Hospitals, rehabilitation centres, and mental health institutions can integrate flower gardening programmes into their supportive care activities to promote patients' recovery and

overall well-being. Participation in planting, nurturing, and maintaining flowering plants can provide a calming environment, encourage physical activity, and support emotional relaxation. When incorporated appropriately into therapeutic programmes, flower gardening may complement conventional treatments by helping patients manage stress, improve mood, and enhance their quality of life.

Promoting Gardening Education and Awareness: Schools and community organisations can implement gardening programmes for children and adults to encourage environmental awareness, promote mental well-being, and strengthen social relationships. These initiatives provide opportunities for participants to learn about plant growth, biodiversity, and sustainable gardening practices while developing practical horticultural skills. In addition, collaborative gardening activities can encourage teamwork, foster a sense of responsibility towards nature, and create stronger community connections.

Challenges and Overcoming Barriers

Challenges in Floral Gardening:

Space Limitations: The scarcity of gardening space in urban environments can restrict opportunities for flower cultivation. However, alternative approaches, including vertical gardening, container cultivation, and rooftop gardens, can help utilise available spaces efficiently.

Time and Labour Requirements: Flower gardening involves regular care, maintenance, and physical effort, which may discourage individuals with busy schedules. Growing low-maintenance flowering plants and adopting automatic irrigation systems can simplify gardening activities and make them more convenient.

Insufficient Gardening Knowledge: Beginners may encounter difficulties in understanding plant selection, cultivation methods, watering requirements, and pest management. Community-based training programmes, online educational resources, and gardening applications can provide practical guidance and improve gardening skills.

Environmental Concerns: The excessive or improper application of chemical fertilisers and pesticides can negatively affect soil health, water quality, and beneficial organisms. Promoting organic inputs, biological pest management, and other sustainable horticultural practices can help minimise these environmental risks.

Future Directions for Floral Therapy

Integration with Digital Technologies: Digital applications and online platforms can improve access to floral gardening by offering cultivation advice, monitoring plant growth, and facilitating communication among gardening enthusiasts. These tools can encourage wider participation and support the adoption of gardening as a regular wellness activity.

Research and Development: Further scientific investigations are needed to understand the psychological and physiological effects of flower gardening. Evidence-based research can help identify its potential benefits, assess its effectiveness for different population groups, and establish appropriate guidelines for therapeutic applications.

Policy and Institutional Support: Government agencies, educational institutions, healthcare providers, and voluntary organisations can promote floral therapy through financial assistance, community gardening projects, awareness campaigns, and the integration of horticultural activities into suitable healthcare programmes.

Corporate Wellness Programmes: Organisations can introduce flower gardening activities as part of workplace wellness initiatives to help employees manage occupational stress, encourage relaxation, and improve workplace satisfaction. Gardening sessions and shared green spaces may also promote teamwork, creativity, and a healthier working environment.

Conclusion

Floral therapy offers a promising nature-based approach to supporting mental and emotional well-being through the cultivation and care of flowering plants. It can encourage relaxation, mindfulness, creativity, physical activity, and social interaction while fostering a sense of purpose and connection with nature. Integrating flower gardening into homes, community spaces, educational institutions, healthcare settings, and workplace wellness programmes can make its potential benefits accessible to diverse groups of people. Although limitations related to space, time, resources, and gardening knowledge may restrict participation, practical solutions such as container gardening, low-maintenance plants, and digital guidance can help overcome these barriers. Promoting sustainable horticultural practices and conducting further scientific research will be important for understanding and validating its therapeutic value. Floral gardening should be viewed as a complementary wellness practice rather than a replacement for professional mental healthcare.

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Nanoparticles for Abiotic and Biotic Stress Management in Fruit Crops

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Introduction

Fruit production represents a major sector of global agriculture and contributes substantially to nutritional security by supplying essential vitamins, minerals, dietary fibre, and antioxidant compounds required for human health (FAO, 2023; Slavin & Lloyd, 2012). However, rapid population growth, changing climatic conditions, and increasing pressure on natural resources have created significant challenges for maintaining sustainable fruit production. Both environmental stresses and pathogen infestations can adversely affect crop performance, resulting in considerable losses in fruit yield and quality (Lesk et al., 2016). Abiotic stresses, including drought, salinity, temperature extremes, nutrient imbalance, and heavy metal toxicity, interfere with various physiological and metabolic functions of plants. In contrast, biotic stresses arising from fungi, bacteria, viruses, nematodes, and insect pests can cause serious damage to crops and substantially reduce productivity.

Nanotechnology refers to the development, manipulation, and utilization of materials at the nanoscale, generally within the range of 1–100 nanometers. Materials at this scale possess distinctive physical, chemical, and biological characteristics that are often considerably different from those of their conventional bulk forms. These specialized properties allow nanoparticles to interact efficiently with plant cells, tissues, and physiological and metabolic processes. Consequently, nanotechnology has emerged as a promising approach for enhancing plant growth and productivity while improving the ability of fruit crops to withstand various environmental and biological stresses.

Nanoparticles and their Role in Horticultural Crop Production

Nanoparticles can be broadly classified into several groups, including metallic nanoparticles, metal oxide nanoparticles, carbon-based nanomaterials, polymeric nanoparticles, and nanoparticles produced through biological synthesis. In horticultural research, several nanomaterials have received considerable attention, particularly zinc oxide (ZnO), titanium dioxide (TiO_2), silicon dioxide (SiO_2), silver (Ag), iron oxide (Fe_2O_3), selenium (Se), copper oxide (CuO), and chitosan-based nanoparticles (Khan et al., 2019).

The unique behaviour of nanoparticles is largely associated with their extremely small dimensions, high surface-area-to-volume ratio, greater catalytic potential, and enhanced movement and interaction within biological systems. These characteristics allow nanoparticles to facilitate more efficient nutrient delivery, regulate the release of bioactive substances, improve nutrient absorption, and interact effectively with different cellular components (Fraceto et al., 2016). Through these mechanisms, nanoparticles can influence a wide range of physiological, biochemical, and metabolic processes associated with plant development and adaptation to stressful environmental conditions.

In fruit crops, nanomaterials can be delivered using different application approaches, such as foliar spraying, incorporation into soil, seed treatment, root-zone application, and nano-encapsulation techniques. Their potential to enhance nutrient-use efficiency, improve plant performance, and strengthen tolerance against environmental stresses has attracted increasing attention from horticultural researchers. As a result, nanotechnology is being explored as a promising tool for developing more efficient and sustainable approaches to fruit crop production.

Role of Nanoparticles in Physiological and Biochemical Stress Tolerance

Nanoparticles improve fruit crop performance through physiological, biochemical, and molecular mechanisms. They enhance nutrient uptake and utilization, supporting vegetative growth, flowering, fruit setting, and development (Pérez-de-Luque, 2017). Nanoparticles such as titanium dioxide and zinc oxide may improve chlorophyll synthesis and photosynthetic efficiency, thereby increasing carbohydrate production and fruit quality (Dimkpa et al., 2012). They also strengthen antioxidant defense systems by stimulating enzymes such as superoxide dismutase, catalase, and peroxidase, which help minimize oxidative damage under stress. Furthermore, nanoparticles can influence stress-responsive genes, hormonal regulation, osmotic adjustment, and ion balance. Collectively, these mechanisms may improve stress tolerance, plant growth, and fruit productivity.

Nanoparticles in Mitigating Abiotic Stresses

Abiotic stresses represent one of the most significant limitations to fruit production worldwide. Water scarcity, salinity, temperature extremes, and heavy metal contamination adversely affect growth, flowering, fruit setting, and quality formation.

Drought stress reduces water availability and impairs physiological processes including photosynthesis, transpiration, and nutrient transport. Nanoparticles improve drought tolerance by enhancing root development, maintaining cellular water status, increasing osmolyte accumulation, and strengthening antioxidant defenses. Silicon, zinc oxide, and selenium nanoparticles have shown considerable potential in reducing drought-induced oxidative damage and improving water-use efficiency (Hussain et al., 2018; Siddiqui et al., 2015).

Salinity stress is characterized by excessive accumulation of soluble salts in the root zone, leading to osmotic stress and ion toxicity. High concentrations of sodium and chloride ions disrupt nutrient uptake, membrane stability, and metabolic activities. Nanoparticles mitigate salinity stress by improving ionic balance, reducing sodium accumulation, enhancing potassium uptake (Khan et al., 2017), and maintaining membrane integrity. Improved photosynthetic performance and antioxidant activity further contribute to stress alleviation.

Temperature extremes, including heat and cold stress, significantly affect fruit crop productivity. High temperatures impair photosynthesis, protein synthesis, and reproductive development, whereas low temperatures disrupt membrane fluidity and metabolic processes. Nanoparticles help stabilize cellular membranes, protect proteins, and enhance antioxidant defenses under thermal stress conditions (Hatami et al., 2016). Their application often results in improved flower retention, fruit set, and yield under unfavourable temperature regimes.

Heavy metal contamination has become an increasing concern due to industrialization and intensive agricultural practices. Excessive accumulation of metals such as cadmium, lead, and arsenic causes toxicity, growth inhibition, and oxidative damage. Silicon and iron nanoparticles have demonstrated protective effects by reducing heavy metal uptake, promoting detoxification mechanisms, and maintaining nutrient homeostasis.

Role of Nanoparticles in Protecting Plants against Biotic Stresses

Biotic stresses caused by pathogens and pests are responsible for substantial losses in fruit production. Nanoparticles possess remarkable antimicrobial properties that make them valuable tools for disease management.

Silver nanoparticles are among the most extensively studied antimicrobial agents. Their small size allows direct interaction with microbial cell membranes, resulting in membrane disruption, leakage of cellular contents, and inhibition of metabolic activities. Silver nanoparticles have shown effectiveness against numerous fungal and bacterial pathogens affecting fruit crops.

Copper oxide nanoparticles also exhibit strong antimicrobial activity through the generation of reactive oxygen species and interference with microbial enzyme systems. Similarly, chitosan nanoparticles possess antifungal and antibacterial properties while simultaneously stimulating plant defense responses.

Apart from their direct antimicrobial effects, nanoparticles can induce systemic resistance in plants. They stimulate the production of defense-related enzymes, phenolic compounds, flavonoids, and pathogenesis-related proteins. These defense molecules strengthen the plant immune system and enhance resistance against a broad spectrum of pathogens.

Nanoparticles additionally contribute to improved efficacy of pesticides through nano-formulations and controlled-release systems. Such formulations increase target specificity, reduce pesticide losses, and minimize environmental contamination.

Application of Nanoparticles for Improved Fruit Production

Improved stress tolerance ultimately translates into enhanced fruit productivity. Nanoparticle-treated plants generally exhibit better vegetative growth, increased flowering intensity, higher fruit set percentages, and reduced flower and fruit drop (Zulfiqar et al., 2019). Enhanced nutrient uptake and photosynthetic efficiency provide a greater supply of assimilates required for fruit development.

Nanoparticles also influence hormonal balance and source-sink relationships within plants. Improved transport of carbohydrates and nutrients toward developing fruits contributes to increased fruit size, fruit weight, and overall yield. Numerous studies have reported positive effects of nanoparticle applications on produ firmnessctivity in mango, citrus, grapevine, strawberry, pomegranate, apple, guava, and other fruit crops.

The ability of nanoparticles to maintain physiological functions under stress conditions is particularly important in sustaining productivity under changing climatic scenarios. By reducing stress-induced yield losses, nanoparticles offer significant opportunities for climate-resilient fruit production systems.

Effects of Nanoparticles on Fruit Quality Attributes

Fruit quality is determined by a combination of physical, biochemical, nutritional, and sensory characteristics. Nanoparticles have demonstrated considerable potential in improving multiple quality attributes.

Enhanced nutrient availability and photosynthetic activity contribute to improved fruit size, weight, shape, and firmness (Zulfiqar et al., 2019). Increased carbohydrate synthesis often results in higher total soluble solids and sugar accumulation, leading to improved sweetness and consumer acceptability.

Nanoparticles also influence the synthesis of secondary metabolites including phenolics, flavonoids, anthocyanins, carotenoids, and ascorbic acid. These compounds contribute to fruit coloration, antioxidant capacity, nutritional value, and health-promoting properties. Selenium and zinc nanoparticles are particularly effective in enhancing antioxidant content and biofortification of fruits.

Improved antioxidant systems delay senescence and reduce oxidative deterioration during storage. Consequently, nanoparticle-treated fruits frequently exhibit extended shelf life, reduced postharvest losses, and better maintenance of quality during transportation and marketing.

The enhancement of nutritional quality is especially significant in the context of increasing consumer demand for functional foods rich in bioactive compounds. Nanoparticles therefore offer opportunities not only for improving productivity but also for enhancing the nutritional and commercial value of fruit crops.

Future Perspectives and Challenges

Despite the promising potential of nanoparticles in fruit production, several challenges remain. The long-term environmental fate of nanoparticles and their interactions with soil microorganisms require further investigation. Concerns regarding nanoparticle accumulation in agricultural ecosystems and possible entry into food chains must be addressed through comprehensive risk assessments.

The effectiveness of nanoparticles depends greatly on their concentration, size, composition, and application method. Excessive concentrations may induce phytotoxicity and adversely affect plant growth. Therefore, the development of standardized protocols for safe and efficient nanoparticle use is essential.

Future research should focus on green synthesis approaches, biodegradable nano-formulations, nano-enabled smart delivery systems, and integration of nanotechnology with precision horticulture. Advances in molecular biology and genomics will further improve our understanding of nanoparticle-plant interactions and facilitate the development of targeted strategies for stress management.

Conclusion

Nanotechnology represents a transformative approach for improving fruit crop productivity and quality under biotic and abiotic stresses. Through their unique physicochemical properties, nanoparticles enhance nutrient uptake, improve photosynthetic performance, strengthen antioxidant defence systems, regulate stress-responsive genes, and suppress pathogenic microorganisms. These effects collectively contribute to improved stress tolerance, higher fruit yields, superior fruit quality, enhanced nutritional value, and extended shelf life. Although environmental and safety concerns require careful consideration, continued research and technological advancements are expected to facilitate the sustainable integration of nanotechnology into modern fruit production systems. The application of nanoparticles therefore holds great promise for achieving climate-resilient, resource-efficient, and sustainable horticultural production in the future.

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Fruit Flies vs. Mangoes: A Battle Worth Billions

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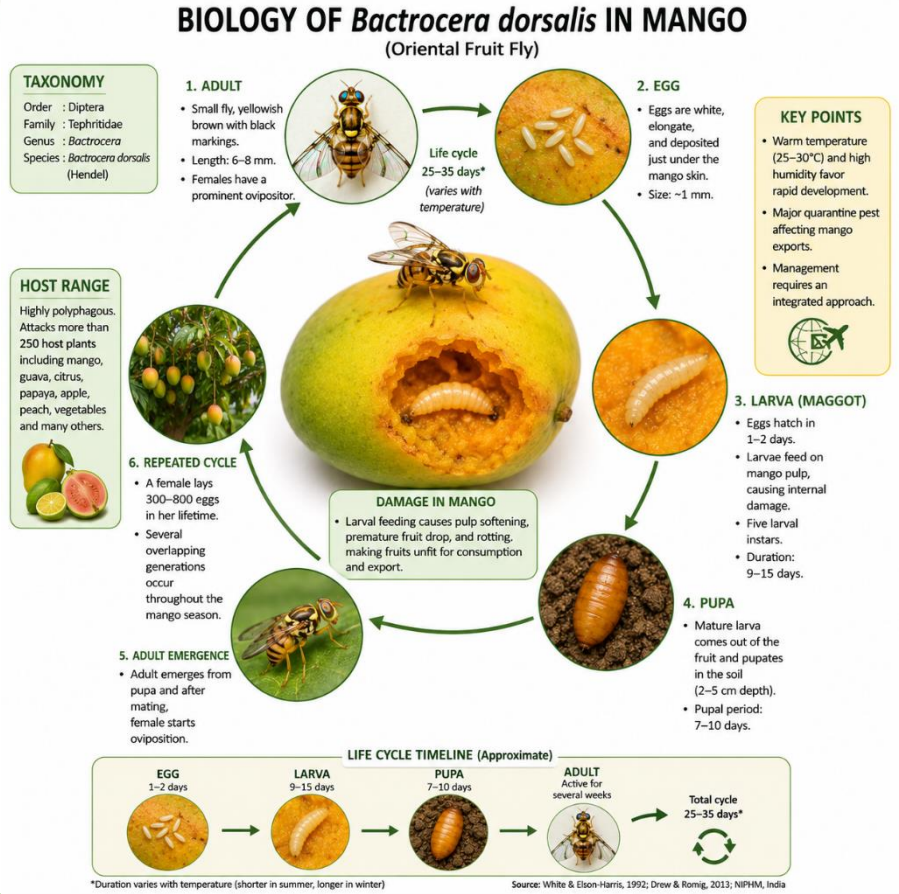
Mango, often celebrated as the "King of Fruits," is cherished worldwide for its rich flavor, aroma, and nutritional value. India is the world's largest producer of mangoes, contributing about 40–45% of global mango production. Some premium varieties such as Alphonso, Kesar, Banganapalli, and Langra were exported to international markets every year worth 47-50 million dollar. Indian mangoes are exported to over 40 countries worldwide, including major markets such as the United States, the United Kingdom, the United Arab Emirates, Japan, and Australia. Generating substantial revenue for farmers and contributing to the country's agricultural economy. However, the global journey of this beloved fruit is increasingly challenged by a tiny insect known as the fruit fly.

In recent years, concerns over fruit fly infestations and quarantine compliance have led several countries to impose strict import requirements, reject consignments, or temporarily suspend mango imports. For instance, this happened in the recent past, from 25th March 2026 japan suspended the mango consignments.

Why Fruit Flies Are Such a Major Concern?

The principal quarantine pest affecting mango exports is the Oriental fruit fly, *Bactrocera dorsalis*, originated in Southeast Asia and has spread to many parts of the world. Female fruit flies lay eggs inside developing mangoes. The larvae feed within the fruit, making infestations difficult to detect externally. The species is remarkably tolerant of a wide range of environmental conditions and can survive not only in tropical regions but also in some temperate areas where suitable host plants are available. If introduced into fruit-growing regions abroad, they can attack hundreds of host plants and cause severe economic losses. As a result, countries such as Japan, the USA, Australia, New Zealand, and South Korea impose strict phytosanitary conditions on mango imports.

Biology of Oriental fruit fly, *Bactrocera dorsalis*



The Oriental fruit fly, *Bactrocera dorsalis*, undergoes four developmental stages: egg, larva, pupa, and adult. Adult females lay eggs beneath the skin of ripe or ripening mango fruits using their ovipositor, usually depositing 3–30 eggs in a cluster. Under favorable conditions (around 28°C), a female can lay up to 3,000 eggs during her lifetime, while under field conditions she typically lays 1,200–1,500 eggs. The eggs hatch within 1–2 days, and the emerging maggots feed on the fruit pulp, passing through three larval instars over about 8–10 days. After completing development, the mature larvae exit the fruit through small holes, drop to the ground, burrow into the soil, and pupate. The pupal stage lasts approximately 4–6 days, after which adult flies emerge, mate, and begin a new cycle. Under tropical conditions, the entire life cycle from egg to adult can be completed in about 14 days, allowing several generations to develop during the mango season.

Quarantine Measures Adopted by India to Safeguard Mango Exports

To prevent export bans and ensure uninterrupted access to international markets, India has established a comprehensive phytosanitary system to manage fruit fly infestations in mangoes. These measures are implemented under the supervision of the Directorate of Plant Protection, Quarantine and Storage (DPPQS), APEDA, and the National Plant Protection Organization (NPPO) of India, in accordance with the requirements of importing countries and international standards prescribed by the International Plant Protection Convention (IPPC).

1. Vapour Heat Treatment (VHT): Vapour Heat Treatment (VHT) is one of the most important quarantine treatments used for the export of fresh mangoes. In this process, harvested fruits are exposed to controlled temperatures and humidity levels for a specified duration to eliminate fruit fly eggs and larvae that may be present inside the fruit. The treatment raises the internal fruit temperature to a level that is lethal to the pest while preserving the quality, taste, and shelf life of the mangoes.

one of the most widely adopted protocols of VHT is that the fruit core temperature be raised to 46.5°C and maintained for at least 30 minutes. This treatment effectively kills all developmental stages of fruit flies, including eggs and larvae, while preserving the fruit's quality, flavor, and marketability.

VHT is a mandatory phytosanitary requirement for mango exports to countries such as Japan, South Korea, and New Zealand, where fruit flies are considered high-risk quarantine pests. Approved VHT facilities operate under strict supervision of Indian plant quarantine authorities and are regularly audited by officials from importing countries. Detailed records of treatment parameters, including temperature, humidity, and treatment duration, are maintained to ensure compliance with international quarantine standards. This treatment has played a crucial role in facilitating market access for premium Indian mango varieties while minimizing the risk of pest introduction.

2. Irradiation Treatment: Irradiation is another internationally recognized quarantine treatment used to ensure the pest-free status of exported mangoes. In this process, fruits are exposed to a carefully controlled dose of gamma radiation that sterilizes or kills fruit fly eggs and larvae without affecting the nutritional quality, appearance, or taste of the fruit. Unlike chemical fumigation, irradiation leaves no harmful residues and is considered an environmentally friendly phytosanitary measure.

This treatment is particularly important for exports to the United States, where irradiation is the primary quarantine requirement for Indian mangoes. To support export activities, India has established several internationally approved irradiation facilities located at Vashi, Nashik, Bengaluru, and Ahmedabad. These facilities operate under stringent regulatory oversight and comply with bilateral agreements between India and importing countries. The adoption of irradiation technology has significantly expanded India's access to high-value international markets.

3. Pre-clearance Inspection: Pre-clearance inspection is a collaborative phytosanitary mechanism that allows importing countries to verify compliance with quarantine requirements before consignments are shipped. Under this system, inspectors from the importing country visit treatment and packing facilities in India to monitor processing operations, inspect consignments, and certify compliance with established protocols.

For example, officials from the United States Department of Agriculture–Animal and Plant Health Inspection Service (USDA-APHIS) periodically inspect irradiation facilities handling mango exports destined for the United States. Similarly, quarantine officials from countries such as South Korea and Japan may participate in facility audits and compliance assessments. The pre-clearance system enhances confidence among importing countries and reduces the likelihood of shipment rejection upon arrival, thereby facilitating smoother international trade.

4. Phytosanitary Certification: Every consignment of mangoes exported from India must be accompanied by an official phytosanitary certificate issued by the National Plant Protection Organization (NPPO). This certificate serves as a formal declaration that the shipment has been inspected and found free from regulated quarantine pests, including fruit flies, and complies with the import requirements of the destination country.

The phytosanitary certification process involves verification of orchard registration, treatment records, inspection reports, and packing procedures. Importing countries rely heavily on this certification to ensure biosecurity and protect their domestic agricultural systems from invasive pests. The certificate therefore acts as a crucial document supporting international trade and maintaining India's credibility as an exporter of high-quality horticultural produce.

5. Orchard Registration and Traceability Systems: India has implemented orchard registration and traceability programmes to strengthen pest management and ensure accountability throughout the export supply chain. Orchards intended for export production are registered with designated authorities and are subject to regular monitoring for fruit fly infestations and other quarantine pests. Farmers are required to follow recommended integrated pest management practices and maintain records of pest surveillance and control measures.

The traceability system enables authorities to track mangoes from the orchard through harvesting, treatment, packing, and export stages. Each consignment can be linked back to its source orchard, allowing rapid identification and corrective action if any phytosanitary issue arises. This system enhances transparency, improves quality assurance, and provides importing countries with greater confidence in the safety and pest-free status of Indian mango exports.

Together, these measures form a robust phytosanitary framework that helps India protect its mango export industry, maintain access to premium international markets, and minimize the risk of trade disruptions caused by fruit fly infestations.

The Challenge of Maintaining Phytosanitary Standards

India has implemented several internationally accepted phytosanitary measures, including Vapour Heat Treatment (VHT), irradiation, pre-clearance inspections, phytosanitary certification, and traceability systems, to protect mango exports from fruit fly infestations. However, export restrictions and shipment rejections occasionally occur because maintaining consistent compliance across the entire export chain remains challenging.

Operational lapses during treatment procedures, inadequate orchard-level pest management, and variations in practices among numerous small growers can affect export quality. Effective fruit fly control must begin in the orchard through proper sanitation and integrated pest management, while post-harvest treatments must strictly follow prescribed protocols. In addition, documentation and traceability play a crucial role in international trade. Errors in certification, incomplete records, or non-compliance with import requirements can lead to shipment rejections even when the fruit is pest-free. Importing countries such as Japan, the United States, Australia, and New Zealand maintain stringent biosecurity standards and often follow a zero-tolerance approach toward quarantine pests.

Climate change, increasing pest pressure, infrastructure constraints during peak export seasons, and evolving international regulations further complicate export management. Therefore, successful mango exports depend not only on effective pest control but also on seamless coordination among farmers, exporters, treatment facilities, and regulatory authorities. Even a minor lapse in biosecurity can have significant trade and economic consequences.

The battle between mangoes and fruit flies is therefore more than a biological interaction—it is a story of biosecurity, international trade, scientific innovation, and economic resilience. Understanding this conflict offers valuable insights into how tiny insects can shape global markets and why effective pest management has become essential for safeguarding the international trade of the world's favorite tropical fruit.

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AI in Entomology: Unlocking New Frontiers in Insect Research

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Artificial Intelligence (AI) is one of the most transformative technologies of the 21st century. Once confined to science fiction, AI has rapidly become an integral part of everyday life, influencing how we communicate, travel, diagnose diseases, and conduct scientific research. Today, more than 5.5 billion people worldwide use the internet, and billions interact with AI-powered systems every day, often without realizing it. AI-based recommendation systems influence nearly 80% of the content consumed on major digital platforms. Agricultural research is no exception to this digital revolution, as AI-driven technologies are helping researchers develop smarter solutions for improving productivity, sustainability, and food security. Artificial Intelligence is increasingly transforming agricultural research by enabling scientists to analyse vast amounts of data from farms, satellites, sensors, and laboratories in real time.

The growing adoption of AI in agricultural research has opened new opportunities in entomology, plant protection, and precision agriculture. By combining machine learning, remote sensing, and computer vision technologies, scientists can detect insect pests earlier, predict outbreaks more accurately, and develop smarter, data-driven pest management strategies. Imagine a world where computers can identify insect pests, translate agricultural advisories into multiple languages, digitize millions of museum specimens, and even help scientists understand the social lives of ants and wasps. This is no longer science fiction. Artificial Intelligence (AI) is rapidly transforming the field of entomology.

For generations, entomologists have combined scientific expertise, patience, and keen observation to unravel the fascinating world of insects. From discovering new species to preserving museum collections and monitoring pest populations to understanding intricate insect behaviours, their efforts have contributed immensely to food security, environmental sustainability, and biodiversity conservation. Artificial Intelligence is emerging as a powerful ally, enhancing the capabilities of entomologists by accelerating data analysis, automating routine processes, and enabling researchers to address increasingly complex scientific questions with greater speed and precision.

What is Artificial Intelligence?

Artificial Intelligence refers to computer systems that can perform tasks that normally require human intelligence, such as learning, pattern recognition, reasoning, and decision-making. In recent years, AI tools have brought this technology into the hands of millions of people. In entomology, AI encompasses machine learning, computer vision, image analysis, and data processing systems that can analyze enormous amounts of information quickly and accurately. These technologies enable researchers to identify insect species from images, monitor pest populations in real time, predict insect outbreaks, and detect behavioural patterns that may be difficult for humans to observe. By integrating AI with traditional entomological approaches, scientists can accelerate research, improve the precision of decision-making, and develop innovative solutions for sustainable agriculture, biodiversity conservation, and ecosystem management.

Applications of AI in entomology

Smarter Pest Management: Counting Insects to Predicting Outbreaks: One of the most exciting developments in modern entomology is the emergence of AI-based smart pheromone traps. Conventional pheromone traps have been used for decades to attract and monitor insect pests using species-specific chemical attractants. However, these traps require manual inspection, insect counting, and data recording, making large-scale monitoring laborious and time-consuming. AI-enabled smart traps are changing this approach by integrating cameras, image recognition algorithms, wireless communication systems, and cloud computing platforms. Once insects are captured, onboard cameras automatically photograph them, AI algorithms identify the species and count their numbers, and the information is transmitted in real time to researchers, extension workers, or farmers through web dashboards or mobile applications.

AI-powered smart pheromone traps equipped with cameras, computer vision algorithms, and wireless communication technologies are emerging as next-generation tools for automated insect monitoring. In cotton, researchers in India and elsewhere are evaluating smart pheromone traps for monitoring the pink bollworm (*Pectinophora gossypiella*), a major pest responsible for significant yield losses. Automated image-based systems can continuously monitor moth populations and provide early warnings, enabling timely pest management decisions. In rice ecosystems, researchers are developing AI-assisted monitoring systems for pests such as the yellow stem borer (*Scirpophaga incertulas*), rice leaf folder (*Cnaphalocrocis medinalis*), and brown planthopper (*Nilaparvata lugens*). These systems combine smart traps with weather data to improve outbreak forecasting and optimize Integrated Pest Management (IPM) strategies. In horticultural crops, smart traps are being increasingly used for monitoring fruit flies (*Bactrocera* spp.), particularly in mango, guava, citrus, and other fruit crops. Australia, Israel, Europe, and several Asian countries have adopted automated trapping

systems that help growers detect pest populations early and minimize unnecessary insecticide applications. Stored grain facilities often struggle with insect infestations that are difficult to detect early. Researchers are now using AI-powered cameras and computer vision systems to identify pests in real time.

India has also begun integrating digital technologies into pest surveillance. The Government of India's National Pest Surveillance System (NPSS), launched in 2024, uses mobile applications, geotagged field observations, and digital platforms to strengthen real-time pest monitoring across agricultural landscapes. AI-enabled trap technologies are expected to complement such national initiatives in the coming years.

Internationally, several commercial systems have already entered the market. Examples include Trapview, which provides AI-powered remote insect monitoring for fruit orchards, vineyards, and field crops, and Pessl Instruments' iSCOUT®, an automated camera trap system capable of remotely monitoring insect populations.

The future of pest management lies in integrating these smart traps with drones, weather stations, satellite imagery, and predictive AI models. Instead of reacting after visible crop damage occurs, farmers may soon receive alerts days or even weeks before pest outbreaks become severe, enabling more precise, economical, and environmentally sustainable interventions. Such technologies could reduce crop losses, minimize pesticide use, and make food storage safer and more efficient.



iSCOUT®, an automated camera trap system



Trapview – AI powered Insect light trap

Breaking Language Barriers in Agriculture

Agricultural extension services are essential for delivering scientific information to farmers. However, language differences often limit access to critical information. Artificial Intelligence is helping break language barriers in agriculture by making scientific information more accessible to diverse farming communities. AI-powered translation tools can rapidly convert pesticide safety manuals, crop advisories, and educational materials into multiple languages and even adapt them to local dialects and reading levels. For example, AI-assisted translations are being used in the United States to provide pesticide safety information in Spanish, while India is leveraging platforms such as Bhashini and Kisan e-Mitra to deliver agricultural information and government services in regional languages. These technologies have immense potential to disseminate insect pest advisories, integrated pest management recommendations, and climate-based alerts directly to farmers in their native languages. However, since technical terms and management recommendations can sometimes be mistranslated, expert review remains essential to ensure accuracy and reliability.

Bringing Museum Collections into the Digital Age

Natural history museums around the world house millions of insect specimens collected over hundreds of years, representing an invaluable archive of global biodiversity. Traditionally, digitizing these collections by photographing specimens, transcribing handwritten labels, and organizing data has been a slow and labor-intensive task. Artificial Intelligence is now accelerating this process through computer vision and machine learning tools that can automatically identify specimens, transcribe labels, and extract biological information.

Innovative systems such as DiversityScanner and DrawerDissect are helping researchers rapidly process large collections, while institutions such as the Smithsonian Institution and the Natural History Museum, London, are digitizing their holdings to make them globally accessible. These digital databases are enabling scientists to study long-term changes in species distributions, biodiversity loss, invasive species spread, and the impacts of climate change, unlocking scientific knowledge that has remained hidden in museum cabinets for decades. The digitization of museum collections may unlock scientific treasures that have remained hidden in cabinets for decades.

Insect Behavioural Studies: Learning from Ant Societies and “Deepfake” Wasps

Artificial Intelligence is also opening exciting new avenues for understanding insect behaviour and social interactions. Researchers are using deep learning algorithms to study how social insects organize their colonies and make collective decisions. For example, scientists have used AI to analyse videos of Jerdon's jumping ant and identify subtle behavioural patterns involved in establishing reproductive dominance hierarchies, patterns that are often difficult for humans to detect through manual observation. In another innovative study, researchers developed “deepfake” technologies for

paper wasp by digitally altering facial patterns and body movements in videos to investigate how wasps recognize individuals and maintain social relationships. These AI-powered approaches are allowing scientists to ask entirely new questions about insect perception, memory, communication, and collective intelligence, providing unprecedented insights into the complex societies of insects. Some of the most fascinating applications of AI involve insect behavior. Scientists are using advanced AI systems to study how ants establish social hierarchies and how individual behaviors influence entire colonies. Deep learning algorithms can identify subtle patterns in insect movement that would be impossible for humans to detect manually.

AI in Entomology: Challenges That Need Attention

Despite its enormous potential, AI is not without risks. AI systems can make mistakes, generate false information, misidentify insects, and even fabricate scientific references. Overdependence on AI may also reduce originality and creativity if scientists rely on machines without critical evaluation. Experts agree that AI should remain an assistant not a replacement for scientists. Human expertise is essential for verifying results, interpreting findings, and making ethical decisions.

The Future of AI in Entomology

The future promises even greater integration of AI into insect science. Some expected applications include:

1. Automated pest detection systems for agriculture.
2. Faster digitization of insect collections.
3. Improved scientific publishing and manuscript preparation.
4. Enhanced accessibility through multilingual educational resources.
5. Better data analysis for biodiversity conservation.
6. Development of tools for visually impaired and underserved communities.

AI is not replacing entomologists; it is empowering them. By taking over repetitive tasks, AI allows scientists to focus on creativity, innovation, and discovery. As this technology continues to evolve, one principle remains clear: the best science will emerge from a partnership between artificial intelligence and human intelligence. The future of entomology may be digital, but its success will still depend on human curiosity.

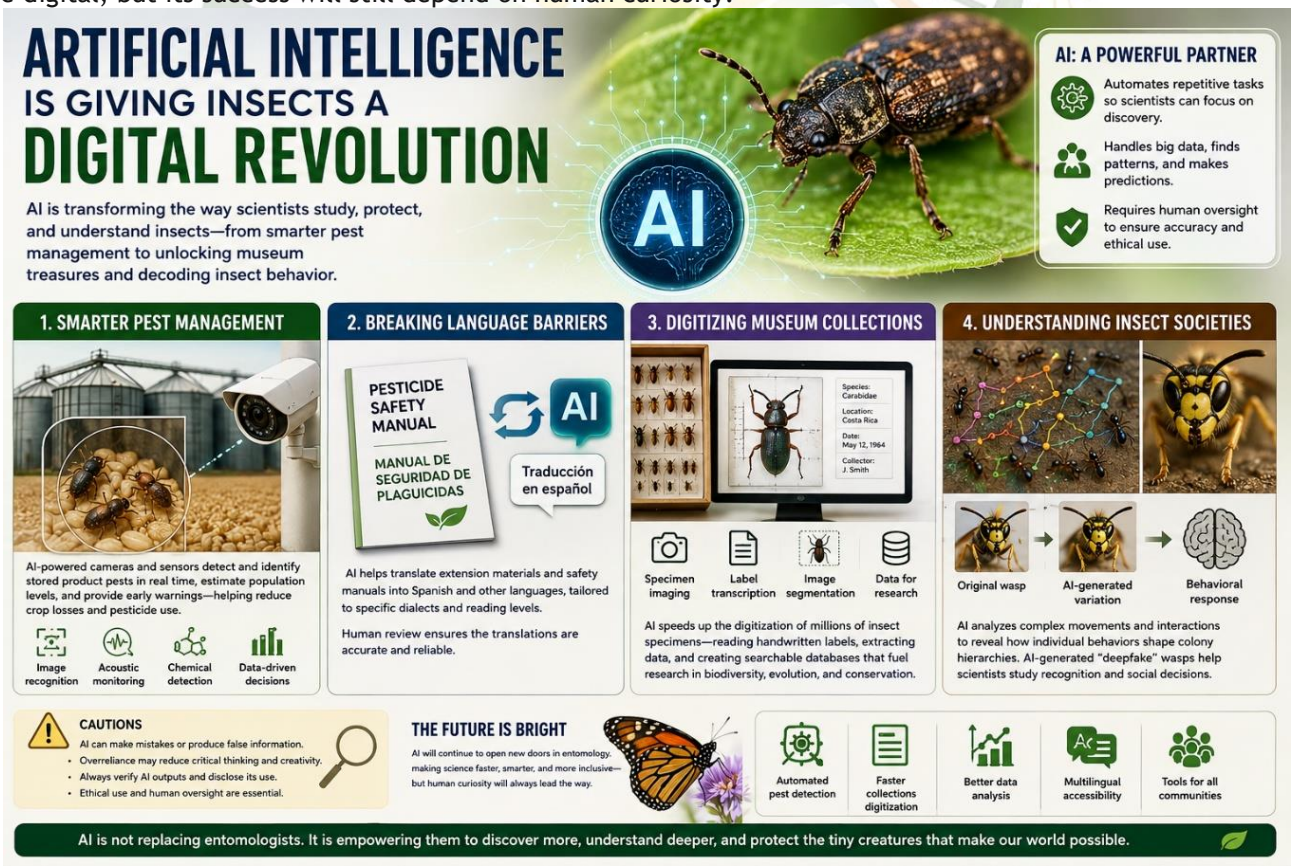


Figure: Applications of Artificial intelligence in Entomology

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Climate-Resilient Fisheries in India: Tackling Drought Through Ornamental Aquaculture

Article ID: 74643

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Abstract
India is one of the world's leading fish producers, but growing water scarcity and unpredictable droughts pose a severe threat to traditional inland food fisheries **(Food and Agriculture Organization [FAO] & IPCC, 2022).** Conventional fish farming requires large open ponds and massive amounts of water. During drought periods, drying ponds lead to water quality breakdowns and heavy financial losses for rural fishers. This article explores how shifting or diversifying into ornamental (aquarium) fish farming offers a low-water, high-profit alternative. By examining real-world initiatives in Indian states like Jharkhand, West Bengal, and Odisha, we demonstrate how micro-scale ornamental fish setups empower smallholders, protect rural livelihoods, and conserve water during dry spells **(ICAR-Central Inland Fisheries Research Institute [ICAR-CIFRI], 2025)**.

Keywords: Climate-Resilient, Aquaculture Ornamental Fisheries, Drought Mitigation, Economic Water Productivity, Inland Fisheries Management.

Introduction
India ranks as the second-largest aquaculture nation globally, with inland freshwater farming traditionally dominated by Indian Major Carps such as Rohu (*Labeo rohita*), Catla (*Gibelion catla*), and Mrigal (*Cirrhinus mrigala*). However, rising global temperatures and shifting monsoon patterns have increased the frequency of severe droughts across agricultural belts **(FAO & IPCC, 2022)**.

In traditional fish culture, producing 1 kg of edible fish requires 400 to over 1,800 liters of water **(Bhargavi & Bhanuprakash, 2026)**. When water levels drop during heatwaves, evaporation concentrates harmful waste products like ammonia, depletes dissolved oxygen, and causes mass fish mortality.

To build climate resilience, India's fishery sector must adopt methods that maximize financial return while using as little water as possible. Ornamental fish production meets this challenge: aquarium species are sold by the individual piece based on color and appearance rather than weight, generating far higher income per liter of water used. **(ICAR-CIFRI, 2025).**

State-Specific Examples in India
1. Jharkhand: Tribal Women and Micro-Tank Aquaculture: In drought-prone districts of Jharkhand such as Ranchi, Simdega, Bokaro, and Jamshedpur rural and tribal women have adopted backyard ornamental fish units with technical support from the ICAR-Central Inland Fisheries Research Institute (ICAR-CIFRI). Operating in small spaces of around 100 sq. ft., households use 400-liter Fiber-Reinforced Plastic (FRP) tanks fitted with basic aerators **(ICAR-CIFRI, 2025)**. By breeding hardy livebearers like Guppies (Poecilia reticulata), Mollies (Poecilia sphenops), and Swordtails (Xiphophorus helleri), these families earn steady monthly income with minimal water requirements, shielding them from agricultural drought shocks.

2. West Bengal: Sundarbans Cluster Model: In West Bengal, particularly within vulnerable coastal and wetland belts like the Sundarbans, smallholders face both water salinity shifts and seasonal water scarcity. Local women's Self-Help Groups (SHGs) have formed ornamental farming clusters **(ICAR-CIFRI, 2025)**. Because small ornamental tanks can be easily sheltered from extreme sunlight and direct evaporation, farmers maintain continuous production cycles year-round without depleting local freshwater reserves.

3. Odisha: Backyard Unit Interventions: In coastal and inland districts of Odisha, including Ganjam, Puri, Kendrapara, and Balasore, institutional programs have established dozens of backyard ornamental fish units. These setups allow smallholder families to rear thousands of colorful juvenile fish in small tank spaces. This approach creates a reliable secondary source of household income when conventional pond aquaculture becomes unviable due to seasonal water shortages **(ICAR-Central Institute of Freshwater Aquaculture [ICAR-CIFA], 2025)**.

Methodology: How Ornamental Fisheries Tackle Drought?
Ornamental fish farming combats drought through a combination of spatial efficiency, lower water consumption, and closed-loop filtration technologies:

1. Low-Volume, High-Value Efficiency: Unlike food fish that require large open earthen ponds (>0.1ha), ornamental fish thrive in small indoor or shaded outdoor tanks (10 - 100 sq. ft.). This reduced surface area minimizes water loss from evaporation **(Bhargavi & Bhanuprakash, 2026)**.

2. Recirculating Aquaculture Systems (RAS): Compact RAS units filter and continuously reuse water through physical and biological filters. Useful nitrifying bacteria convert toxic fish waste into harmless nitrates, allowing systems to replace less than 10% of their total water volume daily.

3. Biofloc and Integrated Aquaponic Systems: Biofloc technology uses beneficial microbes to absorb waste products inside the tank, requiring near-zero water replacement. Alternatively, aquaponic setups circulate fish tank effluent through growing plant beds (such as leafy vegetables), where plants naturally clean the water so it can be safely returned to the fish **(ICAR-CIFRI, 2025)**.

System Type	Primary Nitrogen Treatment Mechanism	Daily Water Exchange Rate and Relative Capital Expenditure (CapEx)	Operational Complexity	Climate Adaptation & Drought Potential
Recirculating Aquaculture System (RAS)	Autotrophic nitrification via fixed or fluidized biofilters	1 - 10% High	High (Requires continuous power & monitoring)	Outstanding (Complete environmental insulation)
Biofloc Technology (BFT)	Heterotrophic microbial assimilation driven by carbon dosing	<1 - 2% (Evaporative top-up only) Moderate	Moderate to High (Requires active C:N management)	High (Operates under near zero-discharge conditions)
Aquaponics / IAAS	Direct plant nutrient uptake (NO_3^-, PO_4^{3-})	2 - 5% Moderate to High	Moderate (Requires dual crop management)	High (Yields secondary crop revenue per unit water)
Homestead FRP Tanks	Static water holding with periodic managed exchange	10 - 20% (Weekly baseline) Low	Low (Well-suited for rural smallholders)	Moderate to High (Low absolute volume requirement)

Table 1. Systems which should be used to tackle Drought conditions.

3. Future Prospects: To scale ornamental fisheries as a nationwide climate adaptation tool across India, several key measures are under development:

a. Policy and Subsidies: Expansion of national schemes like the Pradhan Mantri Matsya Sampada Yojana (PMMSY) provides direct financial subsidies and low-cost setup kits for smallholder backyard units **(Ministry of Fisheries, Animal Husbandry and Dairying [MFAHD], 2020)**.

b. Market Infrastructure: Building cooperative marketing hubs and direct connections between rural producers, urban aquarium shops, and global exporters ensure fair prices for small-scale farmers.

c. Skill Training: Organizing hands-on workshops through KVKs (Krishi Vigyan Kendras) and research institutes ensure proper training in water testing, disease control, and breeding techniques.

Conclusion

Climate-induced droughts present a major challenge to India's traditional food fisheries and rural livelihoods. Transitioning toward or integrating micro-scale ornamental fish production provides a practical, water-smart alternative **(FAO & IPCC, 2022)**.

As demonstrated in states like Jharkhand, West Bengal, and Odisha, ornamental aquaculture requires very little land and water, protects producers from weather extremes, and empowers marginalized communities. Expanding these low-water systems across drought-prone regions will be essential for building a resilient blue economy in India **(ICAR-CIFRI, 2025)**.

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Making Livestock Mobile Applications More Farmer-Friendly: From Digital Access to Practical Impact

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Introduction

Imagine a dairy farmer who notices a sudden decline in milk production in a buffalo. The farmer has a smartphone and has even downloaded a livestock advisory application. However, the information is available only in a language that is difficult to understand, the internet connection is unreliable, and the farmer cannot determine which advice is appropriate for the animal. Despite having access to digital technology, the farmer remains uncertain about what to do next.

This situation highlights an important question: *Are livestock mobile applications designed around farmers' needs, or are farmers expected to adapt to technology?*

Livestock farming is a major source of livelihood, nutrition and employment for millions of rural households in India. Timely information on animal nutrition, breeding, disease prevention, vaccination, housing and government schemes can help farmers make better decisions. Mobile applications offer an opportunity to deliver such information quickly and at scale. However, the availability of an application does not automatically translate into its effective use. The real challenge is not merely to develop more applications, but to make existing and future applications accessible, trustworthy, understandable and useful for livestock farmers. A farmer-friendly application should not simply store information; it should help farmers apply that information in their daily livestock management practices.

The Growing Role of Digital Technology in Livestock Farming

Digital transformation is creating new opportunities for animal husbandry extension services. Mobile applications can connect livestock farmers with veterinarians, extension professionals, research institutions, government departments and service providers. Depending on their design and availability, these applications can support animal identification, health records, breeding management, feeding practices, disease reporting and access to livestock-related schemes.

Why Do Livestock Mobile Applications Remain Underused?

Livestock-oriented mobile applications remain underused due to several practical and behavioural barriers. Language and digital literacy constraints make applications difficult to navigate, while poor connectivity and affordability issues limit access. Concerns about information credibility and data privacy may reduce farmers' trust. Additionally, limited personalisation of advisory services and inadequate interaction, expert guidance, and follow-up support can reduce the relevance and sustained use of these applications. Addressing these challenges is essential to improve their adoption and effectiveness among livestock farmers.

Designing Mobile Applications Around Farmers' Needs

Making livestock mobile applications farmer-friendly requires a shift towards farmer-centred design. Local-language and voice-enabled interfaces can improve accessibility through simple instructions, audio messages and practical videos. Simple navigation with clear icons and easily accessible services can reduce confusion. Offline access and low-data functionality can ensure the availability of essential livestock advisories in areas with poor connectivity. Timely, location-specific advisories on seasonal stress, fodder availability, disease prevention and animal management can improve practical relevance. Information should be scientifically validated, regularly updated and supported by access to veterinary professionals. Privacy and data security must be ensured through transparent data practices. Finally, inclusive and participatory development involving women livestock keepers, smallholders and farmers with limited digital literacy, along with field testing and simple feedback mechanisms, can help develop accessible, reliable and effective applications.

The Role of Extension Professionals

Technology alone cannot ensure adoption. Veterinary and animal husbandry extension professionals play an essential role in helping farmers discover, understand and use digital services. Krishi Vigyan Kendras, veterinary universities, livestock development departments, dairy cooperatives and extension personnel can organise practical demonstrations, village-level training sessions and hands-on mobile application workshops. Instead of merely explaining the features of an application, trainers should demonstrate how to use it to solve specific problems, such as checking a vaccination record or locating an available veterinary service.

Peer learning can further strengthen adoption. Farmers who use an application successfully can demonstrate its benefits to other livestock keepers. Such interactions can reduce hesitation, build confidence and encourage continued use.

Extension professionals should also communicate farmers' feedback to application developers and relevant institutions. This two-way process can ensure that digital services evolve according to actual field requirements.

Measuring Success Beyond Downloads

The success of a livestock mobile application should not be judged solely by downloads, registrations or the number of features it offers. More meaningful indicators include:

1. **Accessibility:** Can farmers use the application in their preferred language and under their existing connectivity conditions?
2. **Usability:** Can they complete essential tasks without repeated assistance?
3. **Credibility:** Do farmers trust the information and understand its source?
4. **Engagement:** Do they return to the application when they need livestock-related information?
5. **Practical application:** Does the information help them improve their management decisions?
6. **Service responsiveness:** Can farmers obtain timely clarification or access appropriate professional services?
7. **Inclusion:** Are women, smallholders and farmers with limited digital skills able to benefit?

Periodic field evaluations and farmer feedback can help institutions identify gaps and improve services. Where feasible, changes in knowledge, management practices, service access and farm outcomes should also be assessed.

The Way Forward: From Digital Tools to Trusted Partners

The future of livestock extension lies in integrating digital innovation with human support. Artificial intelligence, voice assistants and personalised advisory systems may make information more accessible, provided that they are developed with scientific oversight, appropriate safeguards and clear referral pathways to veterinary professionals.

However, advanced technology should not come at the expense of simplicity. A well-designed application that solves a farmer's immediate problem may be more valuable than a sophisticated platform that is difficult to navigate. Institutions developing livestock applications should adopt a continuous improvement approach: understand farmers' needs, co-design solutions, test them in the field, collect feedback and refine the services. Collaboration among veterinarians, extension scientists, software developers, government departments, dairy cooperatives and livestock farmers will be crucial.

Conclusion

Farmer-friendly livestock mobile applications can strengthen the connection between scientific knowledge and everyday animal husbandry practices. Their true value lies not in the technology they contain, but in the problems, they help farmers solve. Local-language communication, simple navigation, offline functionality, reliable information, privacy protection and accessible expert support should be central to application design. Equally important is the role of extension professionals in building farmers' digital confidence and ensuring that technology remains responsive to their needs. The goal should be simple: every livestock farmer should be able to find the right information, understand it, trust it and act on it. When mobile applications are designed with farmers rather than merely for them, digital technology can become a meaningful partner in improving livestock health, farm productivity and rural livelihoods.



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Speed Breeding in Vegetable Crops: Shortening the Road from Cross to Cultivar

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Developing a new vegetable variety typically takes 6-8 years. Speed breeding, which manipulates light, temperature and plant handling to push several generations into a single year, is helping breeders cut that timeline sharply. This article explains how it works, where it has been applied in vegetables, and where the limits still lie.

Why Vegetable Breeders are in a Hurry?

Consumers want tastier, more nutritious and more uniform produce. Growers want higher yields and resilience to heat, drought and salinity. Pathogens and pests evolve faster than breeding programs can respond: tomato leaf curl viruses, *Fusarium* wilts, downy mildews, bacterial wilt and root-knot nematodes keep breaking resistance genes. Climate change adds a moving target.

Conventional breeding runs at the pace of the plant's own life cycle. A tomato takes three to four months from seed to seed in the field. Add the many generations of selfing needed to make a hybrid parent homozygous (usually six to eight), and a single breeding cycle can occupy several years before multi-location testing even begins.

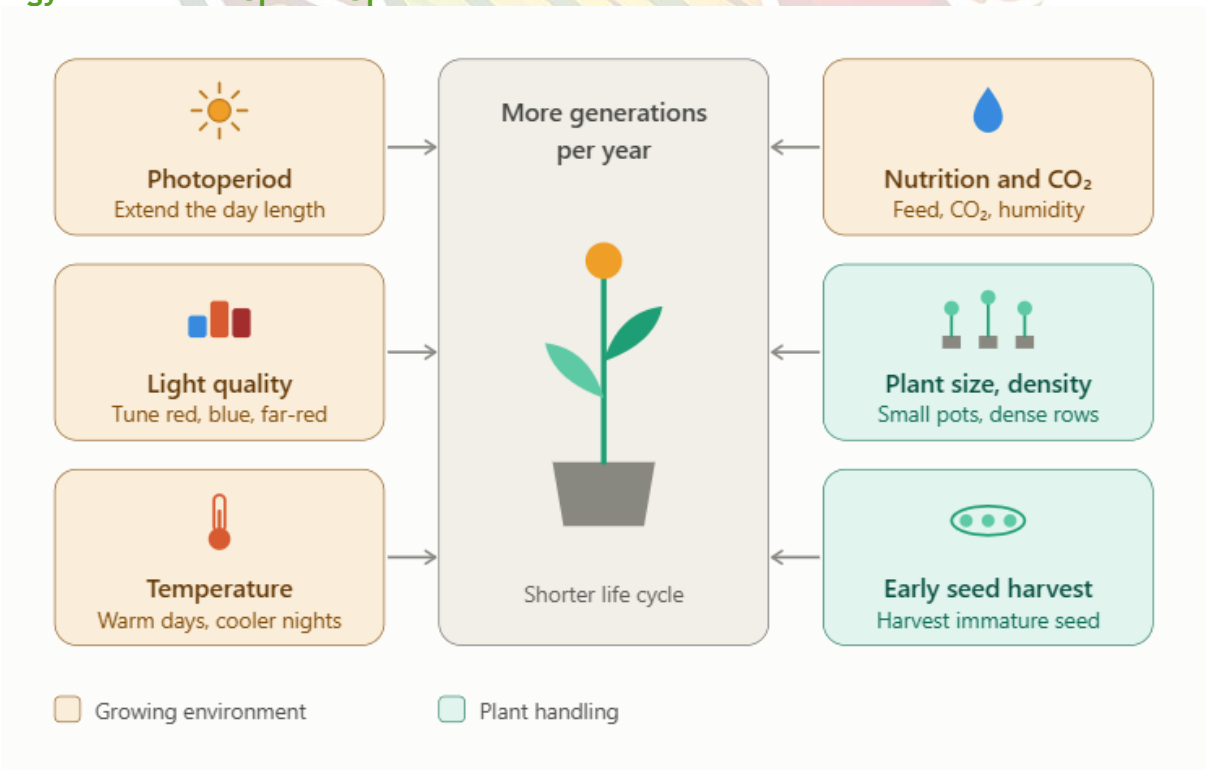
Speed breeding attacks the slowest step: **time per generation**.

What is Speed Breeding?

Speed breeding is a set of growing practices that accelerate flowering and seed set so that more generations can be completed per year than under field or standard greenhouse conditions. The idea has roots in NASA-supported experiments in the 1980s that used continuous light to grow wheat for space-based food systems. The modern term was popularised in 2018 when a team from the University of Queensland and collaborators showed that extended photoperiods (about 22 hours of light) combined with controlled temperature allowed up to six generations per year in spring wheat, barley, chickpea and pea, and about four in canola.

The approach is not a single recipe. It is a toolbox, adapted to each crop's biology.

The Biology Behind the Speed-Up



A Typical Speed-Breeding Workflow for Vegetables

1. **Cross** elite parents (for example, a high-yielding line and a donor of disease resistance).
2. **Grow F_1** under optimised extended-light conditions to confirm hybridity and set F_2 seed.
3. **Advance by single-seed descent (SSD):** from each F_2 plant, take one seed per generation, so that diversity is preserved while the lines rapidly become homozygous.
4. **Screen early.** Use DNA markers on seedlings to discard plants lacking target genes before spending greenhouse space.
5. **Phenotype selected lines** in field or protected cultivation for yield, quality and stress tolerance.
6. **Release or use as parents** for hybrid development.

The real power comes from combining step 3 with marker-assisted selection (MAS) and genomic selection, so that rapid generations are matched with accurate selection.

Crop-by-Crop Status

The level of development varies widely. Some crops have optimised protocols; others have only preliminary reports. Reported generation numbers depend heavily on genotype and facility, so treat the figures below as indicative.

Crop group	Examples	Biology that matters	Speed-breeding outlook
Solanaceous	Tomato, pepper, eggplant	Mostly day-neutral; long fruit maturation	Good. Extended light, warm conditions and early seed extraction allow roughly three to four generations per year in reported work. Pepper and eggplant are slower than tomato.
Legumes	Garden pea, French bean, cowpea, chickpea	Pea and chickpea respond to long days; beans vary	Very good for pea (up to about six generations per year reported). Beans and cowpea need photoperiod tuning, as some lines are short-day sensitive.
Brassicas	Cauliflower, cabbage, broccoli, mustard, turnip	Many are biennial and need cold (vernalisation); rapid-cycling forms exist	Moderate. Annual or rapid-cycling types work well; biennial cole crops need cold treatment, which limits gains.
Cucurbits	Cucumber, melons, pumpkin, gourds	Monoecious or gynoecious flowering; hand pollination needed	Moderate. Sex expression can be manipulated with growth regulators; space and trellising are constraints.
Leafy vegetables	Lettuce, spinach, amaranth, leafy greens	Bolting is triggered by long days and warmth	Good, because the trait breeders usually avoid (bolting) is what is exploited here.
Roots and bulbs	Carrot, radish, onion, beet	Carrot, onion and beet are typically biennial	Difficult for biennials. Radish is easier. Research on vernalisation shortcuts and in vitro methods is ongoing.
Okra and others	Okra, amaranth, Indian spinach	Often short-day or photoperiod sensitive	Emerging. Reports in grain and leafy amaranths show promise.

Tomato: The Model Vegetable

Tomato is the most obvious candidate. It is self-pollinating, has abundant genomic resources, and flowers regardless of day length. Researchers have used extended photoperiods with LED lighting, controlled temperatures and early seed extraction to bring the cycle down substantially compared with open-field production. Because breeders often need resistance to multiple pathogens stacked in a single line, a faster backcross and SSD schedule matters greatly.

Pea and Other Legumes

Pea was one of the headline crops in the original speed-breeding work. Immature seed harvest and long photoperiods make it a good fit. French bean and cowpea are less uniform in response and need cultivar-specific protocols.

Peppers and Eggplant

Peppers flower readily under warm, bright conditions, but fruit development is slow. Harvesting immature fruit and rescuing seed are the main time savers. Wild *Capsicum* relatives hold valuable resistance genes, and speed breeding can help introgress them faster.

Brassicas

Rapid-cycling *Brassica rapa* and related annual types are used widely in research. For cabbage, cauliflower and broccoli, the biennial habit means vernalisation (a cold period) is needed to induce flowering. Breeders therefore combine controlled cold treatment with extended light afterwards.

Cucurbits and Leafy Crops

Cucurbits can be handled at high plant density with trellising, though hand pollination and sex-expression management add labour. In lettuce and spinach, long days and warmth trigger bolting, which breeders can exploit to get seed fast.

Plugging Speed Breeding into the Modern Toolkit

Speed breeding is most effective not on its own but together with other technologies:

1. Marker-assisted selection and backcrossing: Combined with speed breeding, a backcross program that once took six to eight years can be compressed into a couple.

2. Genomic selection: Short generation intervals raise genetic gain per year, which is the central equation of quantitative breeding.

3. Doubled haploids: Where protocols exist (some Brassicas, pepper, eggplant), they offer instant homozygosity; speed breeding provides a low-tech alternative for crops where they do not.

4. Genome editing: Edited plants must be taken through several generations to segregate away the editing machinery and to fix the edit. Speed breeding shortens this.

5. Pre-breeding with wild relatives: Moving genes from wild species into elite backgrounds requires many backcrosses. Faster cycles make such work more practical.

6. High-throughput phenotyping: Imaging and sensors inside growth rooms can score traits on thousands of small plants.

Benefits

1. Faster variety development: Reaching homozygous lines in months rather than years.

2. Quicker response to new disease races and climate threats.

3. Year-round work: Programs are no longer limited to a single season.

4. Smaller footprint: More plants per square metre in controlled rooms.

5. Better protection of germplasm: Controlled conditions reduce risk of weather loss.

Challenges and Limitations

Capital and running costs. LED lighting, climate control and sealed rooms demand investment and reliable electricity. In hot regions, cooling costs can be substantial.

Genotype dependence. A protocol tuned for one cultivar may fail for another. Photoperiod-sensitive genotypes need individual calibration.

Biennials and long-juvenile crops. Carrot, onion, cabbage and similar crops have intrinsic biological barriers.

Trait expression. Traits scored in a growth room may differ from field performance because of stress, light and rooting conditions. Selection for yield and fruit quality must still be validated in real environments.

Inbreeding depression. Rapid selfing in cross-pollinated vegetables (for example, many cucurbits and brassicas) can bring vigour loss.

Pollination and labour. Hand pollination in small chambers is laborious for crops lacking self-compatibility.

Selection pressure on cycle time. Unintentionally selecting for fast flowering can erode other desirable traits unless managed.

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Key Takeaways

1. Speed breeding shortens generation time, the biggest bottleneck in vegetable breeding.
2. It works best in self-pollinating, annual, day-neutral or long-day crops such as tomato, pea and many leafy vegetables.
3. Biennial crops need special solutions for vernalisation.
4. Real gains come when it is paired with markers, genomic selection and gene editing.
5. Final selection must always be confirmed under real production conditions.

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Integration of Speed Breeding, Genomic Selection and Genome Editing for Accelerating Crop Improvement

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Abstract

The growing demand for food, climate change, emerging pests and diseases, and declining natural resources necessitate faster and more efficient crop-improvement strategies. Conventional breeding has significantly enhanced agricultural productivity, but long generation intervals, complex genetic architectures, and extensive phenotyping requirements often delay the development of improved varieties. Speed breeding, genomic selection, and genome editing offer complementary opportunities to overcome these limitations. Speed breeding accelerates plant development and generation advancement through controlled environmental conditions. Genomic selection predicts the genetic merit of individuals using genome-wide molecular markers, facilitating early selection for complex traits. Genome editing enables targeted modifications of specific DNA sequences to improve desirable characteristics. Integrating these technologies can accelerate the development of high-yielding, disease-resistant, climate-resilient, and nutritionally superior crops. This review discusses their principles, applications, integration strategies, limitations, and future prospects, emphasising the importance of reliable phenotyping, genetic validation, economic feasibility, and field evaluation.

Introduction

Crop improvement is essential for ensuring food security, nutritional security, and sustainable agricultural development. Increasing population pressure, climate variability, water scarcity, soil degradation, and emerging biotic stresses demand crop varieties that combine high productivity with improved resilience and resource-use efficiency. Conventional breeding techniques, including hybridisation, pedigree selection, backcrossing, and recurrent selection, have contributed substantially to agricultural progress. However, developing superior varieties often requires several generations of selection, extensive field trials, and considerable financial and human resources. Speed breeding, genomic selection, and genome editing offer complementary approaches to accelerate this process. Speed breeding reduces the time required to advance generations, genomic selection improves the efficiency of identifying superior genotypes, and genome editing enables targeted genetic modifications. Their integration can improve breeding efficiency while retaining the essential role of conventional breeding and field-based evaluation (Watson et al., 2018; Crossa et al., 2017).

Speed Breeding: Principles and Applications

Speed breeding involves manipulating environmental conditions to accelerate plant growth, flowering, and seed production. Extended photoperiods, optimised light intensity, suitable temperatures, and efficient nutrient and water management can shorten generation intervals in responsive crop species. The technique is particularly useful for wheat, barley, chickpea, pea, and other crops in which rapid generation advancement can facilitate the development of inbred lines. It can be combined with single-seed descent, molecular screening, and doubled-haploid techniques to accelerate genetic fixation and the development of uniform breeding materials. Speed breeding also facilitates the rapid advancement of segregating populations generated through hybridisation. Breeders can produce successive generations under controlled conditions and subsequently evaluate promising lines in the field. This approach is valuable when rapid genetic progress is required to address emerging production constraints. Nevertheless, the response to speed breeding varies among crops and genotypes. Photoperiod sensitivity, vernalisation requirements, reproductive biology, and seed maturation can limit acceleration. Excessive light or temperature may reduce pollen viability and seed quality. Furthermore, controlled-environment performance does not necessarily reflect field performance. Consequently, speed breeding should complement rather than replace field evaluation (Watson et al., 2018).

Genomic Selection for Efficient Crop Improvement

Genomic selection is a breeding strategy that predicts the genetic merit of individuals using genome-wide molecular markers. A training population is genotyped and phenotyped to develop a statistical prediction model, which is subsequently used to estimate the breeding values of candidate individuals. Unlike conventional marker-assisted selection, which often focuses on specific major-effect genes or quantitative trait loci, genomic selection captures information across numerous genomic regions. This makes it particularly useful for complex quantitative traits such as grain yield, drought tolerance, heat tolerance, disease resistance, and nutritional quality (Crossa et al., 2017). Genomic

selection can reduce the need for extensive phenotypic evaluation of every candidate during early breeding generations. It enables breeders to prioritise promising individuals, select suitable parents, and allocate resources to the most valuable populations. Statistical approaches such as genomic best linear unbiased prediction and Bayesian regression are commonly used, while machine-learning approaches may provide additional opportunities when appropriate datasets are available.

However, prediction accuracy depends on training-population size, phenotypic quality, marker information, genetic relationships, and environmental representation. Models developed in one population may perform poorly in genetically different populations. Therefore, genomic selection requires continuous updating of training datasets and validation across relevant environments.

Genome Editing and Precision Breeding

Genome editing enables targeted modifications of DNA sequences associated with desirable agronomic traits. CRISPR/Cas9 is one of the most widely used systems because it allows researchers to target specific genomic regions using guide RNA molecules. Other approaches, including base editing and prime editing, enable particular nucleotide changes and other precise modifications. Genome editing can support improvements in disease resistance, abiotic stress tolerance, plant architecture, flowering, grain quality, and nutritional composition. For example, editing a validated susceptibility gene may increase resistance to a particular pathogen, while modifying genes associated with grain composition may improve nutritional characteristics. Multiplex editing can target several genes simultaneously, potentially enabling the improvement of multiple traits. The effectiveness of genome editing depends on accurate target identification, transformation efficiency, plant regeneration, and validation of the resulting modifications. Unintended changes, genetic background effects, and undesirable consequences for other traits must also be assessed. Genome editing generates targeted genetic variation, but subsequent breeding and field evaluation remain necessary to establish agronomic superiority (Chen et al., 2019).

Integration of the Three Technologies

The integration of speed breeding, genomic selection, and genome editing creates a coordinated framework for accelerating crop improvement. Each technology addresses a different limitation, and their combined application can improve the efficiency of the entire breeding pipeline. The process begins by defining breeding objectives and identifying promising genetic backgrounds. Genomic selection can predict the performance of candidate lines using existing genomic and phenotypic information. Genome editing can then introduce validated modifications into selected genetic backgrounds, while speed breeding accelerates the development and advancement of edited progeny. Subsequently, genomic prediction and molecular characterisation can help identify promising plants, confirm the inheritance of desirable alleles, and evaluate their broader genetic potential. Field trials establish whether the improved materials express the intended characteristics under practical agricultural conditions. For example, a wheat breeding programme may identify high-yielding lines using genomic selection, edit a validated gene associated with disease susceptibility, and use speed breeding to accelerate the recovery of stable progeny. The resulting lines can then be evaluated for disease resistance, yield, grain quality, and environmental adaptation. This approach is particularly valuable because editing a single gene does not necessarily improve the overall performance of a variety. Genomic selection helps maintain a favourable genetic background, while speed breeding reduces the time required to develop and evaluate improved materials.

Applications in Major Crops

In wheat and barley, integrated breeding can accelerate the development of lines with improved yield, grain quality, disease resistance, and tolerance to heat and drought. Speed breeding shortens generation intervals, genomic selection assists in predicting complex traits, and genome editing enables targeted modification of validated genes. In rice, these technologies may support the development of varieties adapted to drought, salinity, flooding, and emerging disease pressures. Genomic selection can identify promising genetic combinations, while genome editing can modify selected genes associated with resistance, grain quality, or plant architecture. Accelerated generation advancement can facilitate the development of improved breeding lines. In maize, genomic selection can support the identification of superior inbred lines and the prediction of hybrid performance. Genome editing may address specific limitations involving disease susceptibility or other agronomic characteristics, while speed breeding can accelerate the development of parental lines.

In pulses such as chickpea, lentil, and pigeon pea, integration may facilitate improvements in maturity, productivity, drought tolerance, and disease resistance. In horticultural crops, including tomato, eggplant, and pepper, genome editing offers opportunities to improve fruit quality, shelf life, and disease resistance, while genomic selection can assist in selecting complex traits. Perennial fruit crops, including mango, litchi, and citrus, present additional challenges because of their long juvenile periods and complex reproductive biology. Genomic selection may help identify promising seedlings before maturity, while genome editing could target specific genes where efficient transformation and

regeneration systems are available. Speed breeding may have more limited applicability in such crops, but other accelerated-generation and early-flowering approaches may help shorten particular stages of development.

Improvement of Climate Resilience and Nutritional Quality

Climate-resilient agriculture is an important objective of integrated crop improvement. Drought, heat, salinity, and flooding can significantly reduce crop productivity, particularly in regions where irrigation and other agricultural resources are limited. Genomic selection can identify genotypes with favourable combinations of stress-response characteristics, while genome editing can investigate or modify validated genes involved in stress adaptation. Speed breeding can accelerate the development of populations for subsequent evaluation. However, stress tolerance is usually influenced by several genes and environmental factors, making multi-environment field testing essential. Nutritional improvement is another important application. Breeding programmes may target increased iron and zinc concentrations, improved protein quality, favourable oil composition, and enhanced accumulation of beneficial compounds. Genomic selection can assist in improving these complex characteristics, while genome editing may modify specific metabolic pathways. Nevertheless, nutritional changes must be evaluated alongside yield, crop quality, nutrient bioavailability, and food-processing characteristics. Improving a single biochemical trait does not automatically guarantee better nutritional outcomes.

Major Challenges and Limitations

Despite their potential, integrated breeding programmes face scientific, technical, economic, and regulatory challenges. The first challenge is the availability of reliable phenotypic data. Genomic selection depends on representative training populations and accurate measurements, while genome editing requires dependable methods for evaluating the intended trait. Inadequate phenotyping can undermine the effectiveness of all three technologies. The second challenge is the difficulty of transforming and regenerating some crop species. Certain elite genotypes are poorly responsive to tissue culture, limiting the recovery of edited plants. Speed breeding can accelerate subsequent generations but cannot eliminate these biological constraints.

The third challenge is the complexity of quantitative traits. Yield, drought tolerance, and overall adaptability are influenced by numerous genes and environmental interactions. Editing a single gene may produce only a limited improvement, and favourable effects in one environment may not be maintained in another. Infrastructure and cost are additional concerns. Controlled-environment facilities, sequencing platforms, molecular laboratories, computing systems, and trained personnel require investment. Shared facilities, institutional collaboration, and cost-effective genotyping strategies can help make these technologies more accessible. Regulatory compliance and public acceptance must also be considered. The regulatory treatment of genome-edited crops differs across jurisdictions and may depend on the type of modification and the applicable legal framework. Developers must verify relevant national requirements before conducting regulated trials or pursuing commercial release. Transparent communication, appropriate biosafety assessment, and equitable access to improved varieties are essential.

Future Prospects

Future research should focus on developing crop-specific protocols that combine rapid generation advancement, genomic prediction, and targeted editing. Improved transformation methods, more efficient regeneration systems, and reliable molecular validation will expand the practical application of genome editing. The integration of genomic information with high-throughput phenotyping, environmental data, transcriptomics, and other molecular datasets may improve the prediction of complex traits. Artificial intelligence and machine learning could further assist in identifying promising crosses, analysing plant images, and predicting performance across environments, provided that their predictions are independently validated. Public agricultural institutions should prioritise the development of genomic resources, representative training populations, controlled-environment facilities, and regional field-testing networks. For India, such investments could support the development of improved cereals, pulses, oilseeds, and horticultural crops adapted to diverse agroclimatic conditions. Research should also evaluate whether integrated breeding produces measurable improvements in genetic gain per year, development costs, field-trial efficiency, and the stability of desirable traits. Faster breeding is valuable only when it results in reliable, economically viable, and agriculturally useful varieties.

Conclusion

The integration of speed breeding, genomic selection, and genome editing offers a promising framework for accelerating crop improvement. Speed breeding reduces generation intervals, genomic selection improves the identification of superior genotypes, and genome editing enables targeted genetic modifications. Their coordinated application can facilitate the development of crops with improved productivity, stress tolerance, disease resistance, and nutritional quality. However, successful integration requires reliable phenotyping, accurate genomic prediction, efficient transformation and regeneration, molecular validation, and rigorous field evaluation. Economic feasibility, regulatory compliance, infrastructure, and equitable access must also be addressed. These technologies should complement conventional breeding rather than replace it. Their greatest contribution will arise from combining modern molecular

tools with established breeding principles, sound experimental design, and practical agricultural evaluation. Such integration can strengthen sustainable agriculture and contribute to long-term food and nutritional security.

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Water Scarcity: A Major Challenge to Food Security and Farming Systems

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Introduction

Water scarcity is an urgent global challenge. Billions of people lack reliable access to clean drinking water and sanitation, and approx. 25% of the world population is projected to live under "absolute water scarcity" in the coming future. This pressure on water resources threatens global food production and economic growth of the countries. Agriculture in particular uses about 70% of the available fresh water worldwide, therefore improving irrigation techniques in farming has become crucial. In this context, it is important to evaluate whether micro irrigation technique (such as drip and sprinkler systems) can help to reduce the gap between water supply and increasing demand. The primary question is whether these systems can substantially lessen water usage while maintaining or increasing crop yields. Answering this question is paramount, since one scrutinize projects a 40% shortage in overall water availability by 2030 without changes in practice.

Causes of Agricultural Water Scarcity

Various interdependent factors drive agricultural water scarcity. Shifting rainfall patterns and increased temperatures increase evaporation and lengthen droughts decreasing water availability during critical growing seasons. Rapidly increasing populations and urban areas demand huge amount water for day-to-day and industrial use, leaving less for growing crops. Rigorous groundwater extraction for irrigation has lowered water tables in various regions, resulting in wells run dry and increasing energy costs extract water. Industrial and agricultural pollution (e.g. agrochemicals) have resulted in degradation of water quality moreover limiting usable supplies. In short, growing demand and dropping supply create constant shortages unless water-use is improved.

Micro-Irrigation Systems and their Types

Micro-irrigation is made of two words micro and irrigation, micro margin small or less and irrigation is the water supply to the plant. Altogether it is a method og irrigating field by directly supplying wanted to the root zone of the plants. The main types are:

1. Drip Irrigation (Surface or Subsurface): In this method of micro irrigation water is directly delivered through small pipes with small drippers placed at or below the soil surface. It is a system that provides a slow and continuous water supply to the root zone of plants or rows. In surface drip tape is placed over the soil surface whereas *subsurface drip irrigation (SDI)* uses buried the pipelines just below the soil. SDI helps in reducing evaporation from the oil surface and runoff. It is the most used irrigation method in protected structure. Drip systems are being used for vegetables, fruit trees, orchards, plantation crops (e.g. vineyards).

2. Sprinkler Irrigation: Though a pressurized sprayer water is sprayed all over the area using overhead sprinklers. It is similar to rainfall and distributes water more broadly in the field. It can cover large or uneven field areas. Sprinklers are being used for cereals, pastures, vegetable seed beds and turf. This method saves about 20–40% water compared to flood irrigation, but loses small amount of water due to wind drift and evaporation.

3. Micro-Sprinkler Irrigation: It is an advanced form of sprinkler systems. They work at very low pressure and distributes fine jets or sprays just above ground. They are generally used where precise, gentle watering is needed like orchards, vineyards, nursery crops and horticulture. Micro-sprinklers cover comparatively small areas while using similar amount of water as sprinklers (roughly 20–50% saving versus flood). They require more care and maintenance than the regular sprinklers to prevent it from clogging.

4. Subsurface Drip Irrigation (SDI): As discussed, SDI places drip lines below the soil surface so that water directly goes to rootzone. This reduces evaporation losses and can achieve the highest water-use efficiency. It is considered ideal for growing row crops and high-value intensive crops at places where water is scarce.

Water-Use Efficiency and Mechanisms

Micro-irrigation systems such as drip and sprinkler systems improve water-use efficiency (WUE) by applying water in space and time that best matches crop water needs. The water distribution network of a well-designed drip irrigation system "loses practically no water to surface runoff, deep percolation, or evapotranspiration" because only the root zone is wetted and the rest of the soil surface is kept dry to control weeds. Sprinkler systems use less water than open field irrigation, with water savings of about 20–40% over furrow irrigation, while micro-irrigation systems can use 20–50%

less water than conventional sprinklers. The use of micro-irrigation in landscapes can save 20–50% of the water normally used for irrigation, according to the US EPA. Because farmers who use drip or other subsurface irrigation systems have to pump much less water than those who use surface irrigation systems, there are also significant savings in terms of energy to pump water and in costs for irrigation. Water is held in the root zone at optimal levels thus avoiding situations that cause stress to the plant due to over- or under-irrigation. Systems are available that can be controlled using a variety of techniques including moisture sensors and timers. These methods target water use and seek to minimize water losses, thus greatly improving the water-use efficiency of micro-irrigation systems.

Agronomic, Economic and Environmental Benefits

Adopting micro-irrigation yields multiple benefits:

1. Agronomic: Agronomic benefits from precise watering include increased plant growth, higher production and better quality. Research studies on various crops such as onions, tomatoes, lettuce, melons and cotton showed positive response to the use of drip irrigation system. A study from India reported that drip irrigation enabled farmers to change their cropping pattern towards high-value horticultural crops such as vegetables and flowers. This was possible due to assured water supply to these water-sensitive crops. Agronomic benefits also arise from stable soil moisture which promotes root growth, flowering and fruit formation. Watering crops in a controlled manner also helps prevent water stress in crops and thus higher production during water scarcity periods.

2. Economic: Economically higher. Better-quality produce boost farm incomes. With reliable water farmers can harvest more per hectare and might grow higher-value crops. In the study mentioned, drip adoption raised net plot profits by about 14 percent. Efficient irrigation also cuts costs: pumping water means lower fuel and electricity bills and automation saves labor because farmers do not need to water manually or move heavy pipes. Drip systems last year's so while the initial cost is high the drip system can pay off over time. Precision fertigation further cuts fertilizer expenses. I notice drip increases profits and I see that micro-irrigation can improve profitability, per unit of land and labor making farms more productive and resilient.

3. Food Security & Climate Resilience: By increasing the amount of crops produced per unit of water micro-irrigation helps keep food production steady when there is not enough water. Experts say that changing how agriculture works, including the way it is watered is very important because climate change might reduce crop yields by around 30% by the year 2050. Having an irrigation system during dry time's means farmers can still grow food. For example using a drip system allows farmers to have control in dry years which makes it less likely that all their crops will fail.

4. Environmental: Compared to flood irrigation, micro-irrigation greatly lowers stress. With runoff and deep percolation there is less soil erosion and lower nutrient leaching. This helps protect water bodies from pollution. Keeping the soil dry, between rows can also improve weed control. This means less herbicide is needed in climates. Lower irrigation intensity reduces the risk of waterlogging and salinity. Every drop of water saved helps reduce the strain on rivers and aquifers. The EPA says that switching to micro-irrigation can save tens of thousands of gallons of water each year for one landscape. By conserving both water and energy these methods support sustainable farming.

Barriers to Adoption

Despite benefits many farmers have yet to adopt micro-irrigation. The main barriers include:

1. High Initial Cost: Setting up drip or micro-sprinkler systems means buying pipes, pumps, filters and emitters. In the US this can cost about US$500 to US$1,200 per acre (around $1,300 to $3,000 per hectare). The costs are similar in other places. Even if some parts are subsidized smallholders might not have the money or access to credit to make the payment.

2. Technical. Maintenance: These systems need design, constant care and some technical know-how. Emitters and filters can get clogged with dirt or bacteria if not managed well. Farmers must learn how to create irrigation schedules flush the pipes and fix blockages. If they use fertilizer wrong or ignore the filters the benefits can disappear. One extension note says that drip lines can leak or get blocked and farmers need a plan for cleaning filters and getting rid of the tape. Without training or help many will not try the system.

3. Social and Psychological Factors: Research shows that with help farmers may not want to switch from what they know. In India one survey found that about 16% of farmers used subsidized drip systems while about 24% dug new borewells. Farmers often think that borewells offer a way to deal with risks because they can get more water. They see drip not as helpful in dry years. Things like landholdings being cautious and sticking to old habits can slow the use of new methods. The same study said that if farmers believe in a technology they are more likely to use it. This shows that knowing about the technology is very important.

4. Infrastructure and Scale: Many small farms have land that is broken up or not neat which makes installing the system. In some areas there are no suppliers, spare parts or people who can fix the systems. Faraway places might not have pumps or power for the pressurized systems. Without the things like roads and services farmers might keep using old ways, like flooding or wells.

Successful adoption works best when financial help is combined with sharing knowledge. As one study shows, giving money along, with building skills teaching people and running information campaigns is important. For example projects that get money for drip irrigation now often have training sessions and places where farmers can see the results themselves. This way farmers can see the benefits directly.

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When AI Can Do the Research, What Is Left for Life Scientists in Agriculture?

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Abstract
Artificial intelligence (AI) is transforming agricultural research through genomic analysis, biochemical profiling, disease diagnosis, pest monitoring and crop phenotyping. As AI takes on more analytical work, what will distinguish life scientists' contributions? This perspective examines AI's implications across agricultural life sciences. It argues that AI can accelerate biological discovery but cannot, through prediction alone, establish causality, experimental validity or agricultural relevance. The future of agricultural science depends on integrating computational capabilities with biological expertise to generate reliable and practically useful knowledge.

Introduction: A Changing Role for Life Scientists
AI-enabled tools increasingly assist with literature synthesis, statistical analysis, genomic processing, image classification and manuscript preparation. Integrating them with genomics, biotechnology, multi-omics, and high-throughput phenotyping creates new opportunities for crop improvement.

However, if AI can analyse data and generate plausible explanations, what remains the distinctive contribution of a life scientist? Agricultural systems involve interactions among genes, metabolic pathways, physiological processes, pathogens, insect pests, soil microorganisms and environmental conditions. Identifying patterns is not equivalent to understanding their underlying mechanisms. Life scientists must determine which questions matter, which explanations are biologically credible and which predictions withstand experimental testing.

Beyond Data Analysis: The Changing Role of Life Sciences
AI can integrate complex biological datasets, identify patterns and prioritise hypotheses across biochemistry, genetics, plant physiology, biotechnology, pathology, entomology and soil microbiology. For example, in biochemical research, AI-assisted analysis could identify relationships between genomic variants, biosynthetic genes, and the final metabolic product. However, a correlation between gene copy number and final product does not establish causation; gene expression, enzyme activity, substrate availability, pathway regulation and environmental conditions may also contribute. Similarly, AI can identify candidate genetic variants associated with drought tolerance or disease resistance, but linkage, population structure and environmental confounding may explain observed associations. Functional studies and independent validation remain essential.

In plant physiology and biotechnology, AI can analyse imaging, weather data, spectral measurements and physiological observations to predict crop performance, identify stress responses and prioritise targets for genome editing or molecular engineering. Yet, predicting reduced yield under drought does not explain the underlying physiological mechanisms, and identifying a promising editing target does not guarantee successful transformation, stable expression or improved field performance. Experimental validation remains necessary.

Comparable limitations occur in plant pathology and entomology. AI-based image analysis can recognise disease symptoms, quantify their severity, identify insects and monitor pest abundance. However, different pathogens, nutrient deficiencies, and abiotic stresses can produce similar symptoms, and insect detection alone does not establish economic importance. Reliable decisions require pathogen identification, ecological knowledge, pest thresholds and integration with practical disease and pest-management strategies. Likewise, AI can link soil microbial profiles to plant growth or disease suppression, but these relationships do not prove that specific microorganisms cause the observed benefits. Isolation, inoculation experiments and field validation may be required.

Across these disciplines, the fundamental distinction remains: predicting a biological outcome is not the same as explaining its mechanism or demonstrating its practical significance. AI may identify where to look, but life scientists must establish what is happening and whether the findings are reproducible.

Why is Computational Success Not Enough?
AI models depend on their training data. Incomplete, biased or unrepresentative datasets can limit their reliability in new environments. Disease-detection models trained on controlled images may perform differently in the field; genomic predictions may not transfer between genetically distinct populations; and biochemical relationships may vary with season, plant age, or nutrient availability. These limitations define the conditions under which predictions can be trusted. Life scientists must ensure appropriate experimental design, controls, measurement quality, statistical

assumptions and independent validation. AI-generated explanations also require scrutiny: a reasonable description is not necessarily evidence of the underlying mechanism.

From Publication Production to Meaningful Scientific Contribution

As AI simplifies routine analysis and manuscript preparation, producing a technically competent paper may become less distinctive. This raises questions about evaluation systems that rely heavily on publication counts. Assess scientific contributions by the reliability of new knowledge, methodological rigour, explanatory power, and relevance to agricultural problems. A statistical association may offer limited advancement if it leaves an important uncertainty unresolved, whereas a validated experiment demonstrating how a genetic variant alters a metabolic pathway and improves a crop trait may provide stronger evidence. Descriptive and computational studies remain valuable for discovering patterns and generating hypotheses; their conclusions must simply remain proportionate to their evidence. Scientific training must also evolve. Students should learn to use AI while recognising analytical errors, understanding methodological assumptions, and independently defending their conclusions.

Opportunities for Agricultural Research

AI offers researchers, including those with limited analytical infrastructure, new ways to explore complex datasets and prioritise experiments. Its greatest potential may lie in interdisciplinary integration. Combining genomic variation with gene expression, enzyme activity, metabolite profiles, physiological measurements and field phenotypes can provide a more comprehensive understanding of crop performance. Integrating AI with multi-omics and biotechnology is already an important direction in crop improvement [1]. Nevertheless, sophisticated models and larger datasets do not automatically improve science. Reliable measurements, biological expertise, computational resources and experimental validation remain essential.

Conclusion: The Future Belongs to Scientifically Critical Researchers

AI challenges agricultural life scientists to reconsider which contributions matter most as routine analytical work becomes easier. Across the life sciences, they must distinguish patterns from mechanisms, associations from causation, and predictions from validated knowledge. Future agricultural scientists must combine biological depth, computational competence, experimental rigour and an understanding of agricultural realities. Rather than competing with AI on speed, they must use it to investigate important questions, test competing explanations, and generate knowledge that improves agriculture. When AI can analyse biological data, the life scientist's essential contribution is to establish what those data mean, why the observed patterns occur and whether the resulting knowledge can reliably improve agriculture.

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Knowledge and Practices of Rural Caregivers Regarding Childhood Illness in India

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Abstract

Childhood is a critical period of growth and development, during which children are vulnerable to various illnesses due to their developing immune systems. In rural India, caregivers play an important role in identifying early symptoms, providing home-based care and deciding when to seek medical assistance. Common childhood illnesses include diarrhoea, respiratory infections, pneumonia, malnutrition, skin infections and intestinal worm infestations. Caregivers' knowledge of disease symptoms, causes, prevention and appropriate treatment influences children's health outcomes. But, lack of health awareness, financial constraints, cultural beliefs and lack of access to health care facilities may affect timely treatment and appropriate caregiving practices. The article discusses common childhood diseases, knowledge and practices of rural caregivers, significance of home-based care and government's efforts to enhance health and well-being of children.

Keywords: Childhood illness, rural caregivers, maternal knowledge, home-based care, healthcare-seeking behaviour, child health.

Introduction: A Changing Role for Life Scientists

Childhood is a critical stage of physical, cognitive and emotional development, during which children are particularly vulnerable to infections, nutritional deficiencies and other health problems. Childhood illnesses remain a major public health problem in India, despite improvements in healthcare services, especially in rural and underserved communities where access to timely healthcare, sanitation and nutrition services may be limited.

India's under-five mortality rate has fallen from 48 deaths per 1,000 live births in 2015 to 28 in 2023, according to the United Nations Inter-agency Group for Child Mortality Estimation (UN IGME) as reported by UNICEF (2025). Neonatal mortality dropped from 28 to 17 deaths per 1,000 live births in the same period. These improvements are a reflection of advances in maternal and child healthcare, immunization and community-based health interventions.

The latest National Family Health Survey-6 (NFHS-6) conducted during 2023-24 has brought in encouraging improvements in child health and nutrition. "Stunting in children below five years fell from 35.5 per cent in NFHS-5 (2019–21) to 29.3 per cent in NFHS-6, while severe wasting decreased from 7.7 per cent to 5.2 per cent," the Ministry of Health and Family Welfare (2026) said. The proportion of children with symptoms of acute respiratory infection also reduced from 2.8 to 1.9 per cent, while severe diarrhea was reported in 0.5 per cent. In addition, rotavirus vaccination coverage increased from 36.4 to 85.4 percent, reflecting gains in preventive healthcare services.

However, even with these improvements, it is important to ensure that child care practices at the household level are correct. In rural areas, it is the mothers and grandmothers, the caregivers at the household level, who are most crucial in the early detection of signs, early care, maintaining a clean environment, good nutrition and the decision to seek medical assistance. Their knowledge of common childhood illnesses and appropriate caregiving practices is directly related to children's health and recovery.

However, financial constraints, low health awareness, traditional beliefs, transportation difficulties and poor access to healthcare facilities may delay proper treatment. Pathak et al. (2025) in their study on childhood pneumonia in rural Palwal district, Haryana brought to light the influence of symptom recognition, financial difficulties, family decision making and healthcare accessibility on treatment seeking behavior.

Thus, improving the knowledge and practices of rural caregivers is a key step in preventing childhood illnesses, recognizing early warning signs, encouraging proper home-based care and ensuring timely access to professional health care services.

Common Diseases of Childhood in India

The common childhood diseases are:

1. Diarrhoea: Diarrhea is usually caused by contaminated food or water. Young children often have loose or watery stools and this can lead to dehydration. The prevention of complications consists of adequate fluid intake, timely medical attention and oral rehydration solution (ORS).

2. Infections of the respiratory tract: Cough and cold are common illness in children specially during change of season. Most of these infections are viral and are spread via respiratory droplets and contact with contaminated hands or surfaces. Symptoms can be controlled with enough rest, fluids and medical care.

3. Lung infection: Pneumonia is a serious infection of the lungs. Symptoms include coughing, fever, rapid breathing and difficulty breathing. If they are recognized early and treated promptly by qualified health care professionals, serious complications can be avoided.

4. Poor Diet: Malnutrition and nutrient deficiencies are the result of a lack of dietary diversity and repeated bouts of illness. It can affect the kids growth, immunity and development progress. Nutritional deficiencies can be prevented by eating balanced meals, giving adequate complementary feeding and regular growth monitoring.

5. Infections of the Skin: But usually scabies, ringworm and other infections are linked to poor hygiene and overcrowding. Improved personal hygiene, clean clothes and a healthy environment leads to lower incidence of these.

6. Intestinal Worm Infestation: Poor sanitation, contaminated food and water and not washing hands properly can cause infections with intestinal worms. They can lead to abdominal discomfort, poor appetite, anemia, and poor nutritional status. Good hygiene is important and deworming should be done preventively.

Rural Caregivers: Knowledge and Practice

Rural caregivers are responsible for the daily care of children including feeding, hygiene, supervision and primary management of illness. Their knowledge includes causes, symptoms, transmission, prevention and treatment of common childhood diseases.

It is especially important to watch for early warning signs such as a fever that continues, dehydration, trouble breathing, poor feeding and unusual lethargy. Caregivers need to be able to differentiate between an illness that can be treated at home with appropriate care and one that requires immediate medical attention.

But knowledge does not always result in appropriate practices. Barriers to seeking treatment may be financial limitations, transportation difficulties, household responsibilities, traditional beliefs and lack of healthcare facilities. Some caregivers first consult home remedies or informal health care providers before seeking help from qualified medical practitioners.

In a study on childhood pneumonia in rural Palwal district, Haryana, Pathak *et al*. (2025) showed how symptom recognition, financial difficulties, family decision-making and accessibility of healthcare influenced caregivers' treatment-seeking behavior.

Caregiver Knowledge and Practices in Rural

Rural caregivers are primarily responsible for the daily care of children, including feeding, hygiene, supervision and first response to illness. Their knowledge includes causes, symptoms, transmission, prevention and treatment of common childhood diseases.

It is especially important to watch for early warning signs such as a fever that continues, dehydration, trouble breathing, poor feeding and unusual lethargy. Caregivers need to be able to differentiate between an illness that can be treated at home with appropriate care and one that requires immediate medical attention.

But knowledge does not always result in appropriate practices. Financial constraints, transportation difficulties, household responsibilities, traditional beliefs and limited availability of healthcare facilities may be barriers to treatment. Some caregivers first seek home remedies or informal health care providers before turning to qualified medical practitioners.

Pathak et al. (2025) in their study of childhood pneumonia in rural Palwal district of Haryana, illustrated how caregivers' treatment seeking behavior was influenced by recognition of symptoms, financial constraints, family decision making and access to healthcare.

Significance of Home Care for Children

Home-based care plays a critical role in the prevention and management of common childhood illnesses. Caregivers can contribute to children's health by the following practices:

1. Hygienic food preparation and safe drinking water.
2. Regularly washing hands and maintaining personal hygiene.
3. Encouraging breastfeeding and complementary feeding for infants and children according to their age.
4. Oral rehydration therapy during diarrheal episodes.

5. Maintain the area clean and properly sanitized.

6. Ensuring immunization is timely and growth is regularly monitored.

7. Recognizing signs of danger and getting timely medical help.

8. "Care at home should complement, not replace, professional medical care, particularly when children have serious symptoms.

The Role of Government Programs in Strengthening Child Health

The Government of India has initiated several programs to improve child health, nutrition and caring practices.

The Integrated Management of Neonatal and Childhood Illness (IMNCI) program is a set of guidelines on how to recognize and treat common childhood illnesses, especially among young children. It emphasizes the need for early detection, adequate management, referral and prophylaxis.

Accredited Social Health Activists (ASHAs) provide scheduled home visits to strengthen family-based childcare under the Home-Based Care for Young Child (HBYC) initiative. It promotes proper infant and young child feeding, immunization, growth monitoring, hygiene, age appropriate stimulation and prevention of common childhood illnesses.

The HBYC initiative also promotes coordination between ASHAs, Anganwadi workers and Auxiliary Nurse Midwives (ANMs) to provide continuous guidance and support to caregivers.

Kumar et al. (2020) emphasized the significance of these initiatives by discussing the implementation of HBYC in Bihar, particularly its role in improving infant and young child feeding practices through frontline worker support and counseling.

Ways to Enhance Caregiving Practices

Improving caregivers' knowledge and practices necessitates a concerted effort on the part of families, health workers and community institutions.

1. Health Education: Organize regular awareness programs on common childhood diseases, their symptoms, prevention and appropriate home-based care.

2. Empowerment of Frontline Workers: To upgrade the knowledge, counseling skills and ability to identify childhood illness of ASHAs and Anganwadi workers by regular training.

3. Better nutrition and hygiene: Promote balanced diets, safe drinking water, sanitation, handwashing and appropriate feeding practices.

4. Early identification and referral: Train caregivers on warning signs and the importance of promptly seeking help from qualified health professionals.

5. Community Participation: Encourage sharing of information and positive caregiving practices in mothers' groups, self-help groups and village-level health meetings.

Conclusion

The rural caregiver plays a vital role in safeguarding children from common diseases and in supporting their healthy growth and development. Adequate knowledge, appropriate home-based practices, timely recognition of warning signs and access to healthcare services are crucial to reduce complications related to childhood illness.

Community based education, frontline health workers and government programs can help to raise caregiver awareness, leading to better childcare practices and promote better health outcomes. It is therefore an important step in building healthier childhoods and stronger communities to invest in caregiver knowledge.

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Pointed Gourd (*Trichosanthes dioica*): The Green Gold of Eastern India

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Abstract

Pointed gourd (*Trichosanthes dioica* Roxb.), commonly known as parwal, is an important indigenous cucurbitaceous vegetable crop widely cultivated in eastern and northern India. It is highly valued for its nutritional richness, therapeutic potential and economic importance. Its fruits are rich in vitamins, particularly vitamins A and C, dietary fibre, carbohydrates, proteins and essential minerals such as calcium, phosphorus, potassium, iron and magnesium. The crop also contains important bioactive compounds, including phenolics, flavonoids, tannins and antioxidants, contributing to its functional food value. Its leaves are also nutritionally valuable, containing appreciable amounts of protein, fibre and minerals. Traditionally, different plant parts have been used in Ayurveda and Unani systems of medicine for their potential digestive, hepatoprotective, anti-inflammatory and antioxidant properties. Due to its low-fat content, easy digestibility and health-promoting constituents, pointed gourd has considerable potential as a functional vegetable for nutritional and health security. The crop is perennial and primarily propagated through vine cuttings and root suckers. Commercial cultivation involves improved varieties, balanced nutrient management, efficient irrigation, proper vine training and suitable planting systems, particularly the bower system. Harvesting is generally initiated 75–90 days after planting, with fruits picked at the tender stage at regular intervals. Under improved cultivation practices, yield may reach 25–30 tonnes per hectare. Thus, scientific cultivation, nutritional awareness and value addition can enhance the commercial potential of pointed gourd, improve farmers' income and contribute to sustainable horticultural development.

Keywords: *Trichosanthes dioica,* Cucurbitaceae, Pointed gourd, Vine cutting, Dioecious.

Introduction

Pointed gourd (*Trichosanthes dioica* Roxb.), commonly known as parwal or potol, is an important indigenous vegetable crop belonging to the family Cucurbitaceae. It is native to the Assam-Bengal region of India with a chromosome number of 2n = 2x = 22. The crop is widely cultivated in India, Bangladesh and Nepal, particularly in the eastern and northern states of India such as West Bengal, Bihar, Uttar Pradesh and Odisha. Pointed gourd is highly valued for its nutritional richness, medicinal importance and economic profitability. The crop exhibits considerable variability in fruit shape, size, colour, biochemical composition and yield potential among different genotypes. Due to its adaptability, regular bearing habit and high market demand, pointed gourd has emerged as an important vegetable crop in the farming systems of eastern India.

Pointed gourd is cultivated in nearly 20,000 hectares in India with an annual production of about 3.1 lakh tonnes. It is a perennial, dioecious climbing vine with tuberous roots and vigorous vegetative growth. The plant produces heart-shaped green leaves, simple tendrils and white flowers, while its fruits vary in shape, size and striping pattern among different genotypes. Botanically, the fruit is a pepo, in which the fleshy pericarp and mesocarp are edible. Due to poor seed germination and delayed flowering, the crop is mainly propagated through stem cuttings and is highly cross-pollinated in nature.

Nutritional and Therapeutic Importance

Pointed gourd (*Trichosanthes dioica*) is regarded as one of the most nutritious cucurbitaceous vegetables due to its rich composition of vitamins, minerals and dietary fibre. The edible fruits are a good source of carbohydrates, proteins, vitamin A (153 mg/100g), vitamin C (23 mg/100g) and essential minerals such as calcium, phosphorus, potassium, iron and magnesium and due to which, it is popularly called as 'king of gourds' (Sinha et al., 2026). Besides the fruits, the leaves are also nutritionally rich and contain comparatively higher amounts of protein, fibre and minerals. Owing to its low fat content and easy digestibility, pointed gourd is often recommended in balanced diets and for patients recovering from illness or surgery. Additionally, pointed gourd contains high levels of total soluble solids (TSS), carbohydrates, proteins, phenolics, flavonoids and ascorbic acid, which contribute to its functional and nutritional properties (Sinha et al, 2025). Apart from its nutritional value, pointed gourd has been widely recognized for its medicinal and therapeutic properties since ancient times. The crop holds an important place in traditional systems of medicine such as Ayurveda and Unani. Ancient Ayurvedic literature, including *Charaka Samhita*, mentions the use of pointed gourd fruits and leaves

in the treatment of jaundice, digestive disorders and skin ailments. In Ayurveda, different plant parts are believed to help balance body functions associated with *kapha* and *pitta dosha*.

Different parts of the plant, including fruits, leaves, roots and stems, possess several pharmacological properties. The fruits are known for their antipyretic, anti-inflammatory, antiulcer and cardioprotective effects, while leaf extracts are traditionally used against fever, constipation, liver disorders and oedema. Root extracts have also shown antioxidant and anthelmintic properties. These therapeutic effects are mainly attributed to the presence of important bioactive compounds such as flavonoids, tannins, saponins, alkaloids, triterpenes and peptides like trichosanthin. Recent studies have further highlighted the antioxidant, antidiabetic, hepatoprotective, antihyperlipidemic and immunomodulatory potential of pointed gourd, making it an important vegetable crop for both nutritional and health security.

Cultivation and Economic Importance

Pointed gourd (*Trichosanthes dioica* Roxb.) is a warm and humid season perennial vegetable crop that grows well under tropical and subtropical climatic conditions including eastern India regions such as Jharkhand, West Bengal, Bihar, etc. The crop performs best at temperatures ranging between 25-35°C and thrives in fertile, well-drained sandy loam soils rich in organic matter with a pH of 6.0-7.5. Proper land preparation is essential for successful cultivation, and the field should be thoroughly ploughed and incorporated with well-decomposed farmyard manure before planting. Since pointed gourd exhibits poor seed germination and delayed flowering, it is mainly propagated vegetatively through vine cuttings and root suckers. Healthy vine cuttings of about 25-30 cm length (8-10 nodes), 25000-30000 cutting/ha are commonly used for planting during February–March or June–July depending upon the region. Major cultivars grown in eastern and northern India are listed in Table 1. Different cultivation systems are practiced in pointed gourd depending on local resources and farming practices. In the traditional *Lunda* method, vines are allowed to spread on the ground, requiring low initial investment but often resulting in poor fruit quality and higher disease incidence. The *Lacha* method provides partial support to vines using bamboo sticks or low structures, improving aeration and fruit quality. However, the most efficient and commercially adopted method is the bower or pandal system, in which vines are trained on overhead trellis structures made of bamboo or wire. This system ensures better sunlight interception, reduced disease incidence, improved fruit shape and higher yield. In some areas, vertical trellis systems are also used for efficient vine management and ease of harvesting.

Table 1: Major cultivated varieties of Pointed gourd in eastern and northern India:

Variety	Important Characteristics	Releasing Institute
Swarna Rekha	Dark green fruit with light green striped with thin skin and seeds	ICAR-RCER, Ranchi
Swarna Alaukik	Light green fruit	ICAR-RCER, Ranchi
Swarna Suruchi	light green fruit without stripes; suited to table use and sweet preparations. Soft seeds and soft flesh	ICAR-RCER, Ranchi
Rajendra Parwal-1	Large green striped fruits	RPCAU, Pusa
Rajendra Parwal-2	Big dark green fruits with whitish stripes	RPCAU, Pusa
Arka Neelanchal Kirti	Spindle-shaped dark green fruits with cream-coloured fragmented stripes	IIHR, Bengaluru
Kashi Suphal	Fleshy light green fruits with mild stripes and soft seeds	ICAR-IIVR, Varanasi
Kashi Amulya	Light green fruits with sparse white stripes, soft seeded and suitable for confectionery use	ICAR-IIVR, Varanasi
Kashi Alankar	Small light green fruits without stripes	ICAR-IIVR, Varanasi
Faizabad Parwal-1	Round green fruits	NDUAT, Faizabad
Faizabad Parwal-3	Spindle-shaped fruits with green stripes	NDUAT, Faizabad
Faizabad Parwal-4	Light green spindle-shaped fruits tapering at both ends	NDUAT, Faizabad

Pointed gourd is a heavy feeder crop and responds well to balanced fertilization and regular irrigation. Application of organic manure along with recommended doses of nitrogen, phosphorus and potassium enhances vine growth and fruit production. Irrigation at regular intervals is particularly important during flowering and fruit development stages, while waterlogging should be avoided. As the crop is dioecious in nature, approximately 10% male plants are maintained in the field for effective pollination. Training and periodic pruning of vines improve ventilation, light penetration and flowering. Integrated management practices involving timely weed control, use of healthy planting material and protection against major pests and diseases such as fruit fly, red pumpkin beetle, downy mildew and mosaic virus are essential for obtaining higher productivity. Harvesting generally starts 75-90 days after planting or 12-15 days after fruit set when the fruits are tender and green. Fruits are harvested at regular intervals of 3-4 days to maintain quality and market preference. Depending on the cultivar and cultivation method, the crop can produce yields ranging from 15-25 tonnes per hectare, with significantly higher yields under bower systems. Proper post-harvest handling, grading and packaging further improve shelf life and market value of the produce.

Pointed gourd (*Trichosanthes dioica* Roxb.) is an economically important vegetable crop widely cultivated in eastern and northern India due to its high market demand, nutritional value and profitability. The crop provides regular income to farmers because of its perennial growth habit and long harvesting duration (March-September). Unlike many seasonal vegetables, pointed gourd produces fruits continuously over several months, ensuring stable returns throughout the harvesting period. Pointed gourd cultivation generates employment opportunities in activities such as planting, training, harvesting, grading and marketing. Due to increasing consumer awareness regarding its nutritional and medicinal benefits, the demand for pointed gourd has increased steadily in recent years. Besides fresh consumption, pointed gourd also possesses potential for value addition and processing in the form of pickles, sweets, stuffed products and dehydrated slices, which can further enhance farmers' income. The adaptability, high productivity and premium market price of the crop make it a profitable vegetable crop for small and marginal farmers especially in eastern India. Owing to these advantages, pointed gourd has emerged as an important commercial cucurbit crop in India.

Commercial Cultivation of Pointed Gourd (Parwal)

It is a high-value vegetable crop with a long harvesting period and good market demand. Vegetative propagation through vine cuttings and root suckers is preferred over seed propagation because it ensures true-to-type plants and early bearing.

Climate and Soil Requirements

1. Climate: Warm and humid climate.
2. Optimum temperature: Approximately 25–35°C.
3. Soil: Well-drained sandy loam to loam soil, rich in organic matter.
4. Soil pH: 5.5–7.0.
5. Avoid waterlogging because it causes root and vine deterioration.

Best Planting Material and Propagation

Pointed gourd is dioecious, meaning male and female flowers are borne on separate plants.

Propagation method	Details
Root suckers	Healthy, disease-free suckers with roots
Vine cuttings	Most commonly used commercial method
Seed	Not preferred for commercial cultivation due to variability and delayed bearing

Recommended vine cutting selection:

1. Select healthy, mature, disease-free vines.
2. Use approximately 30–45 cm long cuttings.
3. Each cutting should have 4–6 healthy nodes.
4. Plant cuttings in moist, well-prepared soil.
6. Rooted cuttings are preferable for better establishment.

Maintain approximately 10–15% male plants in the field for adequate pollination. A female-to-male ratio of around 9:1 is commonly followed.

Planting Season and Method

For eastern India, particularly Bihar and Jharkhand:

a. October–November: Suitable for preparing and establishing the plantation using rooted vine cuttings.
b. January–February: Another suitable planting window, depending on local climate and irrigation.

Three important planting methods are followed:

a. Lunda/Lachhi method: Long vines are coiled into a figure-eight shape and buried shallowly, keeping portions of the vine exposed for sprouting.
b. Straight vine method: Long cuttings are placed horizontally in prepared furrows, with both ends exposed above the soil.
c. Ring method: Vine cuttings are bent into a circular ring and partially buried in the soil.

Generally, for commercial cultivation, use healthy, pre-rooted vine cuttings and the ring or straight-vine method. Pre-rooting helps establish a uniform plantation.

A practical commercial spacing is:

a. Row-to-row: 2 m; Plant-to-plant: 2 m
b. Plant population: approximately 2,500 plants/ha.

Land Preparation and Nutrient Management

1. Give 2–3 deep ploughings and prepare a fine tilth. Ensure proper drainage.
2. Incorporate well-decomposed FYM at 20–25 tonnes/ha. A regional package recommendation:

Nutrient	Dose/ha
Nitrogen (N)	80 kg
Phosphorus (P_2O_5)	50 kg
Potash (K_2O)	50 kg

Apply basal nutrients according to soil-test recommendations. Split nitrogen applications during active vine growth and fruiting rather than applying the entire dose at once.

Training and Pruning

Two systems are possible:

1. Ground trailing: Less expensive but harvesting and fruit quality management can be difficult.
2. Trellis/bower system: Better canopy management, light penetration, air circulation and easier harvesting.

Irrigation Management

Pointed gourd is sensitive to waterlogging, particularly during establishment.

1. Give light irrigation immediately after planting.
2. Irrigate at 7–10-day intervals during dry weather, depending on soil type.
3. Maintain adequate soil moisture during flowering and fruit development.
4. Drip irrigation is preferable for commercial production.
5. Avoid excessive irrigation to prevent root rot.

Flowering and Pollination

1. Male and female flowers occur on separate plants. Pollination is mainly insect-mediated, particularly by bees.
2. Maintain a male:female ratio of approximately 1:9 or 1:10.

Harvesting

Harvest fruits at the immature, green and tender stage and should be before seeds become hard and the fruit develops an undesirable fibrous texture. Fruits generally become marketable approximately 10–15 days after fruit set, depending on genotype and growing conditions. Every 2–3 days during peak fruiting, depending on fruit growth and market requirements.

Expected Yield and Crop Duration

Parameter	Expected performance
First harvesting	Approximately 3–5 months, depending on planting season and establishment
Fruiting period	Several months
First-year yield	Approximately 10–18 tonnes/ha under varying conditions
Improved commercial yield	20–30 tonnes/ha or more under good management

ICAR-RCER Ranchi has documented commercial cultivation of its varieties Swarna Alaukik, Swarna Suruchi and Swarna Rekha, with an average potential yield of 25–30 tonnes/ha.

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