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ARTICLE ID: 01

Edible Insects-

Future Protein for a Hungry World?

Introduction

As the global population nears 10 billion by 2050, food production must rise by 50% to meet future nutrition needs. However, traditional livestock farming is increasingly seen as bad for the environment. It accounts for about 14.5% of global greenhouse gas emissions and uses large amounts of essential resources like water.

To tackle these growing issues of climate change and food security, edible insects have surfaced as a promising alternative protein source. With over 2,000 known edible species, insects provide a strong mix of high nutritional value and a small environmental impact. This solution is already culturally accepted in areas like North-East India.

Nutritional Value of Edible Insects

Protein Content and Quality

Insects are highly protein-rich, with protein content ranging from 20% to 80% of their dry weight, depending on the species. This means they can match or surpass traditional animal protein sources. For example, moths have about 30.8-76g of protein per 100g of dry weight, which is much higher than beef (40.5g per 100g of dry weight), chicken (54.7g per 100g of dry weight), or pork (27.7g per 100g of dry weight).

Table 1: Protein Content of Edible Insects and Meats

Insect Type	Protein Range Content (%)
Cockroaches	57.30 - 76.00
Cicadas	53.00 - 64.00
Ants	40.83 - 66.00
Wasps	38.24 - 70.00
Moths	30.88 - 76.00
Grasshoppers	26.80 - 77.95
Chicken	22.2 (fresh), 54.70 (dry basis)
Beef	22.50 (fresh), 40.50 (dry basis)
Pork	21.00 (fresh), 27.70 (dry basis)

In addition to quantity, the quality of insect protein is impressive. Insects provide nearly all the essential amino acids we need, with essential amino acid scores between 46% and 96%. This is important because plant proteins, especially those from cereals, often fall short in lysine, tryptophan, or threonine. Insects can effectively fill those gaps in plant-based diets, supplying the amino acids that grains lack.

Vitamins, Minerals, and Healthy Fats

Edible insects are a highly nutritious food source that provides plenty of protein along with essential vitamins and minerals. Depending on what they eat and their growth stage, certain insects have impressive dietary benefits. Silkworm pupae are rich in vitamin E, crickets contain high levels of vitamin B12, and mealworms can compete with beef for vital minerals and match fish for heart-healthy omega-3 fatty acids. In addition, insects have a unique nutritional edge over other animal proteins because they contain chitin, a prebiotic fiber found in their exoskeletons. This fiber supports gut health and boosts immune function.



Figure 1: Edible insects being sold in markets of Northeast India.

Entomophagy in North-East India

Entomophagy in North-East India is a long-standing cultural tradition that shows a deep understanding of forest ecosystems and seasonal cycles. In states like Manipur, Assam, and Nagaland, indigenous tribes eat

more than a hundred nutritious insect species, including giant water bugs, bamboo worms, and silkworms.

They prepare these insects in various ways, such as roasting, frying, or eating them raw. This practice is important not only for tribal festivals and daily meals as a key source of protein and essential nutrients but also serves an important economic role. It supports local communities, especially women, who collect and sell these delicacies in regional markets.

Challenges and Future Outlook

Despite their potential, the broader acceptance of edible insects faces serious challenges, mainly cultural resistance in Western countries. However, increasing awareness of sustainability and innovative products are slowly changing consumer views. The industry also has to deal with inconsistent global regulations, which need standard protocols to make trade smoother and build consumer confidence. Food safety issues, such as contamination risks during rearing and possible allergic reactions for those allergic to shellfish, require strict quality control and clear labeling. Moreover, increasing production to make insect protein competitive with traditional options will require significant investment, technological progress, and automation to achieve economies of scale while maintaining quality and sustainability.

Conclusion

Edible insects offer a nutritious and environmentally friendly solution to global food security issues, providing high protein content and a much smaller ecological footprint compared to traditional livestock. While they are already accepted and economically viable in places like North-East India, gaining global acceptance will need a multi-faceted strategy. This should include ongoing research, creating attractive consumer products, establishing clear regulations, and educating the public to change cultural attitudes. Ultimately, edible insects are not meant to completely replace traditional meats but to become an essential, sustainable part of diversifying our protein sources and feeding a growing population.

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How insects conquered the sky: 300 million years of wings evolution

Abstract

One of the most intriguing conundrum in evolutionary algorithm is the inception of insect wings. How did tiny, crawling creatures inherit the capacity to fly and eventually take stewardship of almost every terrestrial ecosystem on Earth? For many years, there was a disagreement among professionals regarding whether wings originated from specialized mobile structures or as basic body extensions. Over the past century, important clues to this puzzle have been offered by fossil discoveries. Long before modern forms emerged, early winged insects had freely moving wings, according to evidence from ancient insects. These fossils demonstrate that insect wings were active structures that could move and eventually fly rather than just passive body flaps. Additionally, the fossil record also indicates a close relationship between the evolution of metamorphosis and the development of insect wings. By studying ancient insect nymphs preserved in rocks hundreds of millions of years old, researchers have reconstructed the amazing tale of how wings emerged, changed through time, and made insects into the most successful group of animals on Earth. This article explores the evolutionary journey of insect wings, the role of fossils in solving this mystery, and the connection between wings and metamorphosis.

Introduction: The Secret Behind Insect Success

When we look around any garden, crop field, forest or even our home, and we will find insects everywhere. Their extraordinary success is largely due to their biggest revolutionary innovation that is ability to fly. Insects were the first animals on Earth to achieve powered flight, long before birds or bats appeared. Today, more than a million insect species are known, and many owe their ecological success to wings. Yet one fundamental question has puzzled scientists for over a century: **How did insect wings evolve?** The answer has gradually emerged from an unexpected source- the fossil record. We can learn a lot about the origins of wings and how they impacted the evolution of current insects from ancient insects that have been preserved in rocks.

A World Before Wings

The progenitors of insects were land-dwelling, wingless organisms more than 350 million years ago. These ancient insects were similar to contemporary bristletails and silverfish. They had to crawl, hop and search for food because they couldn't fly. At some point during evolution, specific body structures began to change. They developed into movable appendages after beginning as small lateral expansions. Over millions of years, these structures evolved, eventually giving rise to actual wings. One of the most significant evolutionary developments in the history of life was the development of wings. Insects were able to spread across great distances, get access to new habitats, and improve their ability to evade predators.

What Do Fossils Tell Us?

For a long time, researchers believed that paranota (stiff extension of thoracic body wall) were the source of insect wings. According to this theory, these characteristics first let insects glide before evolving into wings. Fossil evidences however, tells a completely different story. Ancient Paleozoic insect nymphs' articulated and freely moving wings imply that wings were mobile elements from an early stage of life rather than fixed body extensions. These wings were sustained by tubular veins and were able to move actively.

This finding cast doubt on the conventional paranotal explanation and revealed that wings were originally mobile appendages with functional movement long before modern insects emerged.

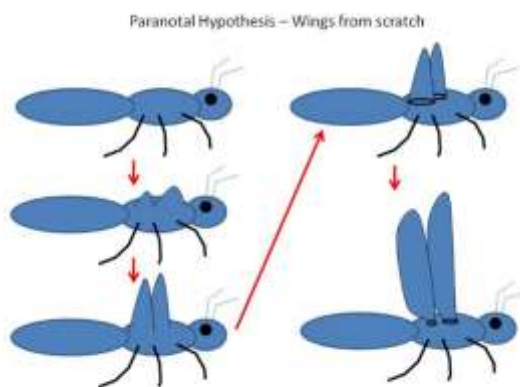


Fig 1. Paranotal hypothesis for the insect wings origin

The First Wings Were Not Just for Flying

A startling discovery from fossil studies suggests that the earliest wing-like structures may not have originated specifically for flights. Researchers have proposed that early wings served a variety of functions, such as:

- Assisting movement in water
- Stabilizing the body
- Improving maneuverability
- Protecting body segments

The wing-like characteristics of some ancient mayfly nymphs were probably used as fins or paddles in watery movements. These features may have provided an evolutionary benefit even before true flight appeared. This idea highlights an important evolutionary principle: structure often evolve for one purpose before being altered for another.

The Remarkable Engineering of Insect Wings

Modern insect wings are example of natural engineering, despite their delicate look. Ancient fossils reveal that wings gradually developed:

- Reinforcing veins
- Flexible joints
- Specialized muscles
- Corrugated surfaces for strength

The vein network of modern wings is not random. Similar to a bridge's framework, these veins sustain the wing while maintain its weight. Researchers claim that wing corrugation evolved before actual flight. These folds increased strength without adding excessive weight, making wings more efficient aerodynamic structures. Over millions of years of natural selection, these developments transformed primitive appendages into incredibly useful flight organs.

When Young Insects Had Wings

Juvenile insects were formerly considerably different from present insect larvae and nymphs, which is one of the most exciting findings from the fossil record. These days, in so many species, young insects have wing pads that stay attached to their bodies until they reach adulthood. According to fossils, ancient bug nymphs had functioning, moving wings for a significant portion of their development. This indicates that current nymphs' immovable wing pads are not archaic characteristics. Rather, they reflect post-Paleozoic evolutionary changes. Scientists' knowledge of insect development and wing evolution was altered by these discoveries.

The Link Between Wings and Metamorphosis

The evolution of wings appears to be closely connected with the evolution of metamorphosis. According to fossil evidence, many early insects developed gradually through a series of juvenile stages and lacked the distinct metamorphic stage seen in modern insects. Their growth was continuous, with wings developing progressively over time. Later in evolutionary history, specialized developmental stages such as pupae emerged. This innovation allowed insects to separate feeding, growth, and reproduction into different life stages.

Complete metamorphosis eventually gave rise to highly successful groups such as:

- Beetles
- Butterflies
- Moths
- Flies
- Wasps

The fossil record suggests that these developmental changes evolved after important modifications had already occurred in the wing system.

Why Flight Changed Everything

The ability to fly transformed insects in ways that few other evolutionary innovations have done. Flight allowed insects to:

- Escape predators more effectively
- Locate food and mates rapidly
- Colonize new environments
- Survive environmental disturbances
- Spread across continents

Because of flight, insects became dominant members of terrestrial ecosystems. From pollinators and predators to decomposers and pests, they have evolved into an infinite variety of shapes performing several ecological roles. Insects would probably never have attained their remarkable diversity and dominance without having wings.

Fossils: Nature's Time Machine

The importance of fossils is among the research's most crucial insights. Only the culmination of millions of years of evolution is visible in living insects. Snapshots of extinct intermediate stages can be found in fossils. Scientists can reconstruct evolutionary processes that took place hundreds of millions of years ago by examining ancient wings, wing joints, and developmental patterns. These findings show that the history of insect flight is significantly more intricate and fascinating than previously thought.

Conclusion

Insect wings are an incredible illustration of ingenuity, flexibility, and survival. Wings did not just simply evolve as passive extensions of the body according to fossil data, rather they developed as moveable structures that progressively picked up the features required for powered flight. Long before modern species appeared, ancient insects possessed articulated wings, and the evolution of these wings was crucial in understanding the insect diversity and metamorphosis. Today, every butterfly fluttering in a garden, every dragonfly gliding over a pond, and every bee visiting a flower carries the heritage of an evolutionary journey that started more than 300 million years ago. The fossil records keep revealing new information of this journey, reminding us that even the tiniest animals have amazing stories hidden within their wings.

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ARTICLE ID: 03**Salinity Tolerance in Indian Mustard (*Brassica juncea* L.): Interplay of Photosynthetic Traits, Ionic Homeostasis and Stress-Responsive Gene Networks****Abstract**

Salinity is a major abiotic stress limiting crop productivity, particularly in arid and semi-arid regions. Indian mustard (*Brassica juncea* L.), an important oilseed crop, is highly sensitive to salt stress, which affects growth and yield through osmotic imbalance, ionic toxicity, oxidative damage, and impaired photosynthesis. Recent studies indicate that salinity tolerance in mustard is governed by coordinated physiological and molecular mechanisms, including efficient photosynthetic regulation, ionic homeostasis, antioxidant defense, and stress-responsive gene expression. Salt-tolerant genotypes such as CS 52-SPS-1-2012 and CS 54 maintain lower Na^+/K^+ ratios, higher photosynthetic efficiency, and stronger antioxidant activity than sensitive genotypes. Key genes involved in tolerance include SOS1, SOS2, SOS3, ENH1, and NHX1 for ion regulation, and APX1, APX4, DHAR3, and MDHAR6 for reactive oxygen species detoxification. This review summarises the interconnected mechanisms of salinity tolerance and highlights opportunities for combining physiological screening, molecular breeding, and genome editing to develop climate-resilient mustard cultivars.

Keywords: *Brassica juncea*, salinity stress, photosynthesis, SOS pathway, NHX1, antioxidant genes, ionic homeostasis, ROS detoxification

Introduction

Soil salinity is a rapidly expanding environmental problem affecting agricultural productivity across the globe. Excessive accumulation of soluble salts in soil severely restricts plant growth, development, and yield. It is estimated that nearly one-third of irrigated agricultural land worldwide is affected by salinity, and the affected area is projected to increase substantially due to climate change, poor-quality irrigation water, rising groundwater tables, and secondary salinization. In India, salt-affected soils are expected to increase considerably by 2050, posing a serious threat to food and nutritional security. Indian mustard (*Brassica juncea* L. Czern and Coss) is one of the most important oilseed crops cultivated in South Asia because of its high oil content, nutritional importance, industrial utility, and adaptability to diverse agro-climatic conditions. However, mustard productivity is highly sensitive to salinity stress, particularly during early vegetative and reproductive stages. Salinity affects mustard growth through osmotic stress, ionic toxicity, nutrient imbalance, oxidative stress, and metabolic disturbances.

Plants exposed to saline environments encounter two primary stresses. The first is osmotic stress caused by reduced soil water potential, which limits water uptake and induces physiological drought. The second is ionic toxicity resulting from excessive accumulation of sodium (Na^+) and chloride ions within plant tissues (Singh J *et al.* 2019). High Na^+ concentration interferes with potassium uptake, disrupts membrane integrity, inhibits enzyme activity, and impairs photosynthetic processes. In addition, salinity-induced oxidative stress generates reactive oxygen species (ROS) that damage proteins, lipids, chloroplasts, and nucleic acids (Singh J *et al.* 2022).

Despite these adverse effects, certain mustard genotypes exhibit remarkable tolerance to saline conditions through activation of adaptive physiological and molecular mechanisms. Understanding these mechanisms is critical for developing resilient mustard cultivars capable of sustaining productivity under salt-affected environments.

Salinity-Induced Alterations in Photosynthetic Machinery

Photosynthesis is among the most sensitive physiological processes affected by salinity stress. Salt-induced inhibition of photosynthesis directly influences plant growth and biomass production. Salinity affects photosynthesis through both stomatal and non-stomatal limitations. Stomatal closure under saline conditions reduces CO₂ diffusion into leaves, thereby limiting carbon assimilation. Reduced stomatal conductance also decreases transpiration rate and disrupts water relations. Simultaneously, ionic toxicity damages chloroplast membranes, photosystem components, and photosynthetic enzymes, resulting in non-stomatal inhibition of photosynthesis. Comparative studies in Indian mustard demonstrated significant reductions in photosynthetic rate (Pn), stomatal conductance (gS), transpiration rate (E), instantaneous water use efficiency (iWUE), and CO₂ assimilation under increasing salinity stress. However, tolerant genotypes such as CS 52-SPS-1-2012 and CS 54 maintained substantially higher photosynthetic efficiency compared with sensitive genotypes Pusa Bold and CS 614-4-1-4-100-13. The higher reduction in photosynthesis observed in sensitive genotypes may be attributed to excessive Na⁺ accumulation in leaves, leading to reduced leaf turgor, stomatal dysfunction, chlorophyll degradation, and impairment of Rubisco activity. Reduced photosynthetic efficiency ultimately affects assimilate production, biomass accumulation, and seed yield under saline conditions (Singh V *et al.* 2018). Water use efficiency represents another important physiological determinant of salinity tolerance. Salt-tolerant mustard genotypes maintained comparatively higher iWUE under stress, suggesting superior regulation of water relations and osmotic

balance. Improved water use efficiency enables plants to sustain carbon assimilation while minimizing water loss under adverse environments.

Ionic Toxicity and Na⁺/K⁺ Homeostasis

Maintenance of ionic homeostasis is considered one of the most critical determinants of salinity tolerance in plants. Excessive Na⁺ accumulation disrupts cellular metabolism by competing with potassium uptake and disturbing cytoplasmic ion balance. High Na⁺/K⁺ ratio impairs enzyme activation, protein synthesis, stomatal function, and membrane stability. Studies in Indian mustard revealed substantial differences in ion accumulation patterns between tolerant and sensitive genotypes. Salt-sensitive genotypes accumulated significantly higher Na⁺ concentrations in both roots and shoots, whereas tolerant genotypes maintained lower Na⁺ accumulation and higher K⁺ retention. The tolerant genotype CS 52-SPS-1-2012 maintained the lowest Na⁺/K⁺ ratio under salinity stress, indicating efficient ion regulation mechanisms. Potassium is essential for numerous physiological functions including osmotic regulation, enzyme activation, protein synthesis, and stomatal functioning. Under saline conditions, Na⁺ competes with K⁺ uptake due to similarity in ionic radius, resulting in potassium deficiency and metabolic dysfunction. Therefore, maintenance of low Na⁺/K⁺ ratio is considered a hallmark of salinity tolerance. Salt-tolerant mustard genotypes appear to regulate Na⁺ transport through ion exclusion and compartmentalization mechanisms. Excess sodium ions are either excluded from root uptake pathways or compartmentalized into vacuoles, thereby minimizing cytoplasmic toxicity. These adaptive mechanisms help preserve metabolic activities and sustain growth under saline conditions.

SOS Signaling Pathway and Ionic Regulation

The Salt Overly Sensitive (SOS) signaling pathway plays a central role in regulating ion homeostasis under salinity stress. The SOS pathway comprises three major components: SOS1, SOS2, and SOS3. These proteins collectively regulate Na⁺ extrusion and cellular ion balance under saline conditions. Under salt stress, increased cytosolic calcium concentration is sensed by SOS3, a calcium-binding protein. SOS3 interacts with SOS2 protein kinase, forming the

SOS2–SOS3 complex. This complex activates SOS1, a plasma membrane-localized Na⁺/H⁺ antiporter responsible for extrusion of excess Na⁺ from the cytoplasm. Enhanced expression of SOS1, SOS2, and SOS3 was observed in salt-tolerant mustard genotypes under saline conditions. The coordinated activation of these genes facilitated efficient Na⁺ exclusion, reduced sodium toxicity, and improved ionic homeostasis. In addition to SOS genes, ENH1 and NHX1 also contribute significantly toward salinity adaptation. ENH1 encodes a chloroplast-localized rubredoxin-like protein associated with ROS detoxification and oxidative stress signaling. NHX1 encodes vacuolar Na⁺/H⁺ antiporter responsible for compartmentalization of Na⁺ into vacuoles (Singh V *et al.* 2018). Enhanced expression of NHX1 in tolerant mustard genotypes suggests efficient vacuolar sequestration of sodium ions. Vacuolar compartmentalization reduces cytoplasmic sodium toxicity, maintains osmotic balance, and supports turgor-driven growth under saline environments.

Oxidative Stress and Antioxidant Defense Systems

Salinity stress induces excessive generation of reactive oxygen species (ROS) due to disruption of electron transport chains in chloroplasts and mitochondria. ROS accumulation causes lipid peroxidation, membrane leakage, protein denaturation, chlorophyll degradation, and DNA damage. To protect against oxidative injury, plants activate complex antioxidant defense systems comprising enzymatic and non-enzymatic antioxidants. Important enzymatic antioxidants include: Ascorbate peroxidase (APX), Dehydroascorbate reductase (DHAR) and Monodehydroascorbate reductase (MDHAR). APX catalyzes conversion of hydrogen peroxide into water using ascorbate as electron donor. DHAR and MDHAR regenerate reduced ascorbate necessary for maintaining redox homeostasis and antioxidant cycling. Comparative expression analysis revealed significantly higher induction of APX1, APX4, DHAR3, and MDHAR6 in salt-tolerant mustard genotypes compared with sensitive genotypes under salinity stress. Enhanced antioxidant capacity in tolerant plants likely contributed to efficient ROS scavenging, reduced membrane damage, and

protection of photosynthetic apparatus under saline conditions. In contrast, lower antioxidant gene expression in sensitive genotypes resulted in excessive oxidative damage and accelerated senescence.

Conclusion

Salinity severely restricts growth and yield in *Brassica juncea* by disrupting photosynthesis, ionic balance, and cellular redox homeostasis. Salt-tolerant genotypes mitigate these effects through efficient Na⁺ exclusion and sequestration, activation of SOS signaling, enhanced antioxidant defense, and maintenance of photosynthetic efficiency. Genes such as **SOS1, SOS2, SOS3, ENH1, NHX1, APX1, APX4, DHAR3, and MDHAR6** play central roles in these adaptive responses. The coordinated regulation of ionic homeostasis and ROS detoxification enables tolerant genotypes to sustain productivity under saline conditions. Integrating physiological screening with molecular breeding and genome-editing approaches offers a promising strategy for developing climate-resilient, salt-tolerant mustard cultivars for sustainable agriculture.

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ARTICLE ID: 04**Nutrigenomics: Approaches to understand Protein
Digestibility in Aquafeed****Introduction**

Aquaculture is expanding rapidly to become one of the fastest-growing sectors of the global food production sector, and is essential for global food security (Iqbal et al., 2025). As the human population grows, the aquaculture industry under pressure to produce cost-effective, high-quality, and sustainable aquafeeds (Khan, 2026). Among the all nutrients supplied in the feed proteins are the most crucial and expensive macro nutrient in the feed formulations, and are essential for healthy growth, physical development, and disease resistance of aquatic species (Gopalraaj et al., 2023; Khan, 2026). Traditionally, aquaculture industry has relied on fishmeal as its primary source of protein, however rising economic costs and severe environmental limitations have forced the sector to look for alternative protein sources (Weththasinghe et al., 2022; Iqbal et al., 2025). Currently fish feeds industry increasingly utilizing plant-based proteins, such as soybean meal, mustard oil cake, groundnut oil cake and other non-conventional feed ingredients (Weththasinghe et al., 2022). Despite their availability, these alternatives are suffer from lower nutritional bioavailability, complex macromolecules, and anti- nutritional factors (ANFs) that hinder digestion process (Gopalraaj et al., 2023). To bridge this critical nutritional gap, scientists are turning to nutrigenomics. By decoding how specific nutrients interact with gene expression, this field offers a promising pathway to significantly improve protein digestibility and metabolic processing in aquaculture species (Iqbal et al., 2025).

Concept of Nutrigenomics

Genetic monitoring of aquatic ecosystems helps to optimize aquaculture feeds and fish health by studying the response of gene expressions. Nutrigenomics or Nutritional genomics is a multidisciplinary knowledge defined as the influence of dietary nutrients and their derivate-bioactive components on gene expression and epigenetic regulation (María Eléxpuru Zabaleta et al., 2020). Nutrigenomics is an advanced science that is at the cutting edge of an interdisciplinary field that includes nutrition science, genomics, bioinformatics, and molecular biology in assessing the impact of specific nutrients in the diet on gene expressions and the health of an aquatic organism (Iqbal et al., 2025; Khan, 2026; Kiani et al., 2022). Nutrigenomics involves both humans and aquatic life, has an exclusive nutritional blueprint that is embedded in their genes (Kiani et al., 2022). Unlike the traditional and general trial-and-error method of preparing fish feeds, nutrigenomics is able to decode the response of fish biological and metabolic systems at the fundamental molecular level. By using highly advanced omics technologies, researchers can find a comprehensive view of fish biology (Iqbal et al., 2025). These tools include transcriptomics, which involves studying tissue-specific RNA transcripts; proteomics, which examines the complex array of proteins; and metabolomics, which identifies metabolic changes caused by specific diets (Kiani et al., 2022).

This deep genetic insight empowers scientists to replace generic feeds with precision designer feeds tailored to the precise genetic and metabolic requirements of a selected fish species, thereby optimizing growth performance and minimizing environmental loss (Khan, 2026).

Protein Digestion

In fish to achieve optimal growth, they must be able to digest proteins of complex diets and break them down into simpler forms of free amino acids and peptides, which can be easily absorbed and utilized through their intestines (Gopalraaj et al., 2023). This crucial digestive process relies entirely on endogenous fish digestive enzymes like protease, lipase, amylase (Gopalraaj et al., 2023). However, the natural digestive capacity of fish varies widely and is complicated by their feeding habits; for example, carnivorous fish exhibit completely different genetic expressions and digest carbohydrates poorly compared to herbivorous fish species (Khan, 2026). The digestion process becomes highly complicated when sustainable, plant-based alternative protein sources were introduced into aquafeeds (Gopalraaj et al., 2023). Various plant derived fish feed ingredients contain Anti-Nutritional Factors (ANFs) that can impair gut health by harming the mucous lining and reducing the surface area for nutrient absorption such as villus length (Gopalraaj et al., 2023). When introducing novel proteins like insect meals digestion is hindered by chitin, a complex compound found in insect exoskeletons that is poorly digestible for fish and acts as a structural filler (Weththasinghe et al., 2022). Therefore, rigorous understanding of the digestive physiology and absorptive capacity of fish is essential.

Role of Nutrigenomics in understanding Protein Utilization

Nutrigenomics can provide a highly effective and scientifically proven strategy to overcome digestive problems and achieve the best protein utilization in aquaculture. First of all, nutrigenomics can play a significant role in the identification of physiological changes to achieve the best protein and lipid balance in the formulation of feeds (Khan, 2026). Genomic and metabolic studies suggest that the reduction of

protein content with a slight increase in the content of lipids can maximize protein synthesis and reduce the production of harmful waste products (Khan, 2026). Second, the basic science behind the strategic application of exogenous enzyme addition, especially proteases, is made possible by the emerging field of nutrigenomics (Gopalraaj et al., 2023). When the genome of the fish cannot produce endogenous enzymes to counteract the ANFs produced by the ingested plants, exogenous proteases are directly used in the diet (Gopalraaj et al., 2023). Experimental studies have proven shown that the addition of such exogenous enzyme supplemented diets to the fish can upregulate the endogenous digestive genes of the fish, which improves the Apparent Digestibility Coefficient (ADC) of crude protein in the diet (Gopalraaj et al., 2023). The action of the exogenous proteases also reduces the thickness of the muscles in the foregut and increases the length of the villi in the intestine, which maximizes the surface area for nutrient absorption (Gopalraaj et al., 2023).

Importance of Nutrigenomics in Aquaculture Species

Nutrigenomics and dietary changes have been successfully implemented to improve the nutrient uptake of several economically important fish species as follows.

Tilapia (*Oreochromis niloticus*): Tilapia is one of the most flexible fish species in water, commonly used as a model to evaluate plant-based diets and other novel feeds (Iqbal et al., 2025). The Tilapia fish fed with plant-based diets supplemented with exogenous proteases were found to improve the structure of the intestines based on the evaluation of genes and tissues. The protease enzyme plays a role in protecting the fish against harmful substances such as conglycinin and glycinin, which are found in soybean meal and act as inhibitors of the development of villi in the intestines. Tilapia showed improved villi development and reduced expression of genes related to stress, such as Heat Shock Protein 70 (HSP70), and cytokines (Gopalraaj et al., 2023; Iqbal et al., 2025).

Rohu (*Labeo rohita*): Being one of the most prominent members of the Carp family, which plays a vital role in freshwater aquaculture, optimizing feed efficiency

in Rohu is highly advantageous. The scientific community has already established through extensive research that supplementing crude proteases, such as bromelain extracted from pineapple juice, in the diet of Rohu fingerlings results in a highly improved Specific Growth Rate (SGR) and Protein Efficiency Ratio (PER). Nutrigenomic studies on this particular issue have shown that supplementing crude protease enzymes in the diet of Rohu fingerlings has led to a significant increase in the activity of endogenous enzymes, such as amylase, protease, and lipase, in the intestine and hepatopancreas of the fish (Gopalraaj et al., 2023).

Salmonids (Atlantic Salmon and Rainbow Trout): Nutrigenomics plays an important role in the evaluation of novel proteins in carnivorous species that have very high protein requirements, such as the BSF. From the findings of extensive meta-analyses, it has been indicated that when BSF replaces traditional fishmeal, there is the need for careful balancing. As BSF is a sustainable protein source, it has poor digestibility in salmon and rainbow trout, causing the apparent protein digestibility of the diets to be reduced. However, when the diets are nutritionally balanced, the salmonids show excellent growth with good feed conversion ratios (Weththasinghe et al., 2022).

Benefits nutrigenomic for Aquaculture Production

Applying nutrigenomic approaches to optimize protein digestibility unlocks a multitude of operational and ecological benefits for the entire aquaculture industry:

By decoding exactly how to effectively digest cheaper, plant based, or insect-based proteins, aquaculture farmers can significantly reduce their reliance on expensive conventional feed ingredients without affecting fish growth rate (Iqbal et al., 2025; Khan, 2026).

Poorly digested dietary protein directly results in high nitrogen and ammonia excretion in the water (Gopalraaj et al., 2023). By using precision genomic approach in the diets and improve protein digestibility, fish absorb more essential amino acids and excrete less waste, which significantly lowers total nitrogen and ammonia which pollute the water (Gopalraaj et al.,

2023; Khan, 2026).

Proper protein utilization is directly linked to a fish immune responses (Khan, 2026). Nutrigenomics has demonstrated that highly digestible, tailored, and functional feeds can successfully downregulate pro-inflammatory genes such as IL-1 β and TNF- α , as well as upregulate crucial immune defense genes, thus rendering the fish much more resilient to bacterial outbreaks and diseases (Gopalraaj et al., 2023; Khan, 2026).

Conclusion

The continuous growth of global aquaculture activities requires innovative solutions for aquaculture feed production, especially regarding the high cost and digestibility of non-conventional proteins. Nutrigenomics is solution to shifting the entire aquaculture industry from traditional, generalized approaches to feeding aquaculture animals to highly specific, and precise. It will help to understating the complex molecular interactions between the genes and diet, scientists can create highly specific, customized diets and fully harness the potential of precise protease its supplementation. This genetic level intervention fully eliminates harmful ANFs, restores the sensitive structures of the intestinal lining, and optimizes nutrient absorption in key economic species such as Tilapia, Rohu, and Salmon as well as other commercial important fish. By fully implementing nutrigenomics, not only improve the economic viability and sustainability of modern aquaculture, but it also ensures that the worlds growing demand for aquatic foods is met in a healthy, sustainable way.

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AI-Enabled Smartphone Technologies in Modern Agricultural Systems

ABSTRACT

Rapid integration of smartphones and Artificial Intelligence (AI) is transforming agriculture into a smart, efficient, and data-driven production system. AI-enabled mobile technologies support precision farming through real-time weather forecasting, crop disease diagnosis, irrigation management, yield prediction, and market intelligence, thereby improving productivity, profitability, and resource-use efficiency. The integration of AI with sensors, drones, satellite imagery, and machine learning is further promoting climate-smart and sustainable agricultural practices. Despite challenges such as digital illiteracy, poor internet connectivity, and high technology costs, these technologies have immense potential to strengthen sustainable agriculture and global food security in the future.

Keywords: Artificial Intelligence, smartphones, digital agriculture, precision farming, machine learning, climate-smart agriculture.

INTRODUCTION

Agriculture has traditionally depended on farmers' experience and conventional management practices. However, challenges such as climate change, water scarcity, labour shortages, and declining soil fertility have increased the need for advanced agricultural technologies. In recent years, smartphones and Artificial Intelligence (AI) have emerged as important tools for improving agricultural productivity, efficiency, and sustainability (Wolfert et al., 2017). AI technologies including machine learning, computer vision, and data analytics help farmers make accurate decisions related to crop management, irrigation, disease diagnosis, and market planning (Russell and Norvig, 2021). The integration of smartphones with AI, drones, sensors, IoT, and satellite technologies is accelerating the development of precision and climate-smart agriculture (Klerkx et al., 2019). India is also promoting digital agriculture through various mobile applications and AI-based advisory systems to enhance resource-use efficiency and sustainable farming practices.



ROLE OF SMARTPHONES IN AGRICULTURE

1. Access to Real-Time Information

Smartphones provide farmers with immediate access to weather updates, rainfall forecasts, pest alerts, crop advisories and government schemes. Accurate weather forecasting helps farmers plan sowing, irrigation, fertilizer application and harvesting operations efficiently. Mobile-based weather applications reduce uncertainty and minimize crop losses caused by extreme climatic conditions (Ray et al., 2017). The Government of India launched several mobile applications such as Kisan Suvidha and Pusa Krishi that provide agricultural recommendations in regional languages. Farmers can also access videos, online training materials and extension services directly through mobile phones.

2. Market Information and Price Forecasting

Farmers often face losses due to inadequate market information and price fluctuations. Smartphone applications now provide daily updates on mandi prices, transportation facilities and buyer information. Digital platforms such as e-NAM (National Agriculture Market) help farmers connect directly with buyers and improve marketing efficiency (Chand, 2016). AI-based systems can analyse historical market trends and predict future price movements. Such technologies help farmers decide which crops to cultivate and when to sell their produce for maximum profit.

3. Digital Financial Services

Smartphones also support digital payments, crop insurance claims, online banking and agricultural credit services. Farmers can receive subsidies and government benefits directly through digital platforms. Mobile banking and Unified Payments Interface (UPI) systems have increased financial inclusion in rural areas.

ROLE OF ARTIFICIAL INTELLIGENCE IN AGRICULTURE

1. Crop Disease and Pest Detection

AI-powered applications use image recognition and machine learning techniques to identify crop diseases and insect pests from smartphone photographs. Farmers can capture images of infected leaves, stems, or fruits and AI systems

analyse the symptoms to provide disease diagnosis and management recommendations. Several studies have reported high accuracy of AI-based disease detection systems in crops such as rice, wheat, tomato and cotton (Mohanty et al., 2016). Early disease detection helps reduce pesticide use, prevent yield losses and improve crop quality.

2. Precision Agriculture

Precision agriculture involves site-specific crop management using digital technologies. AI systems analyze data collected from sensors, drones, GPS devices and satellites to optimize irrigation, fertilizer application and pesticide use (Gebbers and Adamchuk, 2010). Smartphones connected with IoT-based sensors enable farmers to monitor soil moisture, nutrient status and environmental conditions in real time. AI algorithms process these data and recommend precise input application according to crop requirements.

3. Smart Irrigation Management

Water scarcity is one of the major challenges in agriculture. AI-based irrigation systems help farmers use water efficiently by analysing soil moisture, crop growth stage and weather conditions. Automated irrigation systems controlled through smartphones reduce water wastage and improve water productivity. Studies have shown that AI-assisted irrigation scheduling can significantly improve water-use efficiency and crop yields under limited water conditions (Liakos et al., 2018).

4. Yield Prediction and Crop Monitoring

AI technologies use satellite imagery, remote sensing and machine learning models to estimate crop growth and predict yields. Farmers can monitor crop health using drone images and smartphone applications. Early identification of nutrient deficiencies, water stress and pest infestation enables timely corrective measures. AI-based crop monitoring systems are particularly useful for large-scale farming and climate-smart agriculture.

INTEGRATION OF SMARTPHONES, AI and IoT

The integration of smartphones with AI and IoT technologies is creating smart farming systems. IoT devices collect data from agricultural fields

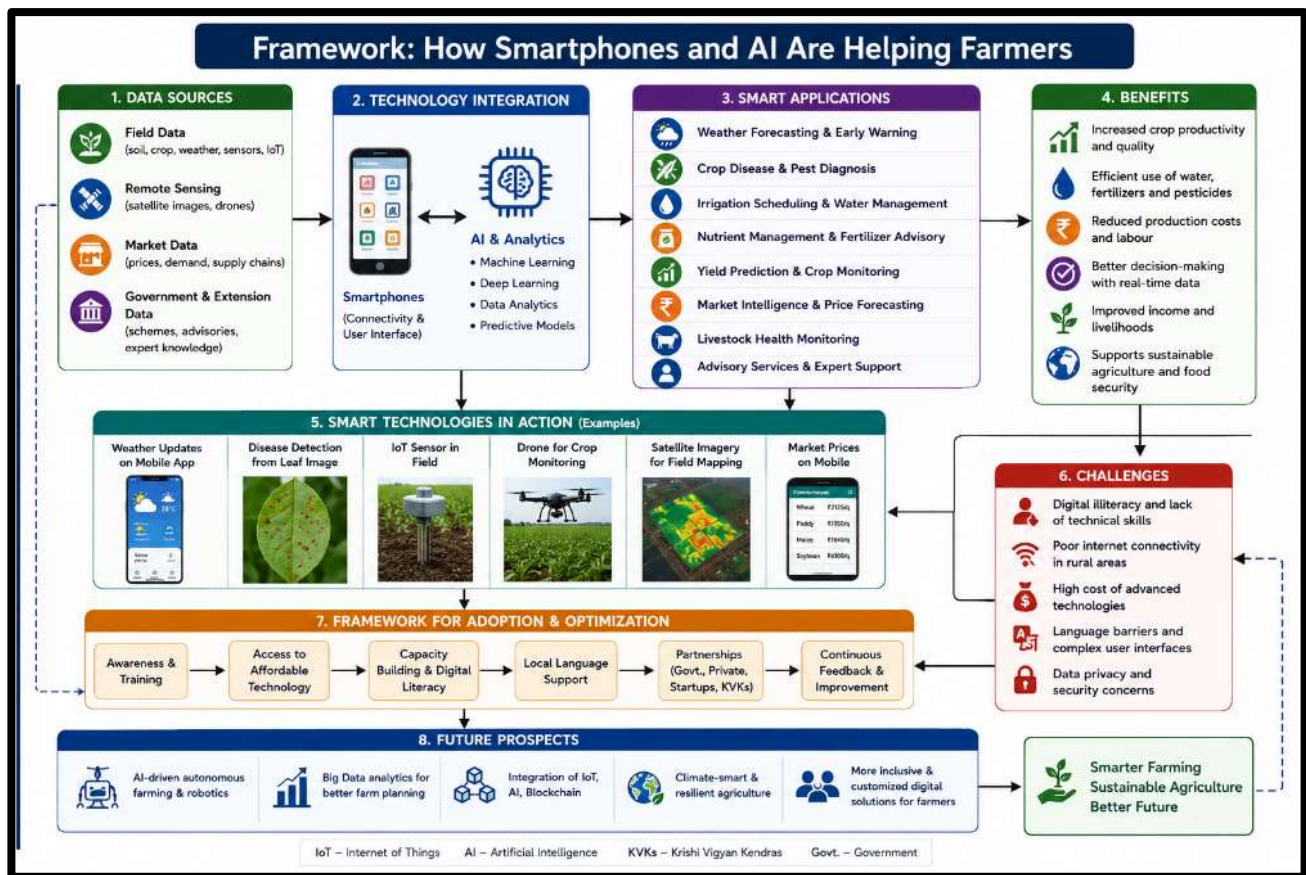


Fig. 1. Operational framework for AI-assisted digital agriculture and smart farming practices.

through sensors that monitor temperature, humidity, soil moisture and nutrient levels. These data are transmitted to cloud-based AI systems that analyse field conditions and provide recommendations to farmers through smartphone applications. For example, smart greenhouses use AI-controlled sensors to regulate temperature, humidity and irrigation automatically. Similarly, livestock farmers use smartphone-based monitoring systems to track animal health, feeding behaviour and milk production. Drones equipped with AI cameras are also helping farmers in crop surveillance, pesticide spraying, weed detection and nutrient deficiency mapping. Such technologies reduce labour requirements and increase operational efficiency.

Framework for Smart Farming Through AI and Smartphones

The framework illustrates how smartphones and Artificial Intelligence (AI) are integrated to support smart and sustainable agriculture.

It begins with different agricultural data sources such as field data, weather information, remote sensing, satellite imagery, drones, market intelligence, and government advisory services. These data are collected and accessed through smartphone applications, which act as a user-friendly interface for farmers. AI technologies including machine learning, predictive analytics, and deep learning process the collected information and convert it into practical recommendations (Wolfert et al., 2017; Liakos et al., 2018).

Based on this analysis, several smart agricultural applications are generated, such as weather forecasting, crop disease diagnosis, irrigation scheduling, nutrient management, yield prediction, livestock monitoring, and market price forecasting. The framework also highlights the role of modern technologies like IoT sensors, drones, and satellite monitoring in real-time field management and precision agriculture (Gebbers and Adamchuk, 2010). The adoption process further depends on awareness

creation, digital literacy, affordable technologies, local language support, and institutional partnerships. Although challenges such as poor internet connectivity, high technology costs, and lack of technical skills exist, the framework demonstrates that proper integration of smartphones and AI can improve productivity, resource-use efficiency, farmers' income, and climate resilience. Overall, the framework emphasizes that digital agriculture technologies are paving the way for smarter farming, sustainable agriculture, and future food security.

BENEFITS OF SMARTPHONES AND AI IN AGRICULTURE

- 1. Increased Productivity:** AI technologies help optimize crop management practices, leading to higher yields and better crop quality.
- 2. Resource Conservation:** Precision agriculture reduces excessive use of water, fertilizers and pesticides, thereby conserving natural resources and reducing environmental pollution.
- 3. Reduced Production Costs:** Automated systems reduce labour requirements and improve input-use efficiency, lowering production costs.
- 4. Climate Change Adaptation:** AI-based forecasting systems help farmers adapt to changing climatic conditions and minimize risks associated with droughts, floods and extreme weather events.
- 5. Improved Decision-Making:** Real-time information and predictive analytics enable farmers to make timely and informed decisions.
- 6. Better Market Access:** Digital platforms connect farmers directly with consumers and markets, increasing profitability and reducing the role of intermediaries.

CHALLENGES IN ADOPTION

Despite several benefits, the adoption of smartphones and AI in agriculture faces multiple challenges.

- 1. Digital Illiteracy:** Many farmers lack technical knowledge required to operate advanced mobile apps and AI tools.
- 2. Poor Internet Connectivity:** Limited internet access in remote rural areas restricts the effective use

of digital agricultural technologies.

- 3. High Initial Investment:** AI-based equipment, sensors and drones are expensive for small and marginal farmers.
- 4. Data Privacy and Security:** Collection and storage of agricultural data raise concerns regarding data ownership and privacy.
- 5. Language Barriers:** Many digital applications are available only in English, limiting accessibility for regional farmers.

CONCLUSION and FUTURE PROSPECTS

Smartphones and Artificial Intelligence are rapidly transforming traditional agriculture into a smart, data-driven, and efficient farming system. These technologies help farmers through real-time weather forecasting, disease diagnosis, precision irrigation, and market intelligence, thereby improving productivity and resource-use efficiency. AI-based digital agriculture also supports climate-resilient and sustainable farming while reducing environmental pollution. Although challenges such as poor connectivity, digital illiteracy, and high technology costs still exist, continuous innovations and government initiatives are accelerating technology adoption among farmers. In the future, advancements in low-cost sensors, robotics, autonomous machinery, and generative AI are expected to further revolutionize agriculture and strengthen global food security.

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ARTICLE ID: 06**FARMER-TO-FARMER EXTENSION APPROACHES FOR
PROMOTING SUSTAINABLE AGRICULTURAL
DEVELOPMENT****ABSTRACT**

Sustainable agriculture is essential for ensuring food security and protecting the environment, which requires ongoing innovation and effective sharing of knowledge. Traditional agricultural extension services, typically led by experts, often struggle to meet local needs due to differences in context and available resources. In contrast, farmer-to-farmer (F2F) extension models focus on peer-to-peer knowledge sharing, allowing experienced farmers to provide practical insights within their communities. This paper investigates the role of F2F extension models in promoting sustainable agriculture, emphasizing their advantages, such as cost-effectiveness, context-specific knowledge and the trust they build among farmers. It reviews various F2F models, including peer trainers, farmer field schools, farmer groups and online platforms. F2F extension encourages sustainable farming practices, boosts productivity and income, enhances climate resilience and strengthens rural communities. Although challenges like differing levels of expertise and cultural barriers exist, F2F models effectively empower farmers and lessen reliance on external support. Implementing best practices, such as investing in training, promoting gender equity and incorporating technology, is vital for expanding the reach and impact of F2F programs.

Introduction

Sustainable agriculture plays a crucial role in ensuring food security and maintaining environmental health worldwide. For agriculture to be genuinely sustainable, it must not only meet the needs of today but also protect the ability of future generations to fulfill their own needs. This necessitates continuous innovation and effective sharing of knowledge regarding sustainable practices, which is where agricultural extension services come into play. However, traditional extension services, often characterized by expert-led training programs, may not adequately address local needs due to variations in context, culture and available resources. This is where farmer-to-farmer (F2F) extension models come into the picture, offering an alternative approach that emphasizes peer-to-peer knowledge exchange. In these models, experienced farmers share their practical insights with fellow farmers in their communities. Research has shown that farmer-to-farmer extension is often more cost-effective, tailored to specific contexts and sustainable, as it leverages the existing knowledge and cultural understanding of farmers. This paper explores the role of F2F extension models in advancing sustainable agriculture, the ways in which knowledge is disseminated and the benefits and challenges associated with these approaches.

UNDERSTANDING FARMER-TO-FARMER EXTENSION MODELS

Farmer-to-farmer extension is a process where local farmers exchange knowledge about agricultural practices, innovations and solutions. The main distinction between traditional extension systems and F2F models lies in the focus on peer learning instead of expert-led interventions. F2F extension is based on the idea that farmers, being the primary practitioners, have a deeper understanding of their local environment, challenges and opportunities than anyone else. As a result, they are ideally positioned to educate one another.

TYPES OF FARMER-TO-FARMER EXTENSION

F2F extension models can vary widely, depending on available resources and community needs. Some key models include:

Peer Trainers and Lead Farmers: In this approach, a select group of skilled farmers (lead farmers) receive training in specific techniques or sustainable agricultural practices. These lead farmers then take on the role of trainers for other farmers in the community, conducting demonstrations, workshops and informal knowledge-sharing sessions.

Farmer Field Schools (FFS): This model emphasizes hands-on learning, where farmers gather in groups at a specific farm or demonstration plot to observe and practice new agricultural techniques. The focus is on participatory learning, allowing farmers to see practices in action and discuss challenges and opportunities in real time.

Farmer Groups and Cooperatives: These groups serve as collective knowledge hubs where farmers can come together, share ideas and discuss farming-related issues. While often informal, these groups can also take on a more structured form, such as agricultural cooperatives that concentrate on specific crops, livestock, or value chains.

Social Media and Online Platforms: Although they are less conventional, these platforms have become increasingly important in expanding the reach of farmer-to-farmer (F2F) models. Farmers from various regions can connect online, discuss challenges, share

resources and learn from one another.

IMPORTANCE OF FARMER-TO-FARMER EXTENSION MODELS

Relevance of Local Knowledge:

One of the key benefits of F2F extension models is the relevance of the knowledge exchanged. Farmers often encounter challenges that are specific to their geographical area, climate, soil type and socio-economic conditions. External experts may provide generalized advice that doesn't always fit these particular circumstances. In contrast, fellow farmers are much more in tune with the local context. They understand the nuances of the climate, pests, soil fertility and market conditions in their region, making their advice more applicable. The knowledge shared in F2F systems is typically context-specific and grounded in practical experiences rather than theoretical concepts.

Cost-Effectiveness

Traditional agricultural extension programs often require significant investments in infrastructure, personnel and resources. These programs may involve hiring outside experts, constructing training centres, or transporting educators to rural areas. In contrast, F2F extension models utilize existing community resources, which greatly lowers costs. Local farmers are already embedded in the community and their role as educators is either voluntary or compensated through incentive schemes that are typically more affordable than hiring external trainers.

Trust and Relationship Building

Trust is essential for effective knowledge-sharing. Farmers often place more trust in their peers than in outside experts because they relate to the common challenges of farming. A farmer who has successfully adopted a new crop variety or pest management technique can motivate others by showcasing results and sharing personal stories. This trust creates a learning community where farmers feel comfortable asking questions, acknowledging their failures and celebrating their achievements.

Empowerment and Capacity Building

Farmer-to-farmer extension empowers farmers by equipping them with the tools and

knowledge needed to enhance their practices independently. Through participation in F2F extension, farmers not only learn new techniques but also cultivate a sense of ownership over their educational journey. Lead farmers, in particular, develop valuable leadership and facilitation skills that can benefit them in various areas of their lives. This empowerment also reaches women and marginalized groups in rural communities. When F2F extension programs are designed with inclusivity in mind, they can offer these groups equal access to agricultural knowledge, thereby boosting their productivity and enhancing their roles in decision-making within both the household and the community.

BENEFITS OF FARMER-TO-FARMER EXTENSION FOR SUSTAINABLE AGRICULTURE

Sustainable Farming Practices Adoption: Sustainable agriculture encompasses methods that conserve resources, safeguard the environment and enhance the long-term viability of farming. Face-to-Face (F2F) models are crucial in advancing sustainable practices by enabling the sharing of practical solutions that farmers can implement right away.

Boosting Productivity and Income : A significant advantage of utilizing F2F extension models is the potential for increased farm productivity. As farmers share insights on enhanced farming techniques, like improved soil management, efficient irrigation methods, or pest control strategies, they can achieve higher yields. This boost in productivity not only contributes to food security but also enhances the earnings of the farmers involved.

Climate Resilience: The increasing effects of climate change pose new challenges for farmers, including changes in rainfall patterns, rising temperatures and the emergence of new pests. Face-to-face (F2F) extension models are particularly effective in promoting the sharing of climate-smart agricultural practices, such as drought-resistant crop varieties, efficient irrigation methods and conservation tillage techniques.

Knowledge Retention and Long-Term Learning :

A significant benefit of F2F extension models is the long-term retention of knowledge. Farmers are more likely to remember information shared by their peers because it is directly applicable to their situations, practical and often tied to local customs and practices.

- **Reinforced through repetition:** When farmers regularly share their knowledge with others, it strengthens their own understanding, as teaching can serve as a form of practice.

- **Continuing education:** F2F extension is not limited to formal training sessions or meetings. It fosters a cycle of ongoing learning where farmers continue to learn from each other, adapt their practices over time and refine their techniques. Consequently, knowledge is transmitted and enhanced within the community across generations, helping to preserve the agricultural skills and expertise of the community.

F2F models promote innovation within communities. : By encouraging local farmers to collaborate on problem-solving, these systems lead to the development of practices that are specifically tailored to the region's needs.

- **Grassroots innovations:** Farmers often take the lead in creating solutions to local issues. For instance, some may develop their own pest-resistant crop varieties or cost-effective irrigation methods that fit their local climate.

- **Adaptation to new challenges:** The sharing of knowledge through F2F models allows farmers to respond more effectively to challenges such as climate change, droughts, or changing market conditions. This innovation is based on real-time, practical problem-solving and tends to be more effective than theoretical solutions imposed from outside the community.

Strengthening Rural Communities : F2F extension programs enhance community bonds and help build social capital, leading to more resilient and unified rural communities.

- **Social cohesion:** As farmers work together, share ideas and tackle challenges, they forge stronger relationships and mutual trust, which can extend beyond agriculture into other areas of life (e.g., assisting each other during harvest or providing support in times of crisis).

- **Community mobilization:** Organizing farmers into

groups or cooperatives fosters a sense of collective responsibility, encouraging them to take ownership of the issues they face and pursue joint solutions. This communal approach can be particularly advantageous during disasters or economic downturns, as shared resources and collective action can help lessen losses.

Strengthening Local Agricultural Economies : Farmer-to-farmer (F2F) models play a vital role in bolstering local agricultural economies by enhancing farm productivity and providing farmers with opportunities to diversify their income streams.

- **Market access:** Farmers frequently share information about where to sell their products and how to reach markets that may have been previously inaccessible. This can involve direct sales, establishing market connections, or adding value to raw products. Improved market access allows farmers to sell their goods at more favourable prices, thereby increasing their income levels.

- **Supply chain development:** In certain F2F programs, farmers collaborate to create more efficient supply chains or cooperatives, reducing their dependence on middlemen. These cooperatives can pool resources to purchase inputs in bulk, access larger markets, or even provide shared processing facilities. By building stronger connections and a more integrated supply chain, farmers can gain better control over their earnings. This expanded market access not only enhances financial sustainability but also empowers farmers to compete in a globalized market, fostering growth within rural economies.

Reducing Dependency on External Assistance : Farmer-to-farmer extension diminishes farmers' reliance on external, often costly, agricultural support services. This fosters a more self-sufficient agricultural ecosystem where farmers are not solely dependent on government extension agents or large NGOs for guidance and resources.

- **Resilience:** As farmers gain more self-reliance, they become better equipped to tackle local agricultural challenges without waiting for external assistance. This leads to more resilient farming systems where knowledge is shared and developed within the community.

- **Sustainability:** Since F2F extension relies on

voluntary and peer-to-peer learning, it tends to be more sustainable in the long run compared to donor-funded, externally-driven programs that can be affected by funding cycles and political changes.

Building Farmer Leadership and Advocacy: By sharing knowledge, farmers enhance their leadership abilities and become advocates for their own needs. Those involved in F2F extension models often acquire important leadership and facilitation skills that empower them to represent their peers in decision-making processes.

Strengthening Food Security: At the heart of F2F extension models is the aim of enhancing food security for both households and communities. By boosting agricultural productivity, improving market access and encouraging sustainable farming practices, F2F models play a crucial role in ensuring a consistent and varied food supply.

- **Increased resilience to food crises:** Sharing knowledge equips farmers to better handle challenges like droughts, floods, or pest outbreaks. Those who are prepared with alternative strategies, such as drought-resistant crops or water-saving techniques, are less likely to experience significant losses during tough times.

- **Diversification of crops:** Through mutual learning, farmers can move towards diversifying their crops, which lessens their reliance on a single crop and helps maintain a more stable food supply. This also enhances the nutritional security of farming families, as a variety of crops can provide more nutrient-rich options. The advantages of food security reach beyond individual farms; a reliable and secure food supply fortifies communities, alleviates hunger and supports local economies.

CHALLENGES OF FARMER-TO-FARMER EXTENSION MODELS

Variability in Farmer Expertise

One of the challenges in implementing farmer-to-farmer extension is the difference in knowledge and expertise levels among farmers. Some may possess extensive knowledge of specific practices, while others might be less experienced. This disparity can lead to an uneven quality of information shared.

Consequently, some farmers may require additional support or training to ensure that the knowledge they provide is both accurate and effective.

Cultural and Social Barriers

In many rural areas, cultural and social barriers—such as gender, age, caste and ethnicity—can hinder certain groups from accessing knowledge-sharing networks. For instance, women or marginalized communities may struggle to participate in predominantly male farmer groups. Overcoming these barriers necessitates deliberate efforts to foster inclusive environments where all farmers can engage and learn from one another.

Limited Access to Resources

Although farmer-to-farmer models can be cost-effective, they still depend on resources like trained lead farmers, meeting spaces and transportation for group visits. In areas with limited resources, mobilizing these necessities can be challenging. For the model to be genuinely effective, support from local governments, NGOs, or other organizations may be essential to provide the necessary infrastructure.

Conclusion

Farmer-to-farmer extension models are essential for promoting sustainable agricultural practices and enhancing food security.

By utilizing the local knowledge and hands-on experiences of farmers, these models provide a cost-effective, relevant and community-focused approach to agricultural extension. Although there are challenges like varying levels of expertise and limited resources, farmer-to-farmer models have shown great success in encouraging sustainable farming methods and strengthening resilience within farming communities. With a strong emphasis on inclusivity, training and the use of modern technology, F2F extension models can significantly influence the future of agriculture. In conclusion, farmer-to-farmer (F2F) extension models offer a promising and cost-effective approach to enhancing sustainable agricultural practices and food security. By facilitating peer-to-peer knowledge exchange, these models ensure that local, context-specific knowledge is shared, fostering trust, collaboration and empowerment within farming communities. F2F models promote the adoption of sustainable practices, boost productivity and increase climate resilience, all while strengthening social capital and local agricultural economies. However, challenges such as variability in expertise, cultural barriers and resource limitations must be addressed for these models to reach their full potential. With continued support, training and inclusivity, F2F extension can significantly contribute to the long-term sustainability of agriculture and food security globally.

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ARTICLE ID: 07

How do plants know seasons? The science behind flowering time

Introduction

Every year, mango trees burst into bloom almost on schedule. Jasmine flowers fill the air with fragrance during particular months, and rice varieties flower only under specific day lengths. But how do plants know which season it is? They have no eyes to see a calendar and no brain to process information. Yet they can accurately sense seasonal changes and flower at the right time. The secret lies in an extraordinary biological system that allows plants to monitor their surroundings and respond to environmental cues such as sunlight and temperature.

Why Timing Matters

For a plant, flowering is one of the most important events in its life cycle. Successful flowering ensures the production of seeds and the continuation of the next generation. Timing is crucial. If a plant flowers too early, frost, drought, or other unfavourable conditions may damage its flowers and reduce seed production. If it flowers too late, seeds may not mature before the growing season ends.

Over millions of years, plants have evolved sophisticated mechanisms that help them determine the most favourable time to flower.

Reading Nature's Calendar

One of the most important signals plants uses is **day length**, a phenomenon known as **photoperiodism**. Plants can distinguish between the long days of summer and the shorter days of winter by measuring the length of darkness each night.

They achieve this using light-sensitive molecules that act like tiny biological sensors. In addition, plants possess an internal biological clock, known as the **circadian clock**, which keeps approximately 24-hour time and helps synchronize growth and development with daily environmental cycles.

Together, these systems enable plants to track seasonal changes with remarkable precision.

Rice: A Crop That Knows When to Flower

Rice is the staple food for more than half of the world's population, making its productivity critical for global food security. One of the key factors determining the adaptability of rice varieties is their flowering time.

Unlike humans, rice plants do not rely on calendars. Instead, they use a network of genes that sense day length and decide when flowering should begin.

Scientists have identified two major flowering pathways in rice. Under **short-day conditions**, a pathway involving genes such as *OsGI*, *Hd1*, *DTH8*, and *Hd3a* promotes flowering. Under **long-day conditions**, another pathway involving *Ghd7*, *Ehd1*, *Hd3a*, and *RFT1* regulates the flowering response (Wang et al., 2024).

Although these gene names may sound complex, their job is simple: they help the plant determine whether environmental conditions are suitable for reproduction.

The Flowering Messenger

One of the most fascinating discoveries in plant biology is the existence of a flowering signal known as **florigen**. In rice, the genes **Hd3a** and **RFT1** (Sun et al., 2023; Wei et al., 2016) produce proteins that act as flowering messengers. These proteins are synthesized in the leaves after the plant has correctly interpreted day-length signals. They then travel through the phloem—the plant's transport system—to the shoot tip, where new leaves and flowers are formed. Once they reach the shoot apical meristem, they activate floral identity genes such as **OsMADS14** and **OsMADS15**, triggering the transition from vegetative growth to flowering. In simple terms, the leaves "decide" that the season is right and send a message to the growing tip saying, "It's time to flower."

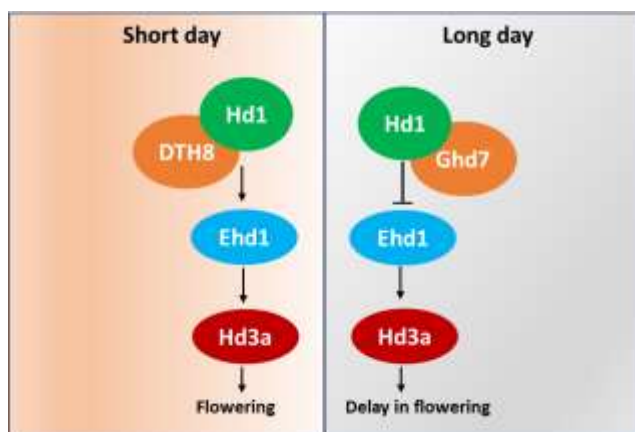


Figure 1. Major genes involved in the regulation of flowering time in rice.

Why This Research Matters

Understanding how plants control flowering has become increasingly important in the face of climate change.

Rising temperatures and unpredictable weather patterns can disrupt flowering schedules, affecting crop yields and food production.

Researchers are now using advanced breeding techniques and modern gene-editing tools such as CRISPR to modify flowering-time genes. These approaches can help develop crop varieties that are better adapted to changing climates, new growing regions, and future agricultural challenges.

Conclusion

Although plants lack eyes, and a brain, they possess remarkably sophisticated systems for tracking the seasons. By measuring day length, monitoring environmental conditions, and using internal biological clocks, plants can determine the perfect time to flower. The next time you see a rice field coming into bloom or a mango tree covered with flowers, remember that the plant is not simply responding to the weather—it is following a carefully programmed biological calendar that has evolved over millions of years.

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Push & Pull Strategies Using Insect Behavior Manipulation: A Modern Approach for Sustainable Pest Management

Introduction

Agricultural production is severely affected by insect pests, causing significant yield losses and threatening global food security. Excessive reliance on synthetic insecticides has led to pesticide resistance, environmental contamination, destruction of beneficial organisms and food safety concerns. These challenges have increased the need for sustainable and eco-friendly pest management approaches. The push-pull strategy is an innovative behavioral manipulation technique that exploits insect sensory responses. It uses repellent stimuli to drive pests away from the main crop (push) and attractive stimuli to lure them toward trap crops (pull). Based on principles of chemical ecology and insect behavior, it reduces pest pressure without heavy dependence on chemicals. The technology was initially developed for cereal stem borer management in East Africa. Since then, it has been successfully adopted in various cropping systems. Push-pull has become an important component of integrated pest management (IPM). Recent advances in chemical ecology, artificial intelligence and precision agriculture are further enhancing its effectiveness and applicability.

Scientific Basis of Push-Pull Technology

Push-pull systems are based on insect sensory biology. Insects utilize various cues to locate their hosts, including:

Chemical Cues

Volatile organic compounds (VOCs) released by plants serve as important signals for herbivorous insects. These chemicals may attract or repel insects depending on their composition and concentration.

Visual Cues

Color, shape and canopy structure influence insect orientation and landing behavior.

Tactile Cues

Surface texture and plant morphology may affect feeding and oviposition decisions.

Push-Pull Strategy

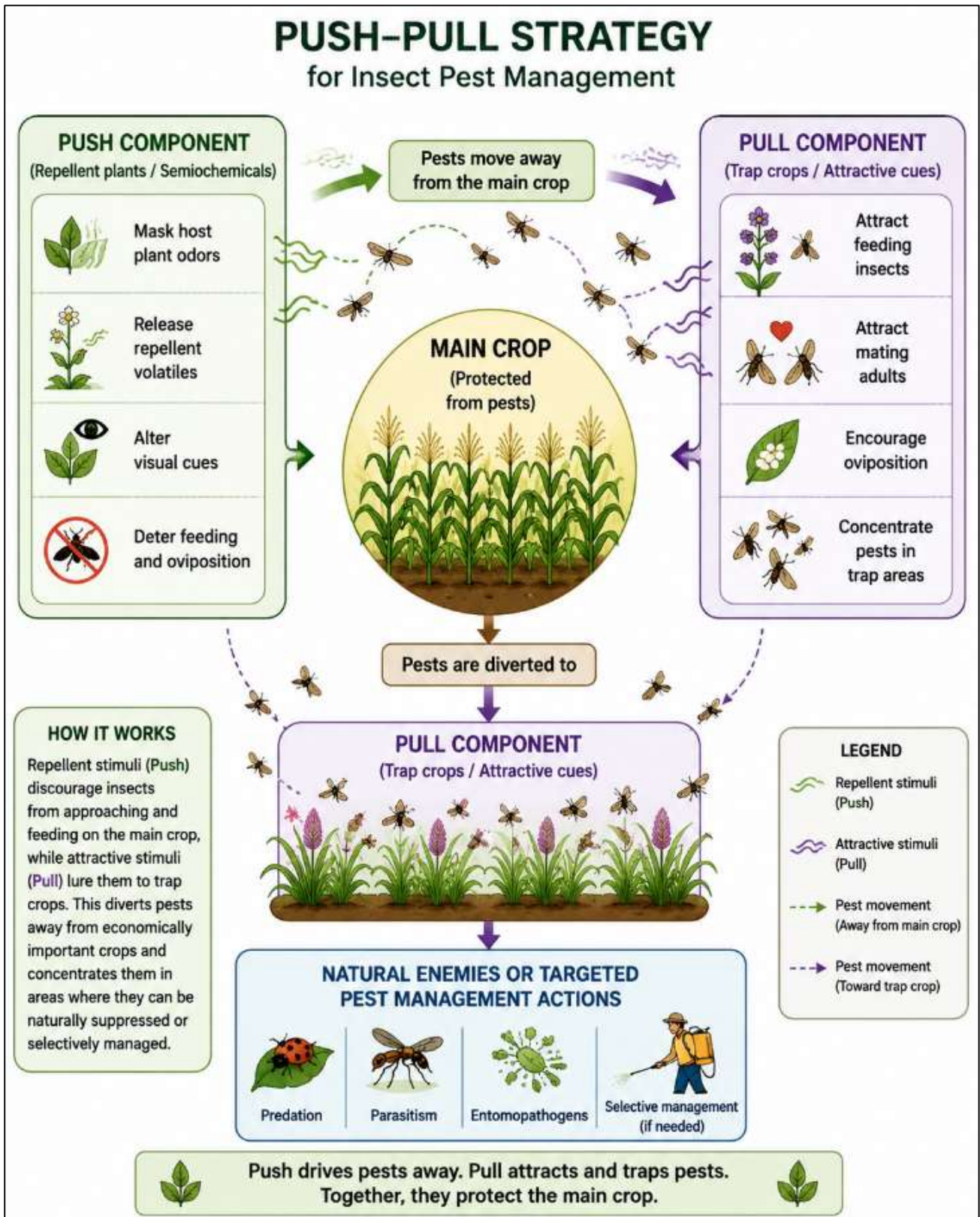
The push-pull strategy is a behavioral manipulation technique that combines repellent and attractive stimuli to alter the distribution and abundance of insect pests. The approach consists of two complementary components:

Semiochemicals

Manipulating these signals enables researchers to modify insect behavior without directly killing the pests. Important semiochemicals involved in push-pull systems include:

– Kairomones	– Allomones	– Synomones	– Pheromones
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PUSH-PULL STRATEGY for Insect Pest Management



Historical Development

The term push-pull was first introduced in Australia during the late 1980s while studying *Helicoverpa* species in cotton.

Components of Push-Pull Systems

Push Plants	Pull Plants
<p>Push plants are intercropped with the main crop and possess characteristics such as:</p> <ul style="list-style-type: none"> Repellent volatile emission Oviposition deterrence Feeding inhibition Host masking effects 	<p>Pull plants are generally planted around field borders and possess:</p> <ul style="list-style-type: none"> High attractiveness to pests Superior oviposition sites Attractive volatile blends
<p>Examples:</p> <ul style="list-style-type: none"> Desmodium spp. Molasses grass Marigold Rosemary Basil 	<p>Examples:</p> <ul style="list-style-type: none"> Napier grass Sudan grass Brachiaria grass Mustard Trap sunflower

Researchers combined repellent and attractive stimuli to alter pest distribution and reduce insecticide dependence.

Major breakthroughs occurred during the 1990s through collaborative research by the International Centre of Insect Physiology and Ecology (ICIPE), Kenya and Rothamsted Research, United Kingdom. Scientists developed a highly successful push-pull system for maize and sorghum production in Africa using *Desmodium* species as push plants and Napier grass as pull plants. This innovation became one of the most celebrated examples of ecological engineering in agriculture.

Natural Enemies: Modern push-pull systems often integrate biological control by enhancing populations of:

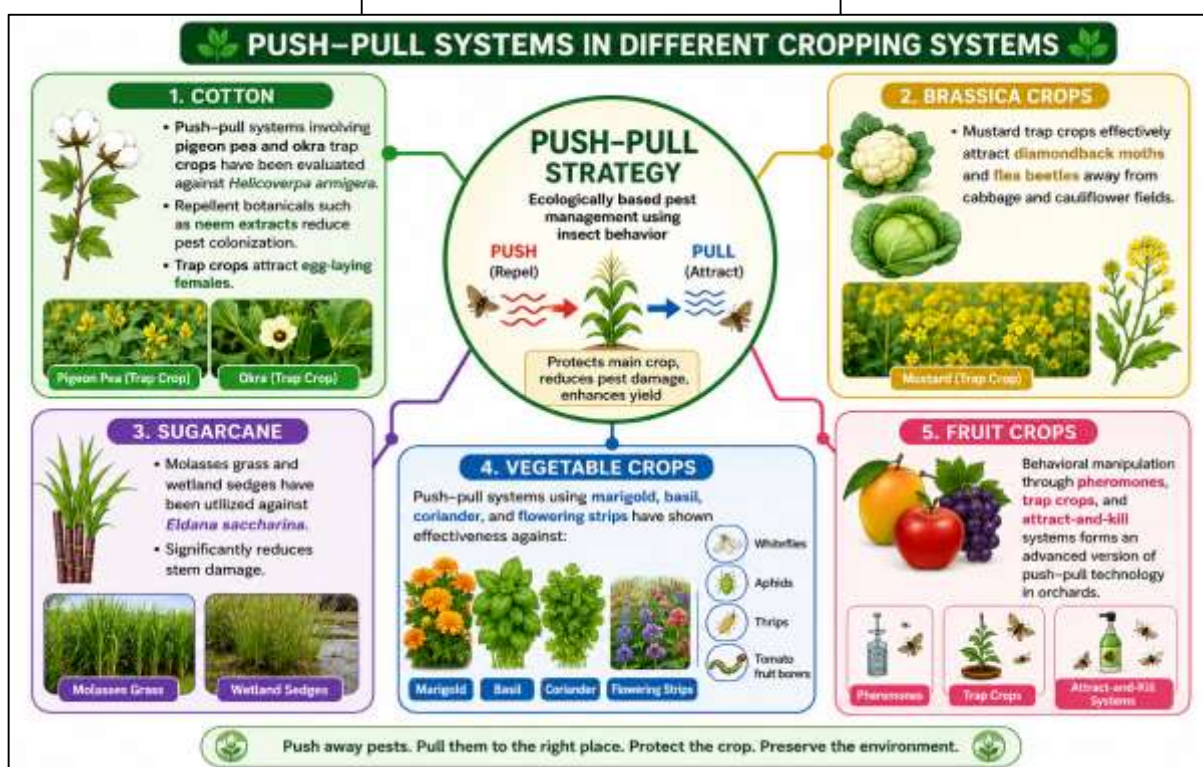
Parasitoids	Predatory beetles	Lacewings	Hoverflies	Spiders
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The African Maize Push-Pull Model

The maize stem borer push-pull system remains the most successful example worldwide.

Push Plant	Pull Plant
Silverleaf desmodium (<i>Desmodium uncinatum</i>)	Napier grass (<i>Pennisetum purpureum</i>)

Applications in Different Crops



Target Pests

<i>Chilo partellus</i>	<i>Busseola fusca</i>	<i>Sesamia calamistis</i>
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Desmodium emits volatile compounds that repel stem borer moths while simultaneously attracting parasitoids. Napier grass attracts female moths for oviposition. Upon hatching, many larvae fail to survive because Napier grass produces sticky substances that trap and kill them.

Yield increases of two to three times have been reported under successful implementation.

Emerging Innovations in Push-Pull Systems

1. Semiochemical Engineering

Scientists are identifying specific plant volatiles responsible for insect attraction and repellence. Synthetic formulations may soon replace companion plants in certain situations.

2. RNA-Based Behavioral Manipulation

RNA interference technology offers opportunities to disrupt insect sensory pathways involved in host selection and feeding behavior.

3. Smart Push-Pull Systems

Artificial intelligence and sensor networks can detect pest movements and automatically deploy attractants or repellents in precision agriculture systems.

4. Drone-Assisted Deployment

Unmanned aerial vehicles can monitor pest populations and facilitate site-specific implementation of push-pull tactics.

5. Climate-Smart Push-Pull

Researchers are developing drought-tolerant companion plants such as *Brachiaria* species to improve system performance under changing climatic conditions.

6. Genomics and Chemical Ecology

Advances in insect genomics are helping identify genes associated with olfaction and host recognition, enabling more targeted behavioral manipulation.

Advantages	Limitations and Challenges
<p>Environmental Safety The strategy minimizes pesticide use and reduces environmental pollution.</p>	<p>Knowledge Requirements Successful implementation requires understanding pest ecology and crop interactions.</p>
<p>Resistance Management Because insects are behaviorally manipulated rather than directly poisoned, selection pressure for resistance development is greatly reduced.</p>	<p>Initial Establishment Costs Seeds and planting materials may not always be readily available.</p>
<p>Biodiversity Conservation Push-pull systems support pollinators and natural enemies.</p>	<p>Crop Specificity Companion plants must be carefully selected for each pest-crop combination.</p>
<p>Improved Soil Health Many push plants contribute organic matter and fix atmospheric nitrogen.</p>	<p>Land Requirement Trap crops occupy space that could otherwise be used for the main crop.</p>
<p>Economic Benefits Farmers save costs associated with pesticide purchase and application while increasing productivity.</p>	<p>Variable Performance Environmental conditions may influence volatile production and pest responses.</p>
<p>Climate Resilience Diversified cropping systems exhibit greater resilience to drought, temperature fluctuations and extreme weather events.</p>	

Future Prospects

The future of push-pull technology lies in integrating ecological principles with advanced technologies. Precision agriculture, artificial intelligence, genomics, remote sensing and chemical ecology are expected to transform traditional push-pull systems into highly efficient pest management platforms.

Next-generation push-pull strategies may incorporate:

- AI-guided pest prediction
- Automated semiochemical dispensers
- Genetically enhanced companion plants
- Digital pest surveillance networks
- Precision biological control integration

Such developments will contribute significantly to sustainable agriculture while reducing dependence on synthetic pesticides.

Conclusion

Push-pull technology represents one of the most successful examples of ecological pest management developed in modern agriculture. By exploiting insect behavior through carefully selected repellent and attractive stimuli, the strategy provides effective, environmentally safe and economically viable pest suppression. Beyond controlling insect pests, push-pull systems improve biodiversity, soil fertility and farm resilience. Recent advances in chemical ecology, genomics, artificial intelligence and precision agriculture are opening new opportunities for the refinement of this technology. As agriculture moves toward sustainability and climate resilience, push-pull strategies are likely to become an increasingly important component of future integrated pest management programs worldwide.

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ARTICLE ID: 09**Enhancing Nutrient Bioavailability in Aqua-feed through
Solid-State Fermentation (SSF)****Introduction**

The aquaculture industry is currently facing a challenge to feed a rapidly growing population of farmed aquatic food without harming the ocean's natural food webs. As the availability of trash fish or discarded fish is reduced over time, so its necessity to reduce fish meal use for aqua feed. To overcome this problem, plant-based protein sources have been extensively adopted as a solution to ensure protein security within the diets of many aquatic species and poultry that have reached great success in the past two decades (Michael et al., 2016; Daniel, 2018). Food waste is also one of the emerging challenges; about 19% of consumable food for the population (approx. 931 million tonnes) was wasted in 2024. It was responsible for 8-10% of global greenhouse gas emissions, accounting for \$1 trillion in economic losses (Food Waste Index Report, 2024). Food waste is also contributing to environmental degradation, economic losses, and increased pressure on global food systems (EFFPA, 2018; Economou et al., 2024). Utilizing these by-products of food industry as alternative raw materials for aquafeed can decrease dependency on conventional feed ingredients in global markets, cut costs, and boost the aquaculture sector through alternative feed ingredients. As plant-based feed contains ANF (anti-nutritional factors), to neutralize the ANF and increase the bioavailability of feed ingredients of aquafeed for potential use in aquafarms, researchers or scientists are looking forward to utilize an ancient biological process known as fermentation. Fermentation is defined as a biochemical process that transforms any organic matter via microbial metabolism, mediated by myriad enzymes (Chai et al., 2022). Submerged fermentation technology (SmF) may be considered a kind of alteration of the natural habitats of wild-type microorganisms. Whereas, solid state fermentation is used to metabolised enzyme and secondary metabolite production because of process engineering problems. Solid-State Fermentation (SSF) is emerging as a natural process that has the ability to neutralize the ANF and improve the bioavailability of plant-based feed ingredients to make nutrient-rich aquafeed. SSF is defined as any fermentation process performed on a non-soluble material that acts both as physical support and source of nutrients in absence of free flowing liquid (Pandey, 1992). The resulting products can offer a complex method for ongoing fermentation in the digestive systems of livestock by supplying residual bioactive components that could potentially break down dietary fractions that were previously indigestible. Improved animal performance has been noted when solid-state fermentation products are included in modern formulations for Nile tilapia *Oreochromis niloticus* (Hassaan et al., 2017).

Bioavailability Gap

Wild trash fish or bycatch that was traditionally used to make fish mela and that fish mela used in preparation of aquafeed cannot reproduce fast enough to meet the current demand (Kalaiselvan et al., 2025).

Historically, for aquafeed, fishmeal is used as a nutrient-rich diet and digestible powder made from wild-caught pelagic fish, like anchovies and sardines. Dependency on fishmeal creates an unsustainable catch of these fishes. It causes the decrease its supply of wild fish, leading fishmeal prices to surge, threatening the economic viability of fish farming (Kari et al., 2021). To reduce dependency on fishmeal, the aquaculture sector is shifting towards terrestrial plant protein sources, primarily soybean meal, mustard oil cake, groundnut oil cake, etc. Because these agricultural products are available in abundant quantity at low cost. However, it faces some limitations in the ingredients taken from plant sources contain a variety of anti-nutritional factors (ANFs) as defensive chemicals that prevent aquatic animals from properly digesting and absorbing the plant-based nutrients. Plant-based ingredients contain proteins and essential minerals such as phosphorus, calcium, and zinc. Moreover, in plants, these minerals are tightly bound in the form of a complex organic molecule called phytic acid (or phytate) or other ANFs. The fish have no intestinal enzyme (phytase) that is required to break the molecule, the minerals remain biologically unavailable and pass through the fish digestive tract (Joseph et al., 2008). Carnivorous farmed fish such as salmon and trout have relatively short digestive tracts designed to process animal protein, not complex plant-based carbohydrates. Feeding them raw soybean meal is similar to feeding a human a diet of raw wheat or rice. Along with that, plants contain other ANFs like trypsin inhibitors (block protein digestion) and saponins (cause inflammation in the fish intestine). When fish consume highly concentrated and unprocessed plant-based feeds, they experience poor growth, weak immune systems, and intestinal inflammation (enteritis). Ecologically, the consequences are equally severe. Undigested phosphorus and nitrogen are excreted into the ecosystem and may cause nutrient pollution, triggering eutrophication and leading to algal blooms that suffocate local aquatic animals (Oiza et al., 2022).

SSF Microbes

Solid-state fermentation, being a natural biochemical process, involves beneficial microorganisms, mainly

filamentous fungi, yeast, and bacteria. Fungi species, i.e., *Aspergillus niger*, *Trichoderma reesei*, *Rhizopus oligosporus*, and *Pleurotus ostreatus*, have been used in SSF for a broad range of enzymes they synthesize, i.e., cellulose, xylanase, protease, lipase, etc., which break down complex carbohydrates, proteins, and lipids, along with a variety of plant-based nutrients (Feng et al., 2024; El-Gendi et al., 2021). Similarly, bacteria, i.e., *Bacillus subtilis*, *Lactobacillus*, and *Streptomyces*, play a vital role in the process of SSF, as they secrete various extracellular enzymes, which may enhance the digestion of feed in fish through an increase in beneficial bacteria in the gut of fish. Also, producing antimicrobial peptides helps in the reduction of pathogens (De Villa et al., 2023).

In the process of SSF, the benefit acts as an external digestive system, which invades the plant material and produces a broad range of strong enzymes to disintegrate the plant's stiff cellular structure, thus pre-digesting the food before the fish ever ingests it.

Biochemical Mechanisms of SSF

The microbes release many extracellular enzymes such as cellulase (breaks down plant fibre), protease (digests plant proteins into absorbable peptides), and phytase. The phytase enzyme targets and digests phytic acid, successfully releasing the bound phosphorus and making it bioavailable (Kalaiselvan et al., 2025). As the microbes digest the plant matter, their own biomass grows. This microbial biomass is also highly rich in high-quality protein. Furthermore, the microbes naturally synthesize essential amino acids (lysine and methionine) and vitamins and improve a low-grade agricultural byproduct to a good quality feed ingredient (Joseph et al., 2008).

Preparation of fish feed

To formulate fish feed, take available conventional and non-conventional feed ingredients, i.e. maize, soyabean meal, de-oiled rice bran (DORB), sesame oil cake (*Sesamum indicum*), mahua oil cake (*Bassia latifolia Roxb*), vegetable oil, minerals and vitamin mixture as per the requirement of fish, and then solid ferment with yeast, *Saccharomyces cerevisiae*, maintaining standard protocol. After solid state fermentation, make fish feed as required e.g. pelleted feed (Das et al., 2021).

Procedure of making Solid-State Fermentation (SSF) of fish feed

Protocol to produce the upgraded feed using yeast (*Saccharomyces cerevisiae*) (Das et al., 2021)

1. Take ground feed in a flask.
2. Autoclave at 15 psi for 15-20 minutes at 121°C.
3. Add 200 ml of sterilized distilled water and 500 ml of already prepared inoculum for 1000 g ground feed.
4. Close the mouth with a screwed wooden lid and incubate at 37°C for 48 hr.
5. Stare at the flask and add sterilized distilled water periodically to maintain 70% water content.
6. Then dry the inoculated feed at 65°C for 24 h, cool and grind
7. Check the microbial count if we want to conform using a standard protocol.
8. Make the feed according to the requirement.

Waste to wealth approach

The scope of SSF is not limited to standard crops like soya, it can also utilize cheap, fibrous agricultural wastes such as citrus peels, apple pomace, wheat bran, and rice husks, etc. (Oiza et al., 2022) by fermenting these materials and transforming them into high-value nutritional food for the aquaculture industry.

Advantage

The application of SSF technology has many benefits across the entire aquaculture supply chain:

- Fish fed with fermented ingredients have better gut health. Fermented feeds actually change the physical structure of the fish's intestines, increasing the length of the intestinal villi. Longer villi mean a larger surface area for nutrient absorption. (Kari et al., 2021).
- Feed cost accounts for 50% to 70% of total operating cost in aquaculture. Locally available agricultural byproducts can be nutritionally upgrading through fermentation.
- SSF breaks down phytic acid so that fish can absorb natural phosphorus instead of excreting it. This process highly reduces the nutrient load in rivers and oceans that prevent toxic algae blooms and maintain aquatic biodiversity (Kalaiselvan et al., 2025).

Conclusion: SSF is a biochemical process well-documented in laboratories. The current challenge in scaling SSF to an industrial level that it requires sophisticated bioreactors capable of managing heat dissipation, moisture levels, and aeration across tons of solid substrate. To utilize the potential of this natural process of solid-state fermentation, the need of the hour is to realize the potential of biochemical changes and nutrient improvement. Although the process of solid-state fermentation is time-consuming, it is more efficient and reliable than the conventional process of feed making in the aquaculture industry.

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Buckwheat: a pseudo cereal with multifunctional properties

Introduction:

Buckwheat (*Fagopyrum spp.*) is an underutilized crop, commonly classified as a pseudocereal, which is getting increased attention from researchers and consumers because of its excellent nutritional value, agronomic adaptability, and functional properties. Buckwheat is gluten free which makes it as alternative for consumers who desire gluten free or are suffering from celiac diseases or gluten intolerances. It has high quality proteins, dietary fiber, essential amino acids, minerals, and bioactive compounds including flavonoids (especially rutin) which has antioxidant, anti-inflammatory and cardio protective properties. This article presents the many dimensions of buckwheat including its Health benefits, nutritional value, food and industrial applications. It may be a fit for health promotion and a contributor to global food security within sustainable diversified agroecosystems.

Keywords: Buckwheat, gluten free, bioactive compounds, nutritional value, sustainable agriculture, Global food security.

Health benefits:

In the verge of prevailing life style health problems like diabetes, obesity, heart disease, and digestive problems. People all over the world are becoming more aware of what they consume and how it affects the health in long term and prevents diseases. Functional foods that are good for health or boost immunity, are gaining popularity. Buckwheat (*Fagopyrum spp.*) is a gluten-free pseudocereal that is not used very often but has a lot of nutrients and bioactive compounds. Buckwheat primary health benefits include its neuroprotective, antioxidant, hypotensive, hypo glyceemic, and hypo cholesterolemic properties. It is different from most staple cereals because it has high-quality proteins with a good balance of amino acids. One of the amino acids, lysine, is often lacking from grains. Incorporating buckwheat into diet on a regular basis can lead to several health benefits. The antioxidants present in buckwheat play a role in decreasing the likelihood of chronic conditions such as heart disease and cancer. It is acknowledged for its ability to boost cardiovascular health by lowering cholesterol and enhancing blood circulation. With its low glyceemic index, buckwheat is a suitable option for individuals with diabetes. Being gluten-free, it is especially advantageous for those with gluten intolerance. Its rich fiber content promotes digestive health and helps prevent constipation.

Nutritional composition of buckwheat:

Buckwheat has balanced composition of macronutrients and micronutrients. It provides high quality protein with essential amino acids such as lysine, which is usually limited in cereals. It is also rich in dietary fiber, which helps digestion and promotes gut health. In addition to macronutrients, buckwheat contains significant amounts of vitamins such as thiamin, riboflavin, niacin, folate, and vitamins A, C, E, and K. It is also a good source of minerals including magnesium, phosphorus, potassium, and calcium.

These nutrients contribute to overall health and help prevent nutritional deficiencies. People with celiac disease or gluten intolerance can consume buckwheat and buckwheat flour as alternative because of its gluten free nature.

NUTRIENTS	VITAMINS
5.68gm of protein	Thiamin
155 Calories (Kcal)	Riboflavin
1.04gm of fat	Niacin
33.5gm of Carbohydrate	Folate
4.5 gm of fiber	Vitamin A C E K
148 mg of potassium	Vitamin B6
118 mg of phosphorus	
86 mg of Magnesium	
12mg of Calcium	

Table 1. Nutritional composition of roasted buckwheat groats (per 168 g). Reproduced from Kandola, A. (n.d.). What are the health benefits of buckwheat?

As a result, it is regarded as a substitute food ingredient in the dietary management of metabolic and chronic conditions like diabetes, high blood pressure, and celiac disease. Additionally, its high nutrient content promotes a healthier eating profile and supports a daily diet. Buckwheat is therefore recognized as a functional food that is used to treat illnesses and is thought to enhance human health.

a. Traditional applications of buckwheat:

Buckwheat has been a staple in human diets for centuries, woven into the culinary fabric of the Himalayas, Eastern Europe, Japan, and numerous regions across China. Traditional buckwheat-based foods exhibit considerable diversity across different cultures, mirroring local culinary traditions and socio-cultural backgrounds. In India's Himalayan regions Uttarakhand, Himachal Pradesh, and parts of the Northeast buckwheat flour is regularly use in cooking. It's a staple in many recipes, appearing in everything from kuttu ki roti and cheela, Dosa, pakoras, chapatis and halwa for festive occasions. These foods are valued not only for their distinctive earthy flavor but also for their ability to provide energy, warmth, and satiety in harsh climates.

Source	Common Buckwheat	Tartary Buckwheat	Wheat, whole	Rice, milled	Barley	Maize, dry	Jowa ^a	Ragi ^b	Varag ^c	Bajra ^d
Energy	343	328	322	356	316	334	334	321	332	348
Carbohydrates	71.5	74.3	64.7	78.2	61	65	67.7	66.8	66.2	61.8
Protein	13.3	10.3	10.6	7.9	10.9	8.8	10	7.2	8.9	11
Lipids	3.4	2.5	1.5	0.5	1.3	3.8	1.7	1.9	2.5	5.4
Dietary Fibre	10	6.3	11.2	2.8	15.6	12.2	10.2	11.2	6.4	11.5
Ash	2.1	1.8	1.4	0.6	1	1.2	1.4	2	1.7	1.4
Moisture	9.8	10.2	10.6	9.9	9.7	9.3	9	10.9	14.2	9

Source: Adapted from Przybylski and Gruczynska [11] and Indian Food Composition Table [12]; ^aJowa (Sorghum vulgare); ^bRagi (Eleusine coracana); ^cVaragu (Setaria Italica); ^dBajra (Pennisetum typhoideum)

Table 3. Comparison of nutritional composition of buckwheat with other crops.

Adapted from Nalinkumar & Singh (n.d.).

FOOD AND INDUSTRIAL APPLICATION:

Food Industry:

Buckwheat has a balanced nutritional value and is a rich source of several vitamins and minerals. It has been utilized for human consumption from ancient times. Buckwheat's primary health benefits include its neuroprotective, antioxidant, hypotensive, hypoglycemic and hypo cholesterolemic properties.

b. Modern applications of buckwheat:

Modern buckwheat foods go beyond traditional preparations and include a wide range of processed and convenience products such as **buckwheat pasta, noodles, bread, cookies, energy bars, breakfast cereals, and ready-to-eat snacks**. Food industries are also utilizing buckwheat in value-added products like **protein-rich flour blends, functional beverages, and plant-based foods**, highlighting its role in the growing market for clean-label and functional nutrition.

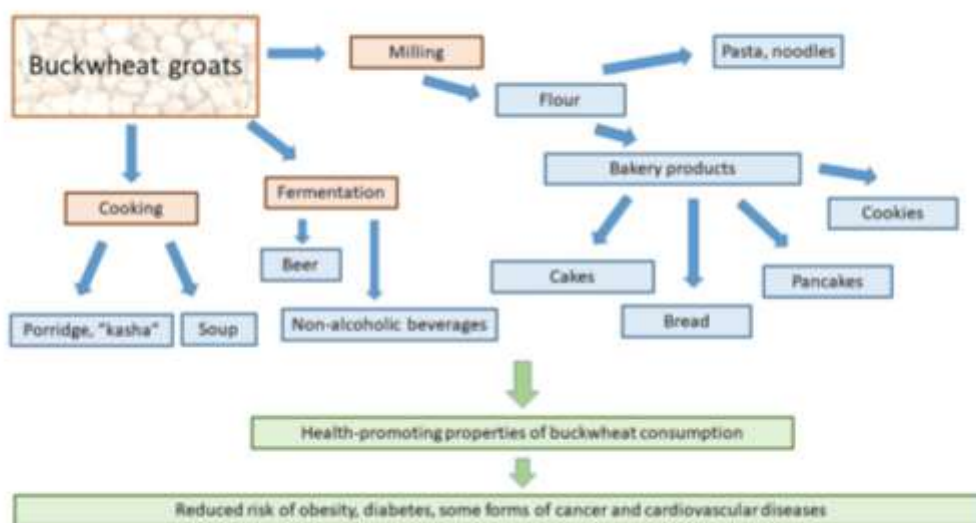


Figure 1. Buckwheat-based foods and associated health effects.

Pharmaceutical applications:

Buckwheat is an important source of bioactive flavonoid such as Rutin and Quercetin. Which has significant application in the pharmaceutical industry. These compounds exhibit strong antioxidant, anti-inflammatory, and vasoactive properties, making them valuable in therapeutic formulation. Rutin is a major flavonoid in Buckwheat, it is widely used for strengthening blood vessels by reducing capillaries fragility and improving vascular function, it is use for mainly treating cardiovascular disorder. Quercetin is formed from degradation of Rutin, also contributes to pharmacological effects such as anti-inflammatory and protective action against oxidative stress. Due to these properties buckwheat derived flavonoids and commonly utilized in nutraceutical and suppliments aimed at improving cardiovascular health and overall physiological function.

Agriculture and Environmental applications:

Buckwheat is a widely valued in Agriculture and environmental management due to its multifunctional role as a green manure, cover crop and Bee forage. As a green manure crop buckwheat grows rapidly and produces sustainable biomass that, when incorporated into the soil, enhances soil fertility by improving organic matter content and nutrient availability particularly phosphorus. Its dense canopy and fast establishment make it an effective cover crop. Helping to supress weeds by outcompeting then for light and nutrients while also protecting soil from erosion caused by wind and water. Its flowers are highly

attractive to pollinators, especially bees making it an excellent forage crop that supports apiculture and leads to the production of high quality dark coloured honey rich in antioxidants. These combined benefits make buckwheat an important compound in sustainable and eco-friendly agriculture system.

Industrial processing and By products:

Many valuable by products are obtained from buckwheat making it an economically and environmentally important crop. One of the primary by product is the buckwheat hull, the outer covering removed during milling, which is widely utilized as an eco friendly filling material in pillow and cushions. these hulls can also be used as a source of biomass for fuel and energy production. Buckwheat processing also yields starch, which has applications in the manufacture of biodegradable films, adhesives, and other sustainable industrial materials because of its favourable physicochemical properties. Furthermore, bran and other milling residues are used in animal feed and nutraceutical products due to their high fiber and antioxidant content. The efficient utilization of these by-products not only adds value to buckwheat processing industries but also supports waste minimization and sustainable resource management.

CONCLUSION:

Buckwheat, a highly valued pseudocereal, holds considerable value due to its nutritional, functional, and economic attributes. Its impressive array of high-quality proteins, dietary fiber, essential

amino acids, vitamins, minerals, and bioactive compounds like rutin and quercetin positions it as an excellent food choice for supporting human health and warding off diseases linked to modern lifestyles. The growing understanding of gluten intolerance and chronic health issues has only amplified its significance as a functional and gluten-free food option.

Moreover, the uses of buckwheat go beyond its health benefits.

It plays a crucial role in both traditional and contemporary food systems, finds application in pharmaceuticals thanks to its bioactive compounds. Despite its many advantages, buckwheat is still not used as much as it could be. Consequently, more intensive research, genetic enhancement, product innovation, and public awareness campaigns are essential to fully realize its potential. Therefore, promoting buckwheat can improve nutrition and health, while also supporting sustainable farming and strengthening global food security.

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Nano Fertilizers: India's Next Agricultural Revolution or Just Another Input?

Abstract

Indian agriculture is currently facing multiple interconnected challenges including declining soil fertility, excessive dependence on chemical fertilizers, rising cultivation costs, climate stress, and increasing pressure on fertilizer subsidies. In recent years, nano fertilizers have emerged as one of the most promoted agricultural innovations in India, attracting attention from policymakers, scientists, fertilizer industries, and farmers alike. This article examines whether nano fertilizers represent a genuine agricultural revolution or merely another addition to the existing input-intensive farming system. The article discusses the growing importance of nano fertilizers in the context of low nutrient-use efficiency associated with conventional fertilizers, particularly urea, where a significant proportion of nutrients is lost through leaching, volatilization, and runoff. It further highlights global disruptions, conflict and fluctuations in international fertilizer markets, exposed the vulnerability of import-dependent fertilizer systems and intensified the search for more efficient nutrient management technologies. The paper explores the various reasons behind India's aggressive promotion of nano fertilizers, including reduction of fertilizer subsidy burdens, decreasing import dependence, support for precision agriculture, climate-resilient farming, and integration with emerging technologies such as drone-based nutrient application. Government initiatives, institutional involvement, and large-scale awareness campaigns are also discussed. At the same time, the article critically examines field-level realities, including mixed farmer experiences, the need for crop- and region-specific recommendations. The discussion emphasizes nano fertilizers as potential components of integrated and efficient farming systems. The article concludes that the future success of nano fertilizers will depend on balanced policy support, independent research, farmer awareness, localized field performance, and their integration with sustainable soil and crop management practices rather than on promotional narratives alone.

Introduction

Indian agriculture is standing at a critical turning point. Farmers today are expected to produce more food from shrinking landholdings under increasingly uncertain climatic conditions. At the same time, cultivation costs are rising, soils are losing fertility, groundwater is becoming polluted, and dependence on chemical fertilizers continues to deepen.

On the other hand, Recent global conflicts and geopolitical disruptions have also exposed the vulnerability of fertilizer dependent agricultural systems, that particularly effecting the global fertilizer supply chains, increased energy prices, and caused sharp fluctuations in fertilizer availability and costs across many countries. In this complex situation, nano fertilizers have emerged as one of the most discussed agricultural technologies in recent years.

From Parliament discussions and government campaigns to fertilizer companies and agricultural universities, nano fertilizers are now being projected as a major component of India's future farming strategy. Products like nano urea and nano DAP are being promoted not merely as fertilizers, but as tools for improving nutrient efficiency, reducing import dependence, lowering subsidy burdens, supporting precision agriculture, and strengthening climate-resilient farming systems.

But an important question remains, are nano fertilizers truly the next agricultural revolution, or are they simply another input entering an already crowded fertilizer market? The answer may lie somewhere in between.

India's Fertilizer Challenge

India's Green Revolution transformed the country from a food-deficit nation into one of the world's leading agricultural producers. However, this transformation came with heavy dependence on synthetic fertilizers, especially urea. Over the decades, fertilizer consumption increased rapidly, often without balanced nutrient management. Many farmers began applying excessive nitrogen while neglecting micronutrients and soil organic matter.

The consequences are now visible across many farming regions:

- declining soil fertility,
- nutrient imbalances,
- groundwater contamination,
- reduced fertilizer-use efficiency,
- and increasing cultivation costs.

India also spends enormous amounts every year on fertilizer subsidies. In addition, the country depends heavily on imports of fertilizers and raw materials, making agriculture vulnerable to international price fluctuations and geopolitical disruptions.

Recent geopolitical conflicts exposed the vulnerability of global fertilizer supply chains and significantly affected fertilizer availability and prices in India. The conflict increased global fertilizer prices, disrupted shipping routes, and created uncertainty in fertilizer availability across many countries. Since India depends heavily on fertilizer imports and imported raw materials, these disruptions increased subsidy burdens

and raised concerns regarding long-term fertilizer security. Studies and policy reports also indicate that the war accelerated India's search for alternative suppliers, efficient nutrient-use technologies, and reduced dependence on conventional fertilizer systems. In this context, nano fertilizers began receiving greater policy attention as part of India's broader strategy toward nutrient efficiency, fertilizer security, and precision agriculture

Climate change has added another layer of uncertainty. Irregular rainfall, prolonged dry spells, heat stress, and water scarcity are forcing policymakers and scientists to rethink how nutrients are supplied to crops.

It is in this context that nano fertilizers are being promoted as a potential solution.

What Are Nano Fertilizers?

Nano fertilizers are fertilizers developed using nanotechnology, where nutrient particles are engineered at an extremely small scale, usually below 100 nanometers. Because of their tiny size and high surface area, these particles are expected to improve nutrient absorption and reduce nutrient losses.

Unlike conventional fertilizers that are generally applied to the soil in large quantities, many nano fertilizers are designed for foliar application, where nutrients are sprayed directly onto plant leaves. The idea is to provide nutrients more efficiently and in smaller quantities.

Among the most widely discussed products in India are nano Urea and nano DAP. Nano micronutrients such as nano zinc and nano copper are also being explored for future use.

Supporters argue that nano fertilizers can increase nutrient-use efficiency, reduce environmental losses, lower transport costs, and improve crop productivity. Critics, however, argue that long-term independent research and location-specific evaluations are still needed before large-scale conclusions can be drawn.

Why Is India Betting Big on Nano Fertilizers?

The growing push for nano fertilizers is not driven by a single reason. Rather, it reflects multiple economic, environmental, and policy priorities.

Reducing Fertilizer Subsidy Burden

One major reason is the rising fertilizer subsidy

burden. India spends massive amounts annually on subsidizing fertilizers, particularly urea. According to the Department of Fertilizers (2025), Indian government's final expenditure on fertilizer subsidies for the 2024-25 fiscal year was ₹1,91,836 crore. Excessive and imbalanced fertilizer use increases this financial pressure. Nano fertilizers are being promoted as a way to improve efficiency while reducing overall fertilizer consumption.

The government's broader message is gradually shifting from "more fertilizer" to "better fertilizer efficiency."

Improving Nutrient-Use Efficiency

One of the biggest challenges in Indian agriculture is the low nutrient-use efficiency of conventional fertilizers. According to Bijay-Singh et al. (2023), nitrogen-use efficiency in India declined from 48% to 35% between the Green Revolution period and 2018. A considerable proportion of applied nitrogen fertilizers is lost before crops can absorb them efficiently.

Studies report that only about 30–40% of applied nitrogen is effectively recovered by crops, while substantial amounts are lost through volatilization, leaching, denitrification, and runoff. Research further indicates that up to 30% of applied nitrogen may be lost through ammonia volatilization and 0–20% through leaching under certain agricultural conditions (Nayak et al., 2017; Huang et al., 2017; Zhang et al., 2015).

Such nutrient losses not only reduce nitrogen-use efficiency (NUE) and increase cultivation costs for farmers, but also contribute to groundwater contamination, greenhouse gas emissions, air pollution, and soil degradation.

Nano fertilizers are also gaining attention because of their controlled and gradual nutrient release characteristics. Unlike highly soluble conventional fertilizers that may lose nutrients rapidly, nano fertilizers are designed to release nutrients slowly and more efficiently according to crop demand. This gradual release mechanism may improve nutrient absorption by plants while reducing nutrient losses to the environment, thereby enhancing fertilizer-use

efficiency (El-Saadony et al., 2021). This approach aligns with India's broader goals of balanced fertilization, resource conservation, and sustainable nutrient management.

Reducing Import Dependence

India's fertilizer sector remains highly import-dependent, with nearly 90% of phosphatic and potassic fertilizer raw materials and over 80% of the natural gas used for urea production sourced from abroad. As a result, geopolitical conflicts and global supply disruptions have exposed the vulnerability of India's fertilizer system and strengthened the need for improved nutrient-use efficiency and alternative fertilizer technologies (Business Standard, 2026).

Precision and Smart Agriculture

Modern agriculture is increasingly moving toward precision farming, where inputs are applied based on actual crop requirements rather than blanket recommendations. Nano fertilizers fit well into this vision because they are linked with targeted nutrient delivery, controlled application, and reduced wastage. This is particularly relevant as India promotes digital agriculture, sensor-based farming, and data-driven nutrient management systems.

India is also integrating nano fertilizers with emerging agricultural technologies such as drone-based spraying systems. Under initiatives such as the Namo Drone Didi Scheme and Sub-Mission on Agricultural Mechanization (SMAM), drones are increasingly being used for foliar application of nano fertilizers and pesticides. Government-supported demonstrations conducted through ICAR institutions, Krishi Vigyan Kendras, and State Agricultural Universities indicate a growing shift toward precision-based and technology-enabled nutrient management systems (Ministry of Chemicals and Fertilizers, 2026).

Climate-Resilient Agriculture

Climate stress is affecting crop productivity in many rainfed regions. Nutrient losses due to erratic rainfall and extreme temperatures are becoming common. Nano fertilizers are often presented as climate-smart tools because they require smaller doses and can potentially improve nutrient availability under stress conditions.

Ease of Storage and Transportation

One of the most publicized comparisons is that a small bottle of nano urea can potentially substitute part of a large bag of conventional urea. Whether this comparison applies equally across all crops and conditions remains debated, but there is little doubt that nano fertilizers offer logistical advantages.

Smaller packaging reduces transportation costs, storage space, and handling difficulties, especially in remote areas.

Integration with Drone Agriculture

India is also rapidly promoting agricultural drones. Nano fertilizers, particularly foliar sprays, fit naturally into drone-based nutrient application systems. This integration could become increasingly important in future large-scale farming operations.

Government Promotion at an Unprecedented Scale

India's promotion of nano fertilizers is occurring at a remarkably large scale. What initially appeared to be a technological experiment is gradually becoming part of national agricultural policy discussions. India's promotion of nano fertilizers is now occurring at a national scale. According to the Ministry of Chemicals and Fertilizers, cumulative sales of nano fertilizers have crossed 1,593 lakh bottles, including nano urea and nano DAP formulations. The Department of Fertilizers, in collaboration with fertilizer companies and research institutions, has launched large-scale awareness campaigns, field demonstrations, and farmer interaction programs across all 15 agro-climatic zones of the country. Nano fertilizers are being distributed through Pradhan Mantri Kisan Samridhi Kendras (PMKSKs) and integrated into regular fertilizer supply planning frameworks (Ministry of Chemicals and Fertilizers, 2026).

To further strengthen adoption, nano urea has been incorporated into the Department of Fertilizers' monthly supply planning framework to ensure regular availability. In addition, nationwide campaigns promoting balanced fertilizer use, including nano fertilizers, are being conducted with the involvement of institutions such as the Indian Institute of Soil Science (Department of Fertilizers (2025)). The involvement of institutions like IFFCO has further

accelerated awareness and commercialization efforts.

A large-scale "Maha Abhiyan" on nano DAP is also being implemented across agro-climatic zones through field demonstrations and farmer interactions. The government is also encouraging modern application methods such as drone spraying and battery-operated sprayers, supported by trained village-level entrepreneurs. Pilot projects covering 100 districts are currently assessing the field-level performance and adoption potential of nano urea under diverse agroecological conditions.

These developments indicate that nano fertilizers are no longer being treated merely as experimental products but are increasingly becoming part of India's broader strategy toward nutrient-use efficiency, precision agriculture, and climate-resilient farming systems.

But Is the Ground Reality Matching the Hype?

This is where the discussion becomes more complex. While several demonstrations and reports show encouraging results, farmer experiences remain mixed and highly location-specific. Some farmers report greener crop growth, reduced urea use, and easier handling of nano fertilizers. Others remain uncertain regarding dosage, consistency, timing, and long-term effects.

Field-level discussions and regional extension campaigns also reveal that many farmers still require proper guidance regarding:

- spray timing,
- dosage,
- crop-stage application,
- and compatibility with existing fertilizer schedules.

Several important practical questions remain:

- Do nano fertilizers perform equally well across all crops?
- How do they behave under different soil and climatic conditions?
- Can they consistently reduce conventional fertilizer requirements?
- How effective are they in rainfed farming systems?

Such questions indicate that the technology is still undergoing field-level validation and acceptance.

This does not necessarily mean nano fertilizers are ineffective. Rather, it highlights the importance of scientific caution and location-specific recommendations. Agriculture in India is highly diverse, and technologies that perform well in one region may not produce identical results elsewhere.

What Farmers Need to Think About

Perhaps the most important issue is not whether nano fertilizers are “good” or “bad,” but how farmers approach them.

Farmers should avoid both blind rejection and blind adoption. Instead, should be evaluated scientifically and practically at the farm level.

Field trials conducted by ICAR institutions and State Agricultural Universities have indicated that nano urea, when applied as a foliar spray along with recommended basal fertilizer doses, may reduce conventional urea use by 25–50% while maintaining comparable yields. In several crops, yield improvements ranging from 3–8% have also been reported under appropriate management conditions. Similar trials on nano DAP have shown the possibility of partial phosphorus fertilizer substitution in selected crops and regions. (Ministry of Chemicals and Fertilizers, 2026).

Despite encouraging trial results, government reports also acknowledge concerns regarding inconsistent field performance and nutrient deficiencies at higher substitution levels, particularly under low-fertility soil conditions. As a result, corrective measures such as long-term multi-locational research, standardized application protocols, and balanced fertilizer recommendations are being emphasized to improve field-level effectiveness (Ministry of Chemicals and Fertilizers, 2026).

Therefore, these Nano fertilizers should be adopted carefully and scientifically rather than through blind rejection. Farmers can start using this nano fertilizer in combination with recommended basal fertilizer doses, will be effectively used based on crop response, soil conditions and local climat. Therefore, a practical and balanced approach is essential while integrating nano fertilizers more into existing farming systems.

Conduct Small Plot Trials

Farmers should first test nano fertilizers on small plots

before making large-scale changes to fertilizer schedules. Crop response, yield performance, and profitability should be carefully observed.

Follow Recommended Dosage and Timing

Field demonstrations and extension programs repeatedly emphasize that correct spray timing and recommended dosage are critical for obtaining proper results. Nano fertilizers behave differently from conventional fertilizers, and overapplication does not necessarily improve crop performance.

Do Not Ignore Soil Health

Nano fertilizers cannot replace healthy soil systems.

Farmers must continue practices such as:

adding farmyard manure,

- improving soil organic carbon,
- crop rotation,
- mulching,
- green manuring,
- and integrated nutrient management.

Use Soil Testing and Balanced Nutrition

Efficient farming depends on balanced nutrient management rather than excessive nitrogen application alone. Soil testing should guide fertilizer decisions wherever possible.

Like many agricultural technologies, nano fertilizers are often surrounded by high expectations. Farmers should evaluate them realistically as one possible component of improved nutrient management rather than as complete solutions to agricultural problems.

Revolution or Transition Tool?

The growing interest in nano fertilizers reflects a broader transformation taking place in Indian agriculture. Farming is gradually moving from bulk-input agriculture toward efficiency-oriented agriculture based on precision, data, and resource optimization.

Future agricultural systems may increasingly depend on:

- precision nutrient management,
- drone spraying,
- digital advisories,
- sensor technologies,
- climate-smart practices,
- and data-driven decision-making.

In such systems, nano fertilizers may play an important role.

However, fertilizer technology alone cannot solve deeper agricultural challenges such as soil degradation, water scarcity, biodiversity loss, market instability, and weak extension systems. The success of nano fertilizers will ultimately depend on scientific validation, farmer trust, localized field performance, and their integration with sustainable farming practices.

Conclusion

Nano fertilizers represent one of the most ambitious technological interventions currently. They are being promoted not only for sustainability, but also for improving nutrient-use efficiency, reducing fertilizer subsidy burdens, strengthening fertilizer security, supporting precision agriculture, and improving climate resilience.

India is clearly investing heavily in this transition. Yet the true success of nano fertilizers will not be decided in laboratories, advertisements, or policy announcements alone. It will ultimately depend on how effectively they are used and performed in farmers' fields across diverse agroecological conditions.

For farmers, the path forward lies neither in complete rejection nor unquestioned acceptance. The real need is scientific evaluation, balanced nutrient management, practical observation, and informed decision-making.

Nano fertilizers may not completely replace conventional fertilizers in the near future. But if integrated wisely with sustainable soil management and precision agriculture practices, they could become an important part of India's evolving agricultural future.

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Agriculture in the Fifth Dimension :
The Metaverse Era of Farming

Introduction

What if a farmer could go to a demonstration plot, check how healthy the crops are, or learn a new way of farming without leaving their home? A year ago, this would have sounded crazy. Now, thanks to new digital tools, this is something farmers can actually do. The Metaverse is not something people talk about; it is a real thing that can create virtual spaces where farmers, the people who help them, scientists, and farming businesses can meet, learn from each other, and work together. At a time when farming is dealing with a lot of problems like weather, not enough workers, and the need to share knowledge quickly, the Metaverse is a new and exciting way to make information about farming easier to get, more interesting, and more useful for everyone who is involved in farming, including the farmers themselves, the people who help them, and the businesses that support them.

1. What is Metaverse?

The Metaverse is a shared, immersive virtual environment where users can interact with one another, digital objects, and real-world systems through technologies such as Virtual Reality (VR), Augmented Reality (AR), Artificial Intelligence (AI), Digital Twins, Blockchain, and the Internet of Things (IoT). It can be seen as the next step in internet evolution, moving beyond just viewing information on screens to entering and experiencing a 3D digital world. In agriculture, these technologies create virtual representations of farms where farmers, researchers, and extension professionals can interact with real-time farm data in an engaging and intuitive way.



1. How the Metaverse Enters the Farm?

The Metaverse is opening new possibilities for agriculture by creating a bridge between physical farms and immersive digital environments. Through these virtual platforms, farmers can monitor crop conditions, participate in interactive training, and make informed management decisions more effectively. This transformation is driven by a combination of advanced technologies that form the foundation of the agricultural Metaverse, including:

a. Virtual Reality (VR)

Virtual Reality creates a fully immersive digital environment that users can explore through VR headsets. In agriculture, VR can be used to train farmers on machinery operation, pest management, and modern farming practices without the risks and costs of field demonstrations. It also allows students and extension personnel to experience virtual farms and agricultural systems.

b. Augmented Reality (AR)

Augmented Reality overlays digital information onto the real world through smartphones, tablets, or smart glasses. Farmers can use AR applications to identify crop diseases, view soil information, and receive real-time recommendations while standing in the field. AR helps bridge the gap between digital data and practical farm operations.

c. Digital Twins

A Digital Twin is a virtual replica of a physical farm, crop, greenhouse, or livestock system. Using real-time data from sensors and farm equipment, the digital twin mirrors actual farm conditions. Farmers can test different management strategies, predict outcomes, and optimize resource use before applying changes in the real world.

d. Artificial Intelligence (AI)

Artificial Intelligence enables computers to analyze large amounts of agricultural data and make intelligent recommendations. AI can predict pest outbreaks, estimate crop yields, detect diseases from images, and support precision farming decisions. By processing data from satellites, drones, and sensors, AI helps farmers improve productivity and sustainability.

e. Blockchain

Blockchain is a secure digital ledger that records

transactions in a transparent and tamper-proof manner. In agriculture, it improves traceability by recording every stage of the food supply chain, from production to consumption. This helps consumers verify product origins while increasing trust and transparency in agricultural markets.

f. Internet of Things (IoT)

The Internet of Things refers to a network of connected devices and sensors that collect and exchange data. In farming, IoT sensors monitor soil moisture, temperature, humidity, nutrient levels, and livestock health in real time. This information helps farmers make informed decisions and automate activities such as irrigation and climate control.



2. Real-World Applications:

The metaverse is rapidly moving from concept to reality, offering practical solutions to some of agriculture's most pressing challenges. By integrating immersive technologies with real time farm data, farmers can learn, monitor, plan, and market their products more effectively than ever before.

The Metaverse is transforming agriculture by blending physical farming with immersive digital technologies, creating new opportunities for learning, decision-making, and market access. Through Virtual Reality (VR), farmers can participate in realistic training programs that simulate the operation of tractors, harvesters, drones, and other modern equipment, allowing them to gain practical skills without the risks and costs of traditional training.

In addition, drones, sensors, and Internet of Things (IoT) devices integrated with virtual platforms allow farmers to remotely monitor their fields, assess crop performance, and respond quickly to emerging

challenges. Beyond production, the Metaverse has the potential to create virtual agricultural marketplaces where farmers, traders, processors, and consumers can interact, negotiate, and conduct business in immersive digital spaces. Blockchain technology strengthens these systems by ensuring secure, transparent, and traceable records throughout the supply chain, enabling consumers to track the journey of agricultural products from farm to fork while enhancing trust and accountability. Together, these applications demonstrate how the Metaverse is reshaping agriculture, making farming more intelligent, connected, and efficient.

3. Real-World Examples of the Agricultural Metaverse

The agricultural metaverse is gradually becoming a reality, with governments, research institutions, and technology companies actively exploring its applications. South Korea is investing in metaverse-based innovations, while Texas A&M University is developing digital twin farms that use AI, drones, and remote sensing for improved farm management. Platforms such as AgriGeo Spaces integrate farm data to support decision-making and collaboration among stakeholders. At the same time, startups are introducing VR-based training programs that help farmers and farm workers learn equipment operation, crop management, and safety practices in immersive virtual environments. These developments demonstrate how metaverse technologies are beginning to reshape agriculture through smarter, more connected, and data-driven farming systems.

4. What Agriculture Could Look Like in 2030

By 2030, agriculture may look very different from the farms we know today. As the Metaverse continues to evolve, farmers could manage highly automated farms where drones, sensors, robots, and artificial intelligence work together to monitor crops, apply inputs, and predict yields with remarkable accuracy. Farmers from different countries could meet in shared virtual spaces to exchange knowledge, attend training programs, and collaborate on solutions to common challenges.

Real-time crop simulations may help visualize the impacts of weather changes, pest outbreaks, or market

fluctuations, allowing proactive and informed decision-making. Virtual agricultural marketplaces could connect producers directly with buyers across the globe, while blockchain-enabled systems ensure transparency and traceability throughout the supply chain. Although many of these innovations are still emerging, they offer a glimpse into a future where agriculture becomes more intelligent, connected, sustainable, and resilient. As financial analysts project the metaverse economy to reach between US\$8–13 trillion by 2030, its influence on agriculture could be both transformative and far-reaching.

Conclusion :

Planting Seeds in the Virtual World - The future of agriculture will not be defined by technology alone but by how effectively technology serves the people who grow our food. The Metaverse is not a substitute for farmers' knowledge, experience, and decision-making; rather, it is a tool that can enhance their capabilities and open new avenues for learning, collaboration, and innovation. From virtual training and digital twin farms to immersive marketplaces and data-driven decision support, the Metaverse has the potential to make agriculture more efficient, resilient, and inclusive. However, turning this vision into reality will require proactive investment and collaboration. Policymakers must strengthen rural digital infrastructure, startups must develop farmer-centric solutions, and agricultural universities and extension systems must integrate immersive technologies into research, teaching, and outreach programmes. The seeds of the agricultural Metaverse are already being sown. By investing today, we can ensure that the farms of tomorrow are not only technologically advanced but also sustainable, productive, and accessible to farmers of all scales.

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Textiles, Govt. of India.***ARTICLE ID: 13****Strategic Utilization of Bed Disinfectants for Augmenting
Mulberry Sericultural Productivity in North-Eastern India****Abstract**

Mulberry sericulture, an economically consequential and labor-intensive agro-rural enterprise, occupies a pivotal position in the socio-economic matrix of North East India by providing sustainable livelihood opportunities, rural employment generation, and women-centric entrepreneurial empowerment. Nevertheless, the perpetually hyper-hygrometric environmental conditions, fluctuating thermoperiodicity, inadequate aeration, and deficient phytosanitary management prevailing within traditional silkworm rearing ecosystems predispose *Bombyx mori* populations to recurrent epizootic outbreaks caused by viral, bacterial, fungal, and protozoan pathogens. Diseases such as grasserie, flacherie, muscardine, and pebrine precipitate severe larval debilitation, cocoon deterioration, filament inferiority, and substantial diminution in sericultural profitability. Under these epidemiologically precarious circumstances, the strategic deployment of scientifically validated bed disinfectants has emerged as an indispensable prophylactic and biosecurity intervention for sustaining disease-free silkworm rearing. Commercially significant disinfectants including Vijetha, Resham Jyothi, Seri-Win, Sericillin, Ankush, Asthra, slaked lime, bleaching powder, formalin, and neem-based phytochemical formulations possess remarkable antimicrobial, hygroscopic, and pathogen-suppressive efficacies. Their judicious application substantially enhances effective rate of rearing (ERR), larval survivability, cocoon compactness, shell ratio, and filament reelability. Furthermore, integration of advanced bed disinfection protocols with environmental sanitation, precision sericultural management, and climate-resilient technologies can profoundly strengthen sustainable mulberry silk production systems within North East India. The present article elucidates the multifaceted significance, strategic application methodologies, and futuristic implications of bed disinfectants in augmenting sericultural productivity and biosecurity resilience.

Key Words: Mulberry sericulture, Bed disinfectants, Epizootic pathogens, Sericultural biosecurity, Cocoon productivity

Introduction

Sericulture represents a sophisticated confluence of entomological science, phytobiological resource management, and rural agro-industrial craftsmanship. Among the diversified silk sectors, mulberry sericulture occupies unparalleled prominence owing to the superior physicochemical attributes and commercial indispensability of mulberry silk. North East India, endowed with luxuriant biodiversity, congenial climatic conditions, and abundant rural manpower, possesses extraordinary potential for sericultural expansion. However, incessant atmospheric humidity, elevated microbial load, inadequate rearing-house sanitation, and ecological instability collectively create favorable conditions for pathogenic proliferation and devastating silkworm disease outbreaks.

The susceptibility of *Bombyx mori* larvae to infectious diseases during rearing stages necessitates the implementation of rigorous hygienic and prophylactic interventions. In this context, bed disinfectants function as indispensable sericultural biosecurity agents capable of suppressing microbial contamination, regulating bed moisture, and preserving larval physiological homeostasis. Strategic utilization of disinfectants has therefore become an integral component of scientific and sustainable mulberry sericulture in North East India.

Epidemiological Importance of Bed Disinfectants

Bed disinfectants perform multifarious functions within silkworm rearing ecosystems, including:

- Suppression of bacterial, viral, fungal, and protozoan pathogens
- Maintenance of hygienic bed microenvironment
- Reduction of excessive bed moisture and microbial fermentation
- Prevention of horizontal disease transmission
- Enhancement of larval vigor and physiological resilience
- Improvement of cocoon quality and filament characteristics
- The regular and judicious application of disinfectants significantly minimizes crop losses and stabilizes sericultural productivity.

Major Silkworm Diseases Prevalent in North East India

1. **Grasserie:** A highly contagious viral disease characterized by hypertrophied, translucent, and fragile larvae exhibiting eventual liquefaction and mortality.
2. **Flacherie:** A polymicrobial bacterial disease causing digestive dysfunction, putrefactive odor, larval lethargy, and extensive crop collapse.
3. **Muscardine:** A mycotic infection induced by entomopathogenic fungi resulting in hardened, mummified larvae covered with fungal sporulation.
4. **Pebrine:** A chronic protozoan disease caused by *Nosema bombycis*, capable of transovarial transmission and catastrophic crop devastation.

Strategic Application of Commercial Bed Disinfectants

1. **Vijetha:** Vijetha is a broad-spectrum antimicrobial bed disinfectant possessing exceptional efficacy against grasserie, flacherie, muscardine, and pebrine pathogens. Its hygroscopic properties facilitate moisture absorption and microbial suppression, thereby improving larval survivability and cocoon productivity.

2. **Resham Jyothi:** Resham Jyothi is a scientifically formulated sericultural disinfectant extensively utilized for maintaining rearing-house hygiene and minimizing microbial contamination during late-age silkworm rearing.

3. **Seri-Win:** Seri-Win functions as an advanced microbial suppressive formulation capable of reducing pathogenic proliferation and stabilizing silkworm physiological performance under humid environmental conditions.

4. **Sericillin:** Sericillin is a synergistic chlorine-based disinfectant exhibiting potent virucidal, bactericidal, and fungicidal properties. Its application significantly reduces disease incidence and enhances effective rate of rearing.

5. **Ankush:** Ankush is an eco-compatible botanical disinfectant possessing environmentally sustainable antimicrobial properties with minimal toxicological hazards to silkworm rearers.

6. **Asthra:** Asthra is a modern broad-spectrum disinfectant designed for integrated disease management in sericulture through enhanced microbial suppression and hygienic stabilization.

7. **Slaked Lime:** Slaked lime functions as a low-cost hygroscopic disinfectant traditionally employed for moisture regulation and fungal suppression within silkworm beds.

8. **Bleaching Powder:** Bleaching powder possesses strong oxidizing and antimicrobial properties capable of eliminating pathogenic contaminants from rearing premises and appliances.

9. **Formalin:** Formalin is extensively utilized for disinfection of rearing houses, appliances, and mountages owing to its remarkable sterilizing efficacy against diverse pathogens.

10. **Neem-Based Formulations:** Neem-derived phytochemical disinfectants contain bioactive compounds such as azadirachtin exhibiting

antimicrobial, antifungal, and insecticidal properties suitable for eco-friendly sericulture.

Scientific Methodologies for Effective Disinfectant Application

i. Post-Moulting Dusting: Application immediately after moulting suppresses residual microbial inoculum before commencement of feeding.

ii. Hygro-Regulation during Late Age Rearing: Intensified disinfection during fourth and fifth instars prevents excessive microbial multiplication caused by increased metabolic heat and moisture.

iii. Bed Cleaning and Sanitation: Removal of excreta, leftover mulberry foliage, and contaminated litter substantially enhances disinfectant efficacy.

iv. Uniform Dissemination: Homogeneous distribution of disinfectant particles across the rearing bed ensures comprehensive pathogen suppression.

Advantages of Strategic Bed Disinfection

- Augmentation of Effective Rate of Rearing (ERR)
- Minimization of larval mortality and crop loss during adverse climatic conditions
- Enhancement of cocoon compactness, shell ratio, and cocoon uniformity
- Improvement in filament denier, reelability, and raw silk recovery percentage
- Stabilization of sericultural profitability and economic sustainability
- Promotion of hygienic, disease-free, and eco-compatible sericulture
- Suppression of bacterial, viral, fungal, and protozoan pathogen proliferation
- Reduction of secondary contamination within silkworm rearing ecosystems
- Regulation of excessive bed moisture and maintenance of favorable microclimatic conditions
- Enhancement of larval physiological vigor, feeding efficiency, and metabolic performance
- Improvement in mulberry leaf utilization efficiency and feed conversion ratio
- Reduction in foul odor, microbial fermentation, and putrefactive conditions in silkworm beds
- Enhancement of spinning behavior and cocoon formation efficiency

- Improvement in market acceptability and commercial value of cocoons
- Reduction in expenditure associated with disease management and crop failure
- Facilitation of uniform larval growth and synchronized moulting
- Preservation of rearing-house sanitation and sericultural biosecurity
- Strengthening of climate-resilient silkworm rearing under hyper-humid North Eastern conditions
- Enhancement of farmer confidence and adoption of scientific sericultural practices
- Improvement in overall silk productivity, quality, and industrial competitiveness

Strategic Application of Bed Disinfectants

A. Pre-Rearing Disinfection

- Thorough disinfection of rearing houses, appliances, trays, mountages, and surrounding premises before commencement of silkworm brushing.
- Application of formalin, bleaching powder, or recommended disinfectant formulations for complete microbial sterilization.

B. Post-Moulting Application

- Dusting of disinfectants immediately after each moult to suppress residual pathogenic inoculum before feeding initiation.
- Ensures enhanced larval resistance during physiologically vulnerable moulting periods.

C. Late Age Rearing Application

- Intensified disinfectant application during fourth and fifth instars to regulate excessive moisture accumulation and microbial multiplication.
- Particularly essential under hyper-humid environmental conditions prevailing in North East India.

D. Bed Cleaning and Hygienic Maintenance

- Removal of leftover mulberry foliage, excreta, and contaminated litter before disinfectant application.
- Maintenance of sanitary rearing conditions to prevent secondary pathogen transmission.

E. Uniform Dusting Technique

- Homogeneous dissemination of disinfectant particles across the entire silkworm bed for comprehensive antimicrobial coverage.
- F. Moisture Regulation
- Application of slaked lime and hygroscopic formulations to absorb excess bed moisture and prevent fungal proliferation.
- G. Preventive Disease Management
- Regular prophylactic application of Vijetha, Resham Jyothi, Seri-Win, Sericillin, Ankush, Asthra, and neem-based formulations throughout the rearing cycle.
- H. Eco-Friendly Botanical Application
- Utilization of neem-derived phytochemical formulations for environmentally sustainable microbial suppression.
- I. Environmental Sanitation
- Periodic disinfection of rearing rooms, equipment, pathways, and storage areas for strengthening sericultural biosecurity.
- J. Integrated Scientific Management
- Synchronization of bed disinfection with environmental monitoring, ventilation management, quality Disease Free Layings (DFLs), and scientific feeding practices for maximizing cocoon productivity.
- Future Prospective**
- Development of biodegradable and eco-compatible bed disinfectants for sustainable mulberry sericulture.
 - Exploration of phytochemical and herbal-based antimicrobial formulations possessing minimal environmental toxicity.
 - Advancement of nano-formulated disinfectants with superior pathogen suppression efficiency and prolonged residual activity.
 - Formulation of climate-resilient disinfectants suitable for hyper-humid and fluctuating environmental conditions prevalent in North East India.
 - Integration of artificial intelligence-assisted environmental monitoring systems for real-time disease surveillance and humidity regulation.
 - Establishment of digital disease forecasting and early warning models for minimizing epizootic outbreaks in silkworm rearing ecosystems.
 - Adoption of precision sericultural advisory platforms for scientific decision-making and optimized disease management practices.
 - Utilization of molecular pathogen diagnostic technologies for rapid identification and containment of silkworm diseases.
 - Promotion of eco-friendly integrated disease management strategies combining sanitation, environmental control, and biological approaches.
 - Strengthening institutional convergence among research organizations, governmental agencies, extension personnel, and sericulture stakeholders.
 - Enhancement of farmer-oriented capacity building, training programmes, and technological dissemination mechanisms.
 - Development of region-specific sericultural biosecurity protocols for sustainable cocoon productivity enhancement.
 - Encouragement of public-private partnerships for commercialization of advanced sericultural disinfectant technologies.
 - Intensification of multidisciplinary research focusing on microbial resistance, pathogen epidemiology, and climatic adaptability.
 - Establishment of resilient and globally competitive mulberry sericultural production systems in North East India.

Conclusion

The strategic utilization of scientifically validated bed disinfectants constitutes an indispensable cornerstone of modern mulberry sericulture in North East India. Their systematic application effectively suppresses pathogenic proliferation, stabilizes rearing-house hygiene, enhances larval survivability, and substantially augments cocoon productivity and silk quality. Integration of advanced disinfection strategies with scientific environmental management and precision rearing technologies can significantly transform the sericultural landscape of North East India into a

resilient, remunerative, and globally competitive agro-industrial enterprise.

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ARTICLE ID: 14**Tiny Molecules, Big Promise: How miRNAs Are Revolutionizing
Disease Detection in Dogs****Abstract**

Dogs are among the most valued companion animals, serving as family pets, working animals, and therapy companions. Maintaining their health is essential not only for animal welfare but also for the well-being of the people who depend on them. However, many canine diseases, including cancer, cardiovascular disorders, kidney and liver diseases, infectious diseases, and immune-mediated conditions, often remain undetected until they reach advanced stages. This limitation has driven the search for novel molecular biomarkers capable of identifying disease at an earlier stage. Among these, microRNAs (miRNAs) have emerged as highly promising diagnostic biomarkers due to their critical role in regulating gene expression and maintaining normal cellular functions. MicroRNAs are small, non-coding RNA molecules that influence numerous biological processes, including cell growth, immune responses, metabolism, and tissue repair. Disease-associated alterations in miRNA expression create unique molecular signatures that can be detected in easily accessible body fluids such as blood, serum, plasma, saliva, and urine. Their exceptional stability and non-invasive accessibility make them attractive candidates for early disease diagnosis and monitoring. Recent studies have demonstrated distinct miRNA expression profiles in canine cancers, heart disease, chronic kidney disease, liver disorders, infectious diseases, autoimmune conditions, endocrine disorders, and neurological diseases. These biomarkers not only facilitate early diagnosis but also aid in disease prognosis, treatment monitoring, and detection of recurrence. Advances in quantitative molecular techniques, next-generation sequencing, nanotechnology, biosensors, microfluidic lab-on-a-chip platforms, and artificial intelligence are further accelerating the clinical application of miRNA-based diagnostics. Although challenges remain regarding standardization, validation, and interpretation across different breeds and physiological conditions, continued research is expected to overcome these limitations. In the future, miRNA-based diagnostics and therapeutics may become integral components of precision veterinary medicine, enabling rapid, minimally invasive, and personalized healthcare for dogs while significantly improving disease management, treatment outcomes, and overall canine health.

Keywords: MicroRNAs (miRNAs), Canine Diseases, Biomarkers, Precision Veterinary Medicine, Biosensors

Dogs have earned the title of "man's best friend" because of the unique bond they share with humans. Whether they are family pets, guide dogs, police dogs, or therapy animals, their health directly influences the lives of the people who care for them. Like humans, dogs can suffer from numerous diseases, including infections, cancer, heart disease, kidney disorders, liver problems, and immune-related illnesses. One of the greatest challenges faced by veterinarians is that many of these diseases do not show obvious signs during their early stages.

By the time symptoms become noticeable, the disease may have already progressed considerably. This has encouraged scientists to search for new methods that can identify illness much earlier. Among the most exciting discoveries in veterinary science is the use of microRNAs, commonly known as miRNAs, as biomarkers for disease detection.

MicroRNAs are tiny molecules made of ribonucleic acid (RNA). Although they are much smaller than most genetic molecules and do not produce proteins themselves, they have an enormous influence on how cells function. Their main role is to regulate the activity of genes by deciding which proteins should be produced and in what quantity. Because of this regulatory function, miRNAs help control many essential biological activities, including growth, tissue repair, immune responses, metabolism, and cell survival. Whenever disease develops in the body, these regulatory processes change, and the levels of specific miRNAs change as well. Scientists have realized that these changes can provide valuable clues about the health status of an animal.

One reason why miRNAs have attracted so much attention is their remarkable stability. Many biological molecules begin to break down soon after a blood sample is collected, making laboratory analysis difficult. In contrast, miRNAs remain stable because they are protected inside microscopic particles known as exosomes or are attached to specialized proteins. As a result, they can be detected in blood, serum, plasma, saliva, urine, and several other body fluids. This means that veterinarians may eventually diagnose diseases using only a small and minimally invasive sample, reducing stress for both the animal and its owner.

Scientists have now shown that every disease leaves behind a characteristic "molecular fingerprint" in the form of altered miRNA expression. Some miRNAs increase in concentration, whereas others decrease depending on the affected tissue and the stage of the disease. Instead of waiting for visible damage to occur, veterinarians may soon be able to recognize these molecular changes long before clinical signs become obvious. This approach represents a major step toward preventive and precision veterinary medicine.

Cancer is one of the diseases in which miRNA

research has shown remarkable progress. Tumours develop gradually, often without producing obvious symptoms during their early stages. Research has demonstrated that dogs suffering from lymphoma, mammary gland tumours, osteosarcoma, melanoma, mast cell tumours, and several other cancers exhibit characteristic changes in circulating miRNAs. These molecular signatures may not only assist in early diagnosis but also help veterinarians monitor whether treatment is working effectively and detect recurrence after surgery or chemotherapy. Heart disease is another area where miRNA biomarkers are showing considerable promise. Disorders such as degenerative mitral valve disease and dilated cardiomyopathy often progress silently before obvious clinical signs appear. During heart muscle injury, certain miRNAs are released into the bloodstream in measurable quantities. Detecting these molecules could enable veterinarians to identify heart damage much earlier than traditional diagnostic methods, allowing timely treatment and slowing disease progression. Chronic kidney disease represents another common problem in ageing dogs. Conventional blood tests usually detect kidney dysfunction only after a large proportion of kidney tissue has already been damaged. Researchers are now investigating specific miRNAs that change during the earliest phases of kidney injury. Similar observations have been reported in liver diseases, where liver-specific miRNAs increase when liver cells become damaged. Such discoveries may eventually allow veterinarians to diagnose organ damage before irreversible changes occur.

The usefulness of miRNAs extends beyond chronic diseases. Infectious diseases caused by viruses, bacteria, parasites, and ticks continue to affect dogs throughout the world. During infection, the immune system responds by activating numerous defense mechanisms, many of which are controlled by miRNAs. Scientists have observed that infections such as canine parvovirus, canine distemper, ehrlichiosis, babesiosis, and leishmaniasis alter the expression of immune-related miRNAs. Measuring these changes may help veterinarians confirm infections more rapidly, estimate disease severity, and monitor recovery after treatment.

Autoimmune disorders also involve disturbances in gene regulation. In diseases where the body's immune system mistakenly attacks its own cells, altered miRNA expression has been linked with excessive inflammation and abnormal immune activity. Understanding these molecular changes may improve diagnosis while also helping researchers identify new targets for future therapies. Similar investigations are underway in neurological diseases, diabetes, obesity, endocrine disorders, and skin diseases, suggesting that miRNAs may become valuable biomarkers across many branches of veterinary medicine.

Another exciting aspect of miRNA research is its connection with modern diagnostic technology. Sensitive laboratory techniques such as quantitative real-time PCR and next-generation sequencing can accurately measure very small amounts of these molecules. At the same time, engineers are developing portable biosensors capable of detecting disease-associated miRNAs within minutes. These devices combine nanotechnology, biosensors, and microfluidic "lab-on-a-chip" systems, allowing rapid testing using only a tiny drop of blood. In the future, such handheld devices may enable veterinarians to perform advanced molecular tests directly in clinics or even during field visits.

Artificial intelligence is also beginning to play an important role in this rapidly developing field. Modern computer algorithms can examine thousands of miRNA patterns together with clinical records, laboratory findings, and medical images. By recognizing hidden relationships among these data, artificial intelligence can support veterinarians in making earlier and more accurate diagnoses while selecting the most appropriate treatment for each patient.

Although the future is highly encouraging, miRNA diagnostics are still evolving. Scientists are working to establish standard methods for collecting samples, analysing miRNAs, and interpreting results. Since factors such as age, breed, nutrition, and environmental conditions may influence miRNA levels, extensive validation studies are required before these tests become routine in veterinary hospitals. Continued research involving large numbers of healthy and diseased dogs will help ensure that these biomarkers are reliable under diverse clinical conditions.

The role of miRNAs may eventually extend beyond diagnosis. Researchers are investigating whether modifying the activity of disease-related miRNAs could itself become a form of treatment. If successful, these tiny molecules may not only reveal the presence of disease but also help control its progression, opening an entirely new chapter in veterinary therapeutics.

The future of canine healthcare is moving toward early detection, personalized treatment, and precision medicine. MicroRNAs fit perfectly within this vision because they provide detailed molecular information long before conventional tests reveal obvious abnormalities. Their stability, sensitivity, and presence in easily obtainable body fluids make them ideal candidates for non-invasive diagnosis. As molecular biology, nanotechnology, biosensor development, and artificial intelligence continue to advance, miRNA-based diagnostics are expected to become an integral part of veterinary practice. These tiny genetic regulators may be small in size, but they have the potential to make an enormous difference in protecting the health and improving the lives of dogs across the world.

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COBS&H, CCSHAU, Hisar***ARTICLE ID: 15****Exploration of Lignocellulolytic Bacterial Consortia for Sustainable Paddy Stubble Degradation****Abstract**

Paddy stubble management is vital due to its environmental impact, especially in rice-wheat systems where residues are produced quickly. Open burning, a common disposal method, harms air quality, emits greenhouse gases, and depletes soil nutrients. Recent research (2024–2026) investigates lignocellulolytic bacterial consortia as eco-friendly alternatives for in situ residue degradation. Paddy straw's complex cellulose, hemicellulose, and lignin make microbial breakdown challenging; thus, microbial consortia with complementary bacteria are used. These produce enzymes like cellulases, xylanases, laccases, and peroxidases, facilitating the breakdown of plant polymers. Advances in metagenomics, enzyme profiling, and microbial engineering are enhancing consortia design. Challenges include environmental variability, microbial survival, formulation stability, and large-scale application. Ultimately, these consortia offer a sustainable solution for residue management, aiding climate change mitigation, soil health, and circular agriculture.

Keywords: Lignocellulolytic bacteria, Paddy stubble, Microbial consortia, Biodegradation, Sustainable agriculture

Introduction

Agricultural sustainability faces challenges due to improper residue management in intensive farming. In paddy fields, large quantities of straw and stubble are produced, especially in countries like India with rice-wheat systems. About one-third of this biomass is wasted after harvest because of mechanization. The short gap between rice harvesting and planting wheat leads farmers to burn residue. However, the practice of burning straw raises several environmental and agronomic concerns. The burning of the straw releases greenhouse gases such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). It also produces particulate matter, including PM_{2.5} and PM₁₀, which contribute to air pollution. From a soil perspective, the burning process causes the loss of important soil nutrients, including nitrogen, phosphorus, potassium, and sulfur, thereby lowering soil fertility. In addition, the temperature rise resulting from combustion disrupts soil microbial life. In this context, biological degradation of crop residues using microorganisms has emerged as a sustainable and eco-friendly alternative. Microbial decomposition not only helps efficiently break down lignocellulosic biomass but also enhances soil health by increasing organic matter content and microbial diversity. Among the various microbial approaches, lignocellulolytic bacterial consortia have attracted considerable attention due to their superior efficiency in degrading complex plant materials.

Paddy straw is mainly lignocellulose, a complex mix of cellulose, hemicellulose, and lignin. Its tight bonding makes it resistant to degradation, called recalcitrance. Single microbes usually can't break down all components, but bacterial consortia with diverse enzymes can collectively degrade these complex substrates.

Lignocellulolytic bacterial consortia work through synergistic interactions, with different members providing specific enzymes like cellulases, hemicellulases, and lignin-degrading enzymes, which collaborate to break down lignocellulose. Some bacteria start by modifying lignin to expose cellulose and hemicellulose, which others then hydrolyze into sugars for utilization. This division of labor boosts degradation efficiency and speeds up decomposition. Microbial consortia are also more adaptable to environmental changes than individual strains, tolerating variations in temperature, moisture, and nutrients. Interactions such as cross-feeding and metabolic cooperation enhance their stability and ongoing activity.

Thus, exploring and applying lignocellulolytic bacterial consortia is a promising strategy for sustainable paddy straw management. Their use not only mitigates the environmental hazards associated with residue burning but also promotes soil health and supports the principles of sustainable agriculture.

Structural Complexity of Paddy Stubble

Paddy straw is a lignocellulosic material composed of three major polymers:

- **Cellulose (40–45%)** – a linear polymer of glucose forming crystalline microfibrils
- **Hemicellulose (20–25%)** – a branched heteropolymer of sugars
- **Lignin (10–15%)** – a complex aromatic polymer providing rigidity and resistance

The tight association between these components forms a recalcitrant matrix that resists degradation. Lignin acts as a physical barrier, limiting enzyme accessibility to cellulose and hemicellulose. Therefore, efficient degradation requires a coordinated enzymatic system, which is best achieved through microbial consortia.

Exploration of Lignocellulolytic Bacterial Consortia

1. Isolation from Diverse Ecological Niches

Recent research emphasises the isolation of potent lignocellulolytic bacteria from natural environments such as compost heaps, forest soils, decaying biomass, and animal gut systems. These environments harbour microbes adapted to degrade complex organic matter.

Advanced screening techniques involve:

- Plate assays for cellulase and ligninase activity
- Enzyme quantification assays
- Molecular identification using 16S rRNA sequencing

A recent study reported the isolation of highly efficient lignocellulolytic bacteria capable of degrading rice straw significantly within a short period under controlled conditions.

2. Development of Synergistic Consortia

The design of microbial consortia involves combining strains with complementary metabolic capabilities.

For example:

- **Cellulolytic bacteria:** *Bacillus*, *Cellulomonas*
- **Hemicellulolytic bacteria:** *Pseudomonas*, *Paenibacillus*
- **Lignin-degrading bacteria:** Actinobacteria, *Streptomyces*

These organisms interact synergistically, where the breakdown products of one organism serve as substrates for another. This cross-feeding mechanism enhances overall degradation efficiency. Recent studies highlight the use of synthetic consortia, in which microbial combinations are deliberately engineered to optimize performance.

Mechanisms of Degradation

Lignocellulolytic bacterial consortia degrade paddy stubble through a coordinated enzymatic system:

Enzymatic Breakdown

- **Cellulases** convert cellulose into glucose
- **Hemicellulases** degrade hemicellulose into simple sugars
- **Ligninases** (laccases, peroxidases) break down lignin

Microbial Synergy

Different bacterial species function at different stages of decomposition:

- Early colonizers break down simple compounds
- Secondary microbes degrade complex polymers
- Late-stage microbes mineralise residues into nutrients

Microbial Succession

Recent findings emphasise the importance of microbial succession, in which community composition changes dynamically during decomposition. This ensures continuous degradation and nutrient cycling.

1. Metagenomic Insights

High-throughput sequencing has enabled detailed analysis of microbial communities and the functional genes involved in lignocellulose degradation. Researchers can now identify key enzymes and metabolic pathways responsible for efficient lignocellulose degradation.

2. Enhanced Decomposition Efficiency

Field studies have shown that microbial consortia can accelerate residue degradation significantly compared to natural decomposition, reducing the time required for residue breakdown.

3. Bioaugmentation Strategies

Bioaugmentation, the direct application of microbial inoculants to fields, has shown promising results in enhancing soil fertility and straw breakdown.

4. Integration with Composting Systems

Degradation and nutrient recovery are further improved by combining microbial consortia with composting methods.

5. Climate-Smart Approaches

In comparison to burning, microbial decomposition lowers greenhouse gas emissions, helping to mitigate climate change.

Benefits of Lignocellulolytic Consortia

- An eco-friendly substitute for burning stubble
- Enhanced fertility and organic carbon in the soil
- Increased access to nutrients (N, P, and K)
- A decrease in greenhouse gas emissions and air pollution
- Support for circular and sustainable agriculture

Challenges and Limitations

● Environmental Constraints

Temperature, moisture, and soil conditions significantly influence microbial activity. Extreme conditions can inhibit enzyme function and reduce degradation efficiency.

● Competition with Native Microbiota

Introduced consortia must compete with indigenous microorganisms, which may limit their survival and effectiveness.

● Formulation and Shelf-Life Issues

Developing stable formulations that retain microbial viability during storage and transport remains a challenge.

● Time Constraints in Cropping Systems

Farmers require rapid residue clearance for timely sowing of the next crop, whereas biological degradation may take several weeks.

● Economic and Adoption Barriers

The cost of microbial inoculants and lack of awareness among farmers hinder large-scale adoption.

● Standardization and Field Variability

Variability in soil type, climate, and residue composition makes it difficult to standardize microbial products.

Future Prospects

Future research directions include:

- Development of multi-functional microbial consortia
- Use of genetic engineering and synthetic biology
- Integration with AI-based monitoring systems
- Large-scale field validation and commercialisation
- Government support and policy interventions

Conclusion

The exploration of lignocellulolytic bacterial consortia offers a sustainable and innovative approach to manage paddy stubble. By harnessing microbial diversity and enzymatic potential, these consortia provide an effective alternative to residue burning. Recent advancements demonstrate significant progress in microbial engineering, functional analysis, and field application. With continued research, technological integration, and policy support, microbial consortia-based solutions can play a pivotal role in achieving sustainable agriculture and environmental conservation.

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ARTICLE ID: 16

FROM COCOON TO GOLD: THE SCIENCE AND ART OF SILK REELING

Introduction

Silk is often called the "Queen of Textiles" because of its beauty, luster, strength and elegance. However, the journey from a silkworm cocoon to luxurious silk fabric involves several important steps, among which **reeling** is one of the most crucial. Reeling transforms the delicate silk filament hidden inside the cocoon into a continuous, strong thread known as raw silk. This process adds value to cocoons and plays a vital role in the sericulture industry, providing employment and income to thousands of farming families.

What is Silk Reeling?

Reeling is the process of unwinding continuous silk filaments from a group of cocoons and combining them to produce a single, strong silk thread. Before reeling, the cocoons are softened in hot water to dissolve the gum-like protein called sericin. The individual filaments from several cocoons are then carefully combined and wound on a reel to form raw silk. A single cocoon contains a filament measuring nearly 600–1200 meters in length, but only about 58% can be reeled into raw silk, while the remaining silk is utilized for spun silk production.

Principle of Silk Reeling

The silk filament is held together by a natural gum called sericin. During reeling, cocoons are immersed in hot water to soften the sericin, allowing the filaments to be unwound without breaking. Several filaments are then joined together and wound continuously onto reels to form raw silk.

Steps Involved in Silk Reeling

1. Sorting And Grading Of Cocoons

Harvested cocoons are sorted according to size, shape, color, and quality. Defective cocoons are removed to ensure uniform silk production.

2. Cooking Of Cocoons

The selected cocoons are immersed in hot water at about 90–95°C. This softens the sericin and loosens the filaments for easy unwinding.

3. Brushing

A small brush or broom is used to locate the loose ends of silk filaments on the cocoon surface.

4. Reeling

Filaments from 6–10 cocoons are combined and reeled together to produce a single raw silk thread of required thickness.

5. Winding

The reeled silk is wound onto reels or skeins while maintaining proper tension and uniformity.

6. Drying And Packaging

The silk skeins are dried, inspected, graded and packed for further processing and weaving.

Types of Silk Reeling Systems

1. Charkha Reeling

Traditional Method

Charkha is the oldest and most widely used traditional reeling system. It is mainly employed for processing defective cocoons and producing coarse silk yarn and dupion silk.

Features

- Simple and inexpensive equipment
- Suitable for small-scale operations
- Utilizes defective cocoons efficiently

Advantages

- ✓ Low initial investment
- ✓ Easy to operate
- ✓ Suitable for rural areas and cottage industries

Limitations

- ✗ Produces coarse and uneven silk yarn
- ✗ Lower productivity
- ✗ Poor quality compared with modern systems



Figure 1. Traditional Charkha reeling machine used for producing coarse silk and dupion yarn from defective cocoons.

2. Cottage Basin Reeling

Improved Reeling Technology

Cottage basin reeling is an improved version of the Charkha system. It consists of separate cooking and reeling basins and incorporates devices such as buttons, croissure wheels, and jetteboute.

An operator can manage 6–8 ends per basin, producing about 0.8–1.0 kg of silk per basin.

Advantages

- ✓ Better quality silk than Charkha
- ✓ Improved filament uniformity
- ✓ Suitable for small and medium enterprises

Limitations

- ✗ Requires skilled labour
- ✗ Moderate production capacity



Figure 2. Cottage basin reeling unit—an improved system with separate cooking and reeling basins for better silk quality.

3. Multi-End Reeling Machine

Semi-Modern Reeling System

Multi-end reeling is a further advancement over cottage basin technology. One operator can handle around 10 ends per basin. It includes:

- Button mechanism
- Croissure wheels
- Jetteboute arrangement
- Individual reel stop motion
- Planetary traverse mechanism

Production ranges from 0.7–1.2 kg per basin depending on yarn denier.



Figure 3. Multi-end reeling machine featuring croissure wheels, jetteboute, and planetary traverse for higher productivity and uniform yarn.

Advantages

- ✓ Higher productivity
- ✓ Better yarn quality and uniformity
- ✓ Reduced thread breakage
- ✓ Increased efficiency

Limitations

- ✗ Higher installation cost
- ✗ Requires trained manpower

4. Automatic Reeling Machine

The Ultimate Reeling Technology

Automatic reeling represents the most advanced stage of silk reeling. Most operations, including cooking, brushing, cocoon feeding, and denier maintenance, are automated. One operator can supervise more than 40 ends simultaneously. Under Indian conditions, automatic reeling provides nearly 50% labour savings while producing superior 2A-grade mulberry silk.



Figure 4. Modern automatic reeling machine capable of producing premium-quality raw silk with reduced labour requirements

Advantages

- ✓ High-quality silk production
- ✓ Excellent denier uniformity
- ✓ Increased productivity
- ✓ Reduced labour requirement
- ✓ Minimal thread breakage
- ✓ Greater profitability

Limitations

- ✗ Very high initial investment
- ✗ Requires technical expertise and maintenance
- ✗ Suitable mainly for commercial units

Key Points to Remember

- ★ Reeling converts cocoons into valuable raw silk.
- ★ About 58% of silk filament can be reeled as raw silk.
- ★ Filaments from 5–10 cocoons are combined to form one silk thread.
- ★ Uniform denier maintenance determines silk quality.
- ★ Automatic reeling machines produce premium-quality 2A-grade mulberry silk.
- ★ Modern reeling technologies increase productivity and reduce labour costs.

Factors Affecting Silk Reeling Quality

- Quality and freshness of cocoons.
- Temperature and duration of cocoon cooking.
- Number of filaments combined.
- Reeling speed and tension.
- Skill of the operator.
- Proper maintenance of reeling equipment.

Economic Importance of Reeling

Silk reeling adds value to cocoons and strengthens the sericulture industry. It generates employment opportunities for rural youth and women, supports cottage industries, and contributes significantly to the country's textile sector. Adoption of improved and automatic reeling technologies can increase farmers' income and enhance the competitiveness of Indian silk in international markets.

Advantages of Silk Reeling

- Produces continuous and strong silk yarn.
- Preserves the natural lustre and smoothness of silk.
- Improves the commercial value of cocoons.
- Supports employment and rural development.
- Supplies quality raw material for textile industries.

Challenges in Silk Reeling

- Breakage of filaments during reeling.
- Variations in cocoon quality.
- High labour requirements in traditional systems.
- Need for skilled workers and modern equipment.

- Fluctuating market demand and prices.

Recent Developments

Modern silk reeling technologies such as automatic reeling machines, energy-efficient cooking systems, and electronic denier control devices have improved productivity and quality. Research institutions are continuously developing advanced techniques to minimize wastage and enhance raw silk production.

Future Prospects

Modern reeling technologies are revolutionizing the sericulture industry. With increasing demand for high-quality silk in domestic and international markets, adoption of multi-end and automatic reeling systems can significantly improve profitability.

Government support, technological advancements and training programs are helping farmers and entrepreneurs establish sustainable silk enterprises.

Conclusion

Silk reeling serves as the bridge between cocoon production and silk weaving. From traditional Charkha systems to sophisticated automatic reeling machines, technological advancements have greatly improved the quality and productivity of silk yarn. For students, understanding reeling provides insight into the science behind silk production, while for farmers and entrepreneurs, modern reeling technologies offer opportunities for higher income and sustainable development. By adopting improved reeling practices, the dream of producing world-class Indian silk can become a reality—truly transforming every cocoon into a golden thread of prosperity.

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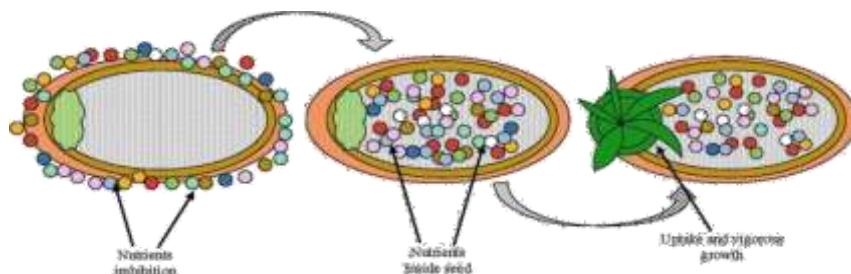
**Frontier Research on Seed Priming and It's Future Perspectives
 in Agriculture**

Introduction

The fragile ecosystems like climate change and continue cultivation practices is challenging for sustainable agricultural growth. To curtail this situation, the adoption of eco-friendly and economical techniques such as seed priming, low-input sustainable agriculture, conservation agriculture, etc., are imperative. Seed priming has long been explored as an effective value-added potential technique that result in improved germination, reduce seedling emergence time, short crop duration, increase stress tolerance and eventually increase higher grain production. To alleviate the effects of modern agriculture, this technique emerged as a viable strategy that protects plants against both biotic and abiotic stresses. The absolute performance of seed priming is more prominent under adverse conditions such as fragile ecosystems than favourable conditions.

What is seed priming ?

Seed priming is a controlled hydration process followed by drying of seeds, that allows the seed to imbibe water and begin internal biological process necessary for germination, but it not allowing the seed to germinate.



Phenomenon of seed priming (Waqas *et al.* 2019)

Types of priming

A. Conventional priming

1. Hydropriming
 - a. Drum priming
 - b. On farming priming
2. Osmotic priming
3. Halopriming
4. Biopriming
5. Solid matrix priming
6. Hormonal priming
7. Nutri priming
8. Nano priming

B. Physical priming

Two types of physical agents are used in this priming

1. Ionizing e.g. X-rays, gamma rays
2. Non-ionizing e.g. The magnetic field, UV radiation, microwaves

A. Conventional priming

1. Hydropriming

Hydropriming involves soaking of seeds in water for a specific duration before sowing and may or may not be followed by air drying of the seeds.

Seeds are immersed in sterilized distilled water kept at appropriate temperature (5-20°C) and the duration of hydro priming is determined by controlling seed imbibition during germination. Hydro primed seeds showed maximum results suggesting that ion accumulation in the seed has no toxic effect on the embryo. This treatment thus can be used to increase tolerance in drought condition and enhance growth leading to environment-friendly technique for improving crop yield and useful for resource poor farmers

a. Drum priming

In this technique, seeds are gently rotating in drum and gradually hydrated by addition of water in vapor form. Drum priming allows seed imbibition in a controlled manner and could be an attractive to conventional hydro priming.

b. On farming priming

Farmers can prime their own seeds.

Soaking of seeds in water followed by surface drying and subsequent sowing.

The duration of treatment obligatorily cannot be longer than "safe limit" (Around 6-12 hours). After soaking, the water is drained off and the seeds are surface-dried by placing them on a cloth or plastic sheet on the ground for 15 to 30 minutes. On-farm priming is especially useful for resource- poor farmers in marginal tropical environment.

2. Osmotic priming

Seeds are soaked in osmotic solution that allows seeds to imbibe water to proceed to the first stage of germination but prevent radicle protrusion through the seed coat.

Osmotic priming of seeds also known as osmo-

priming or osmo conditioning describes incubation of seeds with aerated solutions of low water potential which are washed and dried. e.g. salts (also called halo-priming), sugars, polyethylene glycol (PEG), glycerol, sorbitol or mannitol.

Success depends on treatment duration, temperature and water potential. Osmopriming essentially exposes seeds to a low water potential to restrict the rate and extent of imbibition. Osmopriming is akin to a prolonged early imbibition of seeds that sets in motion a gradual progression of various pre-germinative metabolic activities. E.g. – In muskmelon osmo-primed (PEG) seeds show increase activity of amylase enzyme, leading to improve germination. (Pill *et al.* 1995)

(A) From non-primed seeds



(B) From primed seeds with 5% PEG for 24 h

3. Halopriming

In this technique, seeds are soaked in a solution of inorganic salt followed by drying and subsequent seedling emergence and seedling establishment even under adverse environmental conditions

It can also promote early seedling growth and enhance final crop yield in salt affected soils. Inorganic salt: Potassium nitrate (KNO₃), Sodium chloride (NaCl), Potassium chloride (KCl), Calcium Chloride (CaCl₂) and Calcium sulphate (CaSO₄) etc.

Halopriming increases the superoxide dismutase activity of plants under saline conditions.

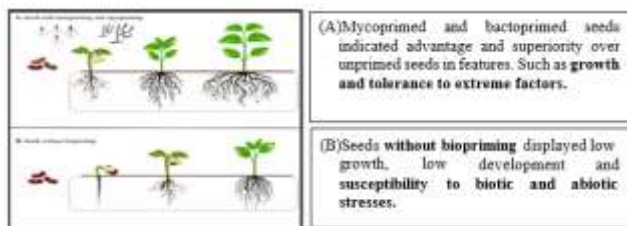
4. Biopriming

Bio-priming is a process of biological seed treatment that refers to combination of seed hydration (physiological aspect of disease control) and inoculation (biological aspect of disease control) of seed with beneficial organism to protect seed.

It is an ecological approach using either bacteria or selected fungal antagonists against the soil and seed-

borne pathogens.

Applying beneficial microorganism to the seed during priming may further improve establishment of the crop, particularly if seed-applied microorganism subsequently becomes established in the root zone of the plant and contribute to the long-term plant health or plant growth promotion.



5. Solid matrix priming

In solid matrix priming or matrix conditioning, solid or semi solid medium is used as an alternative to liquid medium. Afterward, seeds are separated from matrix, rinsed, and back-dried.

Water is slowly provided to the seeds & thus slow or controlled hydration occurs allowing the repair mechanism to operate. Commonly used solid matrices includes cocopeat, perlite, vermiculite, moss, saw dust, expanded calcined clay etc. To successfully accomplish, SMP, materials utilized as matrices should possess specific physical and chemical features such as minimal water solubility, high water holding capacity and surface area, no toxicity to seeds, and ability to adhere to seed surface.

6. Hormonal priming

Seeds imbibition occurs in the presence of plant growth regulators, which can have direct impact on seed metabolism.

The following regulators are commonly used for hormopriming: abscisic acid, auxins, gibberellins, kinetin, ethylene, polyamines, and salicylic acid. Hormonal priming has been found to alleviate the adverse effect of various stresses, including salinity and drought, on seed germination and seedling growth.

Plant hormone likes Gibberellin and Cytokinin regulate different developmental processes in plant. PGRs like Cytokinin act early during shoot initiation and control meristem activity, while GA3 are

responsible for expansion and cell division in shoot elongation, flowering and seed germination.

7. Nutri priming

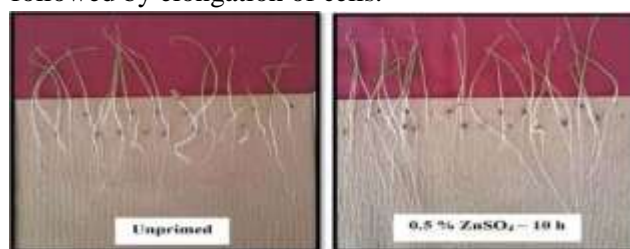
Seeds are soaked with limited nutrient containing solutions instead of pure water. Limited nutrient like, Zinc, copper, manganese, molybdenum which has been proved to fertilize the seed and provides the nutrients.

As a result, both nutritional effect and biochemical advantages of priming which improve germination traits, seed quality and seedling establishment.

Micronutrient application through seed treatment performed better or similar to other application methods.

Being an easy and cost-effective method of micronutrient application, seed treatments offer an attractive option for resource- poor farmer.

Micronutrient Zn involve in biosynthesis of amino acid (tryptophan).The tryptophan is a precursor of auxin and it is responsible for the rapid cell division followed by elongation of cells.



Effect of seed nutripriming treatments on germination (%) and seedling growth in onion

8. Nano priming

It is the process of seed priming in which seeds are primed with the nano particles like SiO₂, TiO₂, ZnO, FeS, silver, zinc and iron nano particles are used. Nano seed priming organization of nanopores in the seed coat for increasing uptake of water absorption, activation of reactive oxygen species (ROS)/antioxidant mechanisms in seed and formation of hydroxyl radicles to loosen the walls of cells and act as an inducer for rapid hydrolysis of starch. Nano-particles enhance activate enzymatic and hormonal responses during seed germination and plant growth. The nanoparticles of gold and silver are known to be very effective in improving the performance of seeds through

priming. Debasish et al. (2020)
 Particles below 100 nm.

B. Physical priming

In physical seed priming applied physical agent and energy directly interact with cellular component and redrying not required. The magnetic field, UV radiation, gamma radiation and microwaves are some of physical agents that are used for seed priming. Non-ionizing radiation has certain biological advantages over ionizing radiation since it does not generate charged ions while passing through a subject, but enough energy to cause biological effect

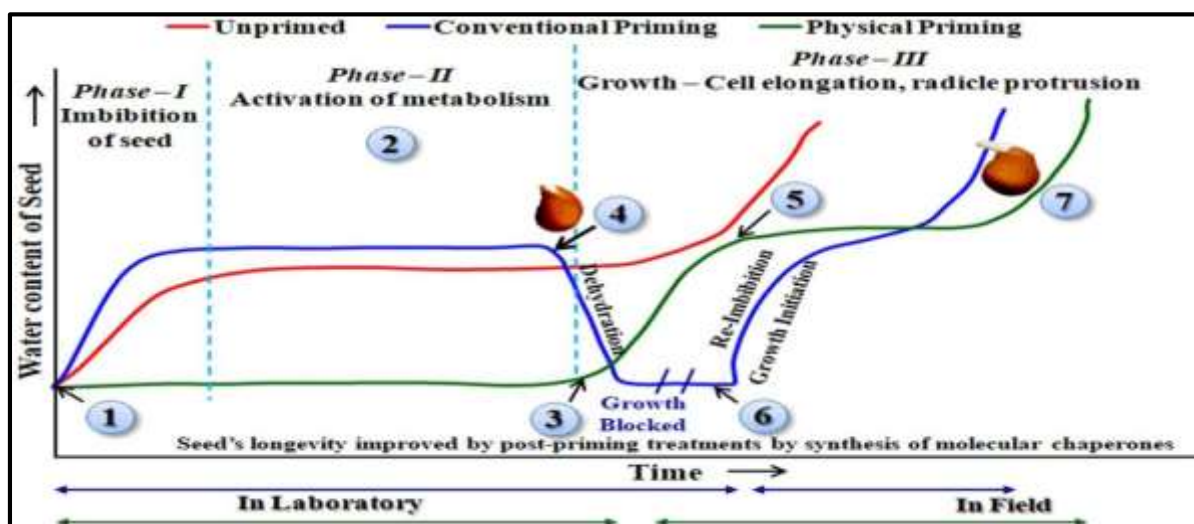
Magneto seed priming

Magneto-priming is considered as treating the seeds with magnetic field. The unpaired electrons of magnetic field change the properties of cell membrane and cell division which brings alteration in functioning and metabolism of cell and the energy is transformed into chemical energy, level of amylase enzymes increases leading to enhanced germination. (Panda *et al.* 2020).

Mechanisms of seed priming

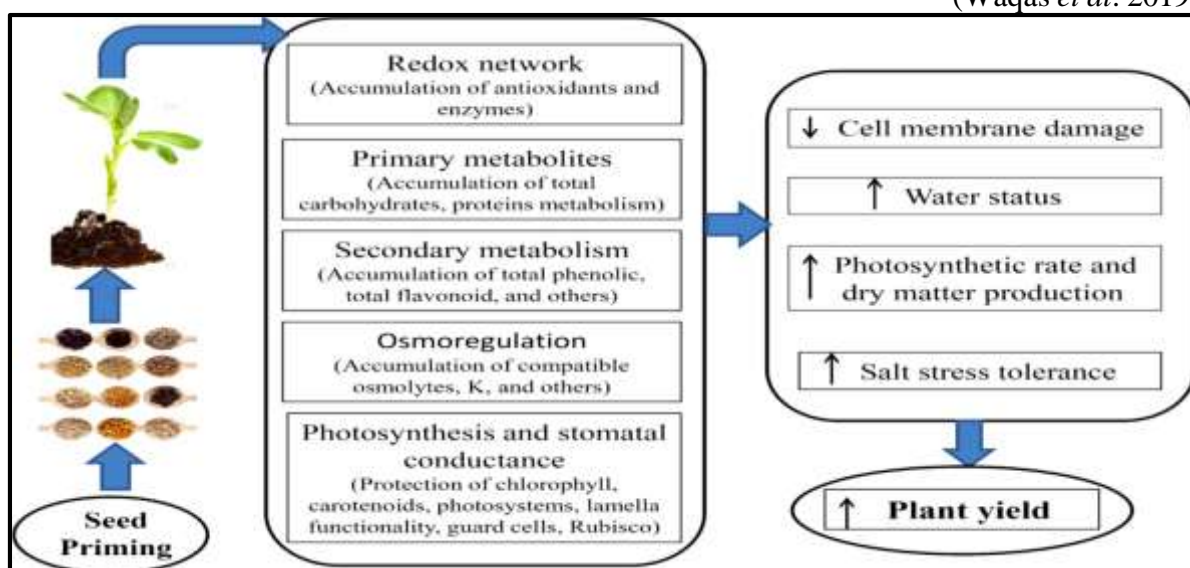
Phase I: Seed imbibition phase

In this phase include rapid water absorption, initiation of de novo protein synthesis and respiratory activities.



Seed hydration curves and germinating phases in unprimed and primed seeds

(Waqas *et al.* 2019)



Phase II: Metabolic activation phase

In which involves the initiation of different metabolic activities, enzyme activation and repairing process. Hydration remains stable and germination remain a reversible processed remain alive during storage.

Conventional priming shows two distinct slopes for hydration levels of seeds, first in Phase I and the other in Phase III.

Phase III: Germination phase

Where Re-imbibition of water, cell elongation and radical emergence occur. When re-initiate germination under suitable conditions after seed storage.

Advantages of seed priming

- Increase the germination percentage.
- Increase the seed vigour of low vigorous seeds.
- Enhance hydration.
- Increase stress tolerance.
- Improves the shelf life of seeds.
- Protect seed from seed-borne fungi.
- Reduce seedling emergence time.
- Increase the yield.

Factor affect on seed priming

- Seed Species and Variety
- Seed age and quality
- Priming solution composition
- Priming duration and temperature
- Osmotic potential and hydration level
- Environmental conditions during priming
- Storage conditions after priming
- Seed coat permeability
- Genetic factor
- Interaction with soil environment

Conclusion

From the foregoing discussion, it can be concluded that with the help of seed priming techniques, the various growth factors like seed germination, root and shoot length, plant height can be achieved along with crop yield and nutrient uptake in crops as well as economically viable.

- Among discussed priming technologies hormonal priming found best in wheat and coriander crops while osmopriming in chickpea and black gram crops etc.
- Hydropriming found suitable for the hard seed coat crop like soybean crop

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ARTICLE ID: 18

Soybean: A Nutritional Powerhouse for Human Health

Introduction

Currently, as consumers become increasingly sensible of their health and quality diet choices, soybean (*Glycine max*) has emerged as a notable nutritious and valuable crop worldwide (Kamshybayeva et al., 2017). Soybean, often called the “golden bean,” is recognized for its exceptional nutritional composition and wide range of health-promoting properties. It is an excellent source of plant-based protein, unsaturated fats, vitamins, minerals, and natural antioxidants, that contribute significantly to maintaining good health and enhancing overall well-being (Rashid et al., 2025). Although soybean originated in East Asia thousands of years ago, it is now cultivated and enjoyed in many forms across the world. From traditional recipes to innovative plant-based products, soybean has become an essential ingredient in diets across diverse culture (Joshi et al., 2026). A wide range of soybean-based products, including soy milk, tofu, soy flour, and textured vegetable protein, are gaining popularity among consumers (Rizzo, 2020; Figure 1). Their high nutritional value, bioactive ingredients and sustainability make them attractive choices for people seeking healthy and environmentally friendly food options. This article highlights the nutritional composition, health benefits, and dietary importance of soybean and soy-derived products in supporting human health and sustainable nutrition.



Figure 1. Diverse Soy-Based Food Products Including Traditional and Processed Forms. Illustration showing various soy-derived food products, including soy milk, tofu, tempeh, soy flour, soy protein isolate, edamame, soy nuts, textured vegetable protein, and fermented soy foods. *Image generated using artificial intelligence (AI) for illustrative purposes.*

1. Rich Source of High-Quality Protein

One of the key remarkable features of soybean is its exceptionally high protein content, accounting for approximately 35–40% of the seed. Unlike many other plant-based foods, soybean contains all essential amino acids needed for human growth and development, and proper body functioning, making it a complete protein source (Mishra et al., 2024). This unique quality characteristic makes soybean an excellent dietary option for vegetarians, vegans, and populations with limited access to animal-based protein sources. Soy protein plays an important role in supporting muscle growth and development, tissue repair, strengthening the immune system, and overall body maintenance (Basson et al., 2024). Due to its high nutritional quality and easy digestibility, it is commonly incorporated into sports nutrition products, protein supplements, and health-focused diets.

Table 2. Popular Soy-Based Foods with Nutritional Components and major health benefits

Soy-Based Product	Major Nutritional Components	Key Health Benefits
Soy Milk	Protein, calcium (fortified), vitamin D, potassium, isoflavones	Promotes bone health, cardiovascular health, and lactose-free nutrition
Tofu	High-quality protein, calcium, iron, magnesium	Supports muscle development, bone strength, and contributes to overall nutritional well-being.
Tempeh	Protein, dietary fiber, probiotics, B vitamins	Improves digestive function, a healthy gut microbiome, and protein intake
Soy Flour	Protein, dietary fiber, healthy fats, minerals	Enhances nutritional quality of baked food products and healthy digestive function
Soy Protein Isolates	Concentrated protein (up to 90%), essential amino acids	Supports muscle development, sports nutrition, and healthy weight management

Soy-Based Product	Major Nutritional Components	Key Health Benefits
Soy Nuts	Protein, healthy fats, fiber, antioxidants	Promotes cardiovascular health, satiety, and serves as a nutritious snack option
Edamame (Green Soybean)	Protein, fiber, folate, vitamin K, antioxidants	Supports cardiovascular health and provides nutrient-rich nutrition
Textured Vegetable Protein (TVP)	Protein, iron, dietary fiber, low fat	Serves as a plant-based protein alternative and helps support muscle health and maintenance
Fermented Soy Products (Miso, Natto, Soy Sauce)	Protein, probiotics, vitamins, bioactive compounds	Enhances digestive wellness, nutrient absorption, and immune immune

2. Potential health benefits of soybean

Soybean is a highly nutritious that provides high-quality protein, healthy fats, dietary fiber, vitamins, and essential minerals. Regular consumption may support heart health, improve digestion, help regulate blood sugar levels, and promote overall well-being (Kim et al., 2021). Its bioactive compounds, including isoflavones and antioxidants, also contribute to bone health and protection against chronic diseases ((Basson et al., 2024).

(A) Heart Diseases-Soybean is beneficial for heart health due to its low saturated fat content and absence of cholesterol. It contains healthy omega-3 and omega-6 fatty acids that support normal heart function and healthy blood lipid levels (Dukariya et al., 2020). Regular consumption of soy foods may help reduce low-density lipoprotein (LDL) (“bad”) cholesterol and promote cardiovascular health.

(B) Diabetes Management-Soybean is a nutritious food with a low glycemic index and high levels of fiber and protein, which help in controlling blood sugar levels. Because it is digested and absorbed gradually, it helps avoid rapid fluctuations in blood glucose (Kim et al., 2021). This makes soybean

particularly suitable for people with diabetes and those susceptible to developing the condition. Furthermore, its bioactive components may contribute to improved insulin function and better overall metabolic health.

(C) Bone Health-Soybean is a rich source of important minerals including, calcium, magnesium, phosphorus, and potassium, all of which play vital roles in maintaining strong bones and teeth (Dukariya et al., 2020). Furthermore, soybean is also rich in isoflavones, natural plant compounds that may help maintain bone strength and reduce bone degradation. Several researchers found that Regular consumption of soy foods can support bone health, especially in postmenopausal women who are more vulnerable to osteoporosis.

(D) Gastrointestinal Health-The dietary fiber content present in soybean contributes to proper healthy digestion and overall gut function. It helps regulate bowel movements, reduces the risk of constipation, and promotes the growth of beneficial gut bacteria (Belobrajdic et al., 2023). A healthy gut microbiome plays a significant role in overall well-being, supporting digestion, immunity, and nutrient uptake (Kang et al., 2023). Soybean-based foods help promote a balanced and healthy digestive system.

(E) Cancer Prevention-Soybean contains various bioactive compounds, including isoflavones, saponins, phytosterols, and antioxidants (Dukariya et al., 2020). These naturally occurring substances have gained considerable attention for their potential role in reducing the risk of certain cancers and promoting overall health. While research in this area is still ongoing, current reports indicates that moderate intake of soy-based foods may help reduce the risk of certain hormone-related cancers (Alleza et al., 2025). Soy consumption may also promote cellular health by helping to combat oxidative stress and inflammation.

(F) Weight Management-Soybean provides high-quality protein that helps build and maintain muscle mass. Its protein content promotes fullness, reducing unnecessary snacking and supporting appetite control (Dukariya et al., 2020). Additionally, soybean may assist in healthy weight management through its beneficial effects on metabolism and body fat regulation.

(G) Maternal Health-Soybean is also rich in folic acid and B vitamins, which are important for supporting a healthy pregnancy and fetal developmental growth. Adequate folic acid intake may help reduce the risk of neural tube defects in infants (Greenberg et al., 2011). However, pregnant women should consult their healthcare provider regarding the appropriate amount of soy to include in their diet.

(H) Blood Circulation and pressure-Soybean contributes to cardiovascular health through its rich supply of protein, iron, copper, potassium, magnesium, and beneficial isoflavones. These nutrients support red blood cell formation, efficient oxygen transport, healthy blood vessel function, and proper circulation (Mishra et al., 2024). Regular inclusion of soybean in the diet may help maintain normal blood pressure and promote overall heart health and metabolic efficiency.

3. A Sustainable Source of Nutrition

As global demand for nutritious and sustainable foods sources increases, soybean offers an important option. Producing plant-based protein generally requires fewer natural resources than animal-based protein production (Langyan et al., 2022). Therefore, soybean contributes not only to human nutrition but also to sustainable agricultural systems. Its wide range of food applications makes it easy to incorporate into diverse diets and cuisines across different regions and cultures (Rizzo et al., 2018). This versatility enhances its value as a nutritious and environmentally responsible food source.

4. Popular Soy-Based Foods

Soybean is widely consumed in the preparation of several nutritious and versatile food products across the world. Common soy-derived foods include soy milk, tofu, tempeh, edamame, soy flour, soy nuts, and textured vegetable protein, all of which provide valuable protein and essential nutrients (Table-2). These products offer healthy alternatives for individuals seeking balanced, plant-based diets.

Conclusion

Soybean has been a staple food in traditional Asian diets for thousands of years, whereas it was introduced to Western countries only about a century ago. It is a nutrient-rich crop that provides high-quality protein,

healthy fats, dietary fiber, essential vitamins, minerals, and bioactive compounds that support overall health and well-being. Regular consumption of soybean and soy-based foods may contribute to cardiovascular health, glycemic control, bone strength, digestive function, weight management, maternal nutrition, and protection against certain chronic diseases. Moreover, as a sustainable plant-based protein source requiring fewer natural resources than animal-derived proteins, soybean plays an important role in promoting food security, environmental sustainability, and healthy dietary patterns worldwide.

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Sericulture is an important agro-based rural industry in India that provides employment and livelihood opportunities to millions of farmers and rural families. However, the sector faces several challenges such as silkworm diseases, climate change, low productivity, and lack of technical knowledge among farmers. Research Extension Centres (RECs) under the Central Silk Board play a vital role in transferring scientific technologies, conducting farmer training programmes, and promoting sustainable sericulture practices. Training and extension activities help farmers improve cocoon quality, disease management, and income generation. Strengthening extension support and farmer capacity-building programmes can ensure sustainable growth of the sericulture sector and contribute to rural development.

Key Words: Sericulture, Research Extension Centres, Farmer Training, Silk Industry, Climate Change, Silkworm Diseases, Mulberry Cultivation, Sustainable Development, Rural Livelihood, Atma Nirbhar Bharat.

Introduction

India's sericulture sector has long played a vital role in rural development, employment generation, and sustainable livelihood creation. As one of the world's largest silk producers, India has a rich tradition of silk cultivation and weaving that supports millions of farmers, women, artisans, and rural youth. Sericulture not only contributes significantly to the national economy but also promotes self-employment opportunities in remote, tribal, and economically weaker regions. The sector is particularly important because of its labour-intensive nature and its ability to generate regular income throughout the year.

Challenges Faced by the Sericulture Sector

Despite its enormous potential, the sericulture industry continues to face numerous challenges that affect productivity, cocoon quality, and farmer income.

Silkworm Disease Infestation

One of the most serious problems is silkworm disease infestation. Diseases such as pebrine, grasserie, muscardine, and flacherie frequently result in severe crop losses among farmers. Poor hygiene in rearing houses, improper disinfection practices, contaminated equipment, and unfavorable environmental conditions increase the incidence of disease outbreaks. Since silkworms are highly sensitive insects, even minor negligence in rearing management can lead to the destruction of an entire silkworm crop, causing significant economic losses to farmers and rearers.

Impact of Climate Change

Climate change has further intensified the difficulties faced by the sericulture sector. Unpredictable rainfall patterns, rising temperatures, prolonged droughts, and excessive humidity adversely affect both mulberry cultivation and silkworm growth.

Shortage of Quality Inputs

Another major issue is the shortage of quality mulberry leaves and disease-free layings (DFLs). Many farmers still depend on traditional cultivation methods and have limited access to improved mulberry varieties, irrigation facilities, balanced fertilizer application, and certified silkworm seed. This reduces productivity and limits the profitability of sericulture farming. In addition, fluctuating cocoon prices, labour shortages, inadequate marketing facilities, and lack of awareness regarding modern technologies continue to hinder the growth of the sector.

Role of Research Extension Centres (RECs)

In this context, the role of Research Extension Centres (RECs) under the Central Silk Board has become highly significant. These centres serve as an important bridge between research institutions and farmers by transferring improved technologies and scientific knowledge from laboratories to field level implementation.

The major mandate of RECs is to strengthen sericulture development through extension services, farmer training programmes, field demonstrations, awareness campaigns, and farmer-scientist interactions.

Technology Transfer and Extension Services

Research Extension Centres regularly organize field inspections, exposure visits, technology dissemination programmes, and on-farm demonstrations to educate farmers about scientific sericulture practices. Extension officials provide technical guidance on mulberry cultivation, chawki rearing, silkworm management, disease prevention, cocoon production, and post-cocoon activities.

Through continuous interaction with farmers, RECs identify local problems and recommend suitable technological solutions for improving productivity and sustainability in sericulture farming.

Importance of Farmer Training Programmes

Among all extension activities, farmer training programmes have emerged as one of the most effective tools for strengthening the sericulture sector.

Skill Development and Scientific Knowledge

Training programmes equip farmers with practical knowledge and scientific skills required for successful silkworm rearing and crop management. Farmers are trained in proper disinfection methods, environmental management techniques, integrated disease and pest management practices, improved mulberry cultivation methods, and scientific handling of silkworms.

Such knowledge helps reduce crop losses and improves cocoon quality and productivity.

Capacity Building Through Government Schemes

Capacity-building initiatives conducted under programmes such as the Samarth Scheme have greatly contributed to skill development among sericulture farmers and rural youth. These programmes provide hands-on training and encourage the adoption of modern technologies in sericulture practices.

As a result, farmers become more confident in scientific crop management, leading to better cocoon production, improved silk quality, and enhanced income generation.

Women Empowerment Through Sericulture

Research Extension Centres also play a major role in promoting women empowerment through sericulture activities. Women actively participate in silkworm rearing, cocoon harvesting, spinning, reeling, and weaving operations. By providing technical training and extension support, RECs help rural women become economically independent and strengthen household livelihoods.

Sericulture has therefore emerged as an important

tool for inclusive rural development and gender empowerment.

Promotion of Climate-Resilient Technologies

Another important contribution of RECs is the dissemination of climate-resilient and farmer-friendly technologies. Farmers are guided on adaptive cultivation practices, improved silkworm breeds, water management techniques, and sustainable farming approaches to minimize losses caused by climate variability.

Such interventions are essential for ensuring the long-term sustainability and resilience of the sericulture industry.

Future Perspectives

The future of the sericulture sector depends on strengthening research-extension linkages, expanding farmer training programmes, and promoting sustainable farming technologies. Greater emphasis should be given to developing disease-resistant silkworm breeds, improved mulberry varieties, and eco-friendly disease management practices.

Digital extension services, mobile-based advisories, and climate-smart sericulture technologies can further improve farmer awareness and productivity. Strengthening Research Extension Centres and increasing investment in extension activities will help ensure sustainable growth of the silk industry in the coming years.

Conclusion

Sericulture continues to hold tremendous potential for rural development, employment generation, and sustainable economic growth in India.

However, addressing the challenges of disease outbreaks, climate change, low productivity, and inadequate technical knowledge requires coordinated efforts from research institutions, extension agencies, and farmers themselves.

Strengthening Research Extension Centres and expanding farmer training programmes can play a transformative role in improving the livelihoods of sericulture farmers and ensuring sustainable growth of the silk industry. With effective scientific intervention, strong extension support, and active farmer participation, sericulture can continue to thrive as a powerful instrument of rural empowerment and contribute significantly toward the vision of Atma Nirbhar Bharat.

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Sericulture, the rearing of silkworms for silk production, is one of the oldest and most sustainable rural industries in India. In the Himalayan state of Sikkim, sericulture is gradually emerging as an important livelihood activity due to the state's rich biodiversity, favorable climate, and organic farming policy. The industry not only supports rural employment and women empowerment but also promotes eco-friendly and sustainable development. Sikkim's unique mountain ecosystem provides excellent opportunities for both mulberry and non-mulberry sericulture. With increasing institutional support from the Central Silk Board and State Government agencies, sericulture is gaining importance as a supplementary source of income for farmers and tribal communities.

Agro-Climatic Advantage of Sikkim

Sikkim possesses diverse agro-climatic conditions because of its wide altitudinal variation ranging from 300 meters to above 4,000 meters. The subtropical and temperate climatic zones are highly suitable for sericulture activities.

The state experiences moderate temperatures ranging from 18°C to 28°C in many mid-hill regions, which are considered ideal for silkworm growth and cocoon formation. Relative humidity ranging between 70–85% supports healthy silkworm rearing, although proper ventilation and disease management are essential during high humidity periods.

Heavy rainfall and fertile soils support the cultivation of mulberry, castor, and other host plants required for silk production. Moreover, Sikkim's organic farming system enhances the quality and eco-friendly nature of silk produced in the state.

Types of Sericulture Practiced in Sikkim**Mulberry Sericulture**

Mulberry sericulture is one of the major silk production systems practiced in Sikkim. It involves the rearing of the silkworm *Bombyx mori* on mulberry leaves. Mulberry cultivation is mainly concentrated in East, West, and South Sikkim. Improved mulberry varieties such as Kosen and BC259 are cultivated for silkworm feeding. Farmers mainly rear bivoltine silkworm races, which produce superior-quality silk with better filament length and market value. Bivoltine silk has high export potential and contributes significantly to improving farmer income through quality cocoon production.

Eri Sericulture

Eri sericulture is another important silk activity in Sikkim. The eri silkworm, *Samia ricini*, is reared mainly on castor and kesseru leaves. Eri silk is popularly known as "Ahimsa Silk" or "Peace Silk" because the silk is extracted without killing the silkworm. Due to its eco-friendly nature and soft texture, eri silk has gained popularity in both domestic and international markets.

Eri culture requires comparatively low investment and is highly suitable for small and marginal farmers. Multiple rearing cycles throughout the year also provide continuous income opportunities for rural households.

Muga and Oak Tasar Possibilities

Although limited in scale, muga and oak tasar sericulture also possess future potential in Sikkim's lower and temperate hill regions. These sectors require further scientific research, pilot projects, and technology support for expansion under Himalayan conditions.

Socio-Economic Importance of Sericulture

Rural Employment Generation

Sericulture is a labour-intensive activity that generates year-round employment opportunities for rural families. Activities such as mulberry cultivation, silkworm rearing, cocoon harvesting, spinning, weaving, and marketing involve family labour and support livelihood security.

Women Empowerment

Women play a major role in various sericulture activities, particularly in silkworm rearing, spinning, weaving, and post-cocoon processing. Participation in sericulture helps rural women become financially independent and improves household income.

Income Diversification

For many farmers in Sikkim, sericulture acts as an important supplementary income source alongside traditional agriculture and horticulture. Since the industry requires relatively low landholding, even small farmers can benefit from silk production activities.

Environmental Sustainability

Sericulture aligns well with Sikkim's organic farming mission. Mulberry plantations contribute to soil conservation and ecological sustainability, while eri silk production promotes environmentally friendly textile production.

Institutional Support and Government Initiatives

Several organizations are actively supporting sericulture development in Sikkim. These include:

- Central Silk Board (CSB)
- State Sericulture Department
- Research and Extension Centres (REC)

Various government schemes such as the Silk Samagra Scheme and SAMARTH Skill Development Programme provide support through:

- Supply of Disease-Free Layings (DFLs)
- Farmer training programmes
- Infrastructure development
- Financial assistance and subsidies
- Technology dissemination activities

These programmes help improve farmer awareness, scientific rearing practices, and cocoon productivity.

Scientific Sericulture Practices

Mulberry Cultivation

Successful sericulture begins with healthy mulberry plantations. Farmers are encouraged to use organic manures such as farmyard manure and vermicompost. Proper land selection, drainage management, pruning, and timely leaf harvesting are essential for quality leaf production.

Silkworm Rearing

Scientific silkworm rearing involves maintaining hygienic rearing houses, proper temperature and humidity, regular bed cleaning, and timely feeding practices. Good management practices improve cocoon quality and reduce disease incidence.

Disease Management

Silkworm diseases such as grasserie, flacherie, and muscardine are common challenges in Sikkim due to high humidity conditions. Proper sanitation, disinfection, ventilation, and environmental regulation are essential preventive measures.

Post-Cocoon Activities

Post-cocoon operations such as cocoon grading, reeling, spinning, weaving, and dyeing add value to silk products. Mulberry silk is mainly reeled into filament silk, whereas eri silk is spun into yarn for weaving eco-friendly textiles.

Challenges Faced by the Sector

Despite its vast potential, sericulture in Sikkim faces several challenges:

- Small and fragmented land holdings
- Difficult hilly terrain and transportation problems
- High humidity leading to silkworm diseases
- Limited technical knowledge among farmers
- Shortage of skilled manpower

- Weak market infrastructure and marketing channels

These constraints limit large-scale commercialization and productivity improvement.

Strategies for Sustainable Development

To strengthen sericulture development in Sikkim, several measures are necessary:

- Establishment of Chawki Rearing Centres (CRCs)
- Cluster-based sericulture development
- Strengthening extension and advisory services
- Promotion of improved silkworm breeds and technologies
- Development of market linkages and branding
- Encouragement of youth entrepreneurship
- Expansion of post-cocoon and value-addition enterprises

Scientific interventions and farmer-oriented extension programmes can significantly improve cocoon productivity and profitability.

Future Prospects

Sikkim has tremendous potential to emerge as a producer of premium organic silk in the future. The increasing global demand for eco-friendly textiles, handloom products, and natural fibres creates new market opportunities for eri and bivoltine silk produced under organic conditions.

Branding and promotion of “Sikkim Silk” can improve market visibility and create premium value for silk products. Integration of sericulture with handloom, handicrafts, and eco-tourism can further strengthen rural livelihoods and local entrepreneurship.

With continuous institutional support, scientific management, and market development, sericulture can become a major pillar of sustainable rural development in Sikkim.

Conclusion

Sericulture in Sikkim represents a sustainable and inclusive rural enterprise with strong potential for employment generation, women empowerment, and ecological sustainability. The state’s favorable agro-climatic conditions and organic farming system provide a unique advantage for the production of quality silk.

Although challenges such as difficult terrain, disease incidence, and market limitations continue to affect the sector, proper technological interventions, institutional support, and farmer training programmes can significantly improve productivity and profitability.

With scientific planning and coordinated efforts, Sikkim can emerge as an important centre for organic and eco-friendly silk production under Himalayan Mountain ecosystems.

Table 1: Agro-Climatic Parameters of Sikkim for Sericulture

Parameter	Range/Condition	Suitability for Sericulture
Altitude	300–4000 m	Suitable for diverse silk types
Temperature	18°C–28°C	Ideal for silkworm rearing
Relative Humidity	70–85%	Favourable (requires control)
Rainfall	2000–3000 mm	Supports host plant growth
Farming System	100% Organic	Enhances silk quality

Table 2: Comparison of Sericulture Types

Type	Silkworm Species	Host Plant	Output Type	Suitability
Mulberry	<i>Bombyx mori</i>	Mulberry	Filament silk	Mid-hills
Eri	<i>Samia ricini</i>	Castor/Keseru	Spun silk	All regions
Muga	<i>Antheraea assamensis</i>	Som/Sualu	Golden silk	Limited
Oak Tasar	<i>Antheraea proylei</i>	Oak	Wild silk	Temperate zones
Type	Silkworm Species	Host Plant	Output Type	Suitability

Table 3: Cocoon and Silk Yield (Estimated for Sikkim Conditions)

Parameter	Mulberry (Bivoltine)	Eri Culture
DFLs per Crop	100	100
Cocoon Yield (kg)	60–70	80–100
Silk Recovery (%)	18–20%	10–12%
Crops per Year	2–3	4–6
Income Potential (₹/year)	40,000–80,000	30,000–70,000

Table 4: Socio-Economic Benefits of Sericulture

Aspect	Impact
Employment	Year-round rural employment
Women Participation	High involvement in rearing & spinning
Income	Supplementary and stable
Sustainability	Eco-friendly and organic
Rural Development	Promotes cottage industries

Table 5: Common Silkworm Diseases

Disease	Cause	Control Measures
Grasserie	Viral	Sanitation, proper feeding
Flacherie	Bacterial	Temperature control
Muscardine	Fungal	Disinfection, dry conditions

Table 6: Post-Cocoon Processes and Technologies

Process	Mulberry Silk	Eri Silk
Stifling	Steam/Hot air	Not required
Reeling	Multiend reeling	Not applicable
Spinning	Limited	Hand/motorized spinning
Weaving	Handloom/power loom	Handloom
Dyeing	Chemical/Natural dyes	Mostly natural dyes

Table 7: Major Challenges in Sikkim Sericulture

Constraint	Impact
Small land holdings	Limits scale
Hilly terrain	Transport difficulty
High humidity	Disease incidence
Lack of awareness	Low adoption
Weak market linkage	Reduced profitability
Constraint	Impact

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Integrated Assessment of Phytoplankton, Zooplankton, Periphyton Communities and Chlorophyll-a Concentration for Evaluating Aquatic Ecosystem Productivity

Abstract

Aquatic biological communities are widely recognized as effective indicators of ecosystem health, productivity, and water quality. The present study assessed the composition, abundance, and diversity of phytoplankton, zooplankton, and periphyton communities, along with chlorophyll-a concentration, in selected aquatic ecosystems. Phytoplankton samples were collected using the sedimentation method and preserved with Lugol's iodine solution, whereas zooplankton samples were obtained by filtering water through a 55 µm mesh plankton net and preserved in formalin. Periphyton samples were collected by scraping known areas of submerged substrates. Identification of organisms was carried out using standard taxonomic keys and recognized identification manuals, while quantitative estimation was performed through microscopic counting techniques. Chlorophyll-a concentration was determined using the acetone extraction and spectrophotometric method and served as an indicator of phytoplankton biomass and primary productivity. The abundance and diversity of phytoplankton, zooplankton, and periphyton communities reflected the ecological condition, trophic status, and biological productivity of the aquatic environment. The integrated assessment of these biological indicators provides valuable information for monitoring ecosystem health, evaluating water quality, and supporting sustainable aquatic resource management and conservation strategies.

Keywords: Phytoplankton; Zooplankton; Periphyton; Chlorophyll-a; Water Quality; Aquatic Ecosystem; Primary Productivity; Bioindicators; Biodiversity; Trophic Status.

Introduction

Aquatic ecosystems are highly productive environments that support diverse biological communities and provide essential ecosystem services such as nutrient cycling, primary production, fisheries resources, and water purification. The structure and abundance of aquatic organisms, particularly phytoplankton, zooplankton, and periphyton, are closely linked to environmental conditions and are widely used as indicators of ecosystem health and water quality (Wetzel, 2001; Dodds and Whiles, 2020).

Phytoplankton serve as the primary producers of aquatic food webs and are important indicators of nutrient status and productivity. Zooplankton form a crucial link between primary producers and higher trophic levels, while periphyton contribute significantly to primary production, nutrient recycling, and ecological functioning. Changes in the composition and abundance of these communities reflect variations in environmental quality and ecosystem productivity (Battish, 1992; Bellinger and Sigeo, 2010; Reynolds, 2006). Chlorophyll-a, the principal photosynthetic pigment in algae, is widely used as an indicator of phytoplankton biomass, trophic status, and primary productivity. Its concentration provides valuable information on nutrient enrichment and the biological condition of aquatic ecosystems (APHA, 2017; Wetzel, 2001).

Methodology

Zooplankton Sampling, Identification and Quantitative Estimation

Zooplankton

Zooplankton are microscopic aquatic animals that drift in water bodies and occupy a central position in aquatic food webs. They act as primary consumers by feeding on phytoplankton and serve as an important food source for fish larvae and juvenile fishes. The abundance and diversity of zooplankton are widely used as indicators of water quality, trophic status, and biological productivity of aquatic ecosystems. Major freshwater zooplankton groups include Rotifera, Cladocera, Copepoda, and Ostracoda (Battish, 1992; Wetzel, 2001).

Table 1. Major Groups of Freshwater Zooplankton and Their Characteristics

Group	Examples	Ecological Importance
Rotifera	<i>Brachionus</i> , <i>Keratella</i>	Indicators of eutrophication and water quality
Cladocera	<i>Daphnia</i> , <i>Moina</i>	Important grazers of phytoplankton
Copepoda	<i>Cyclops</i> , <i>Diaptomus</i>	Link between phytoplankton and fish
Ostracoda	<i>Cypris</i> , <i>Stenocypris</i>	Contribute to nutrient cycling

Principle

Zooplankton present in a known volume of water are concentrated using a plankton net of suitable mesh size. The concentrated sample is preserved and examined microscopically. Organisms are identified using standard taxonomic keys and counted using a Sedgwick–Rafter counting cell. The density of zooplankton is then calculated and expressed as individuals per litre (ind. L⁻¹) following the Drop Count Method (Lackey, 1938).

Materials Required

- ❖ Plankton net (55 µm mesh size)
- ❖ Collection bucket
- ❖ Measuring cylinder
- ❖ Sample bottles (100 mL)
- ❖ 4% formaldehyde solution

- ❖ Sedgwick–Rafter counting cell
- ❖ Compound or binocular microscope
- ❖ Glass pipettes
- ❖ Taxonomic identification manuals
- ❖ Distilled water

Sample Collection

1. Collect water samples from the surface of each sampling station.
2. Filter 50 litres of water through a plankton net made of bolting silk cloth having a mesh size of 55 µm.
3. The plankton net should have a mouth diameter of 25 cm and a length of approximately 80 cm.
4. Wash the net thoroughly from outside to ensure all organisms are collected in the cod end.
5. Transfer the concentrated sample into a clean collection bottle.



Sample Preservation

1. Transfer the concentrated sample into a 100 mL plastic bottle.
2. Add sufficient formaldehyde solution to obtain a final concentration of 4%.
3. Mix gently and label the bottle properly.
4. Store the samples in a cool, dark place until laboratory analysis.

Laboratory Examination

Sample Mixing

Before analysis, gently shake the preserved sample to ensure uniform distribution of zooplankton organisms.

Loading the Sedgwick–Rafter Cell

1. Using a pipette, withdraw a well-mixed aliquot of the sample.

- Carefully fill the Sedgwick–Rafter counting chamber without introducing air bubbles.
- Allow the organisms to settle for 2–3 minutes.

Microscopic Observation

- Observe the chamber under a binocular microscope.
- Count all organisms present in the counting field.
- Identify organisms to the lowest possible taxonomic level using standard taxonomic keys.

Species Identification

Identification of zooplankton species is carried out using morphological characteristics such as body shape, segmentation, appendages, carapace structure, and locomotory organs. Standard identification manuals including Battish (1992), Edmondson (1959), and Pennak (1989) may be used for species determination.

Quantitative Estimation

The abundance of zooplankton is estimated using a Sedgwick–Rafter counting cell following the Drop Count Method.



Quantitative Estimation Using Sedgwick-Rafter Cell

Formula

Zooplankton Density (ind. L⁻¹)

$$N = (C \times V_c) / (V_a \times V_s)$$

Where:

N = Zooplankton density (individuals L⁻¹)

C = Number of organisms counted

V_c = Volume of concentrated sample (mL)

V_a = Volume of sample examined (mL)

V_s = Volume of water filtered (L)

Example Calculation

If:

C = 250 organisms

V_c = 100 mL

V_a = 1 mL

V_s = 50 L

Then:

$$N = (250 \times 100) / (1 \times 50)$$

$$N = 500 \text{ individuals L}^{-1}$$

Zooplankton Count

Sample	Water Filtered (L)	Concentrated Volume (mL)	Volume Examined (mL)	Organisms Counted	Density (ind. L ⁻¹)
Site 1					
Site 2					
Site 3					

Precautions

- ❖ Collect samples from representative locations.
- ❖ Thoroughly wash the plankton net after filtration.
- ❖ Preserve samples immediately after collection.
- ❖ Mix samples properly before counting.
- ❖ Avoid air bubbles while loading the Sedgwick–Rafter cell.
- ❖ Count organisms systematically to avoid duplication.
- ❖ Clean all glassware before use.
- ❖ Carry out identification using standard taxonomic keys.

Periphyton Collection and Identification

Table 2. Major Groups of Periphyton and Their Ecological Importance

Group	Examples	Ecological Importance
Diatoms (Bacillariophyceae)	<i>Navicula</i> , <i>Nitzschia</i>	Indicators of water quality
Green Algae (Chlorophyceae)	<i>Spirogyra</i> , <i>Cladophora</i>	Primary producers
Blue-Green Algae (Cyanophyceae)	<i>Oscillatoria</i> , <i>Anabaena</i>	Nitrogen fixation
Desmids	<i>Cosmarium</i> , <i>Closterium</i>	Indicators of clean water
Protozoa and Bacteria	Various species	Nutrient recycling

Periphyton: Periphyton is a complex assemblage of algae, cyanobacteria, bacteria, fungi, protozoa, and organic detritus attached to submerged surfaces in

aquatic ecosystems. It plays an important role in primary productivity, nutrient cycling, and serves as a natural food source for fish and aquatic invertebrates. Due to its rapid response to environmental changes, periphyton is widely used as a biological indicator of water quality and ecosystem health (Wetzel, 2001; Dodds and Whiles, 2020).

Principle: Periphyton attached to submerged substrates is collected by scraping a known surface area. The collected material is preserved in formalin solution and examined microscopically. Organisms are identified using standard taxonomic keys based on their morphological characteristics. Species composition and diversity provide information on the ecological status and productivity of aquatic ecosystems.

Materials Required

- ❖ Sterile scalpel or blade
- ❖ Soft brush
- ❖ Measuring scale
- ❖ Sample collection trays
- ❖ Plastic containers (80–100 mL)
- ❖ 4–5% formalin solution
- ❖ Compound microscope
- ❖ Glass slides and cover slips
- ❖ Pipettes
- ❖ Distilled water
- ❖ Taxonomic identification manuals

Sample Collection

1. Select submerged substrates such as stones, wood, and decaying logs from the sampling station.
2. Mark a known surface area (1–2 cm²) on the substrate.
3. Gently scrape the surface using a sterile blade or brush.
4. Collect the detached material into a clean container.
5. Repeat the process for multiple substrates to obtain a representative sample.

Sample Preservation

1. Transfer the collected material into labelled plastic containers.
2. Add sufficient formalin solution to obtain a final concentration of 4–5%.

3. Mix gently to ensure proper preservation.
4. Store samples in a cool and dark place until laboratory examination.

Laboratory Analysis

Slide Preparation

1. Shake the preserved sample gently.
2. Place a drop of the sample on a clean glass slide.
3. Cover with a cover slip.
4. Prepare permanent slides if long-term storage is required.

Microscopic Examination

1. Observe the slides under low and high magnification.
2. Record morphological characteristics of the organisms.
3. Photograph representative taxa when necessary.

Species Identification

Periphytic organisms are identified using standard taxonomic keys, illustrations, and descriptions provided in recognized manuals and scientific literature. Identification is carried out up to the lowest possible taxonomic level based on characteristics such as:

- ❖ Cell shape
- ❖ Cell size
- ❖ Colony formation
- ❖ Pigmentation
- ❖ Cell wall ornamentation
- ❖ Arrangement of cells

Periphyton Abundance Estimation

Formula

$$D = \frac{N \times V_t}{V_s \times A} \quad (\text{cells cm}^{-2})$$

Where:

D = Periphyton density (cells cm⁻²)

N = Number of cells counted

V_t = Total sample volume (mL)

V_s = Volume of subsample examined (mL)

A = Area scraped (cm²)

Observation Table

Periphyton Species Composition

Sample Site	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Desmids	Others
Site 1					
Site 2					
Site 3					

Periphyton Density

Site	Cells Counted (N)	Total Volume (mL)	Volume Examined (mL)	Area Scraped (cm ²)	Density (cells cm ⁻²)
Site 1					
Site 2					
Site 3					

Precautions

- ❖ Collect samples from representative submerged substrates.
- ❖ Measure the scraped area accurately.
- ❖ Avoid contamination during sampling.
- ❖ Preserve samples immediately after collection.
- ❖ Prepare clean microscope slides.
- ❖ Identify organisms using standard taxonomic references.
- ❖ Record observations carefully.
- ❖ Store preserved samples away from direct sunlight.

Phytoplankton Sample Collection, Preservation, Identification and Enumeration

Sample Collection: Phytoplankton samples were collected from selected sampling sites using clean 1-L plastic bottles following the sedimentation method described by Bellinger and Sigeo (2010) and Rice et al. (2017). The collected water samples were immediately preserved by adding 2–3 mL of 1% Lugol's iodine solution until a light golden-brown (beer-like) coloration was obtained. The preserved samples were then transported to the laboratory for further analysis.

Preparation of Lugol's Solution: A 1% Lugol's solution was prepared by dissolving 10 g iodine (I₂) and 20 g potassium iodide (KI) in 200 mL distilled water, followed by the addition of 20 mL concentrated

glacial acetic acid. The prepared solution was stored in a dark glass bottle to protect it from light-induced degradation.

Sample Concentration by Sedimentation: In the laboratory, the preserved samples were kept undisturbed at room temperature for 24–48 hours to allow phytoplankton cells to settle at the bottom of the container. After complete sedimentation, the supernatant water was carefully siphoned off without disturbing the settled material. This process concentrated the sample volume to approximately 50–100 mL.

Microscopic Examination and Identification: For phytoplankton analysis, a 5 µL aliquot of the concentrated sample was placed on a clean glass slide and allowed to dry either naturally or on a hot plate. A drop of distilled water was then added to the dried sample, and a coverslip was carefully placed over it. The prepared slides were examined under a trinocular light microscope. Phytoplankton species were identified using standard taxonomic references such as Bellinger and Sigeo (2010), Edmondson (1992), and Rice et al. (1998). Scientific names and taxonomic classifications were verified using the algal database AlgaeBase (Guiry and Guiry, 2023).

Quantitative Analysis of Phytoplankton: The density of phytoplankton was estimated according to the method described by Semina (1981). The total phytoplankton abundance was calculated using the following formula:

Formula for Phytoplankton Density

$$N = \frac{V_2}{V_3} \times n$$

Where:

- N = Total phytoplankton density (units L⁻¹)
- V₂ = Volume of concentrated sample after sedimentation and siphoning (mL)
- V₃ = Volume of concentrated sample examined on the microscope slide (mL)
- n = Total number of phytoplankton cells counted in the subsample

Chlorophyll-a (Chl-a):

Chlorophyll-a (Chl-a) is the primary photosynthetic pigment found in phytoplankton and all other oxygen-producing photosynthetic organisms.

<p>Spectrophotometric Method</p> <p>Measures absorbance of extracted pigments at specific wavelengths (e.g., 664 nm and 750 nm).</p> <p>Principle: Based on the absorbance of light by chlorophyll-a in a solvent extract.</p>	<p>HPLC Method</p> <p>Separates chlorophyll-a from other pigments and quantifies it using a detector.</p> <p>Principle: Based on the separation of pigments using a column and detection by absorbance or fluorescence.</p>	<p>Fluorometric Method</p> <p>Measures fluorescence emission of chlorophyll-a when excited by specific light.</p> <p>Principle: Based on the natural fluorescence emitted by chlorophyll-a molecules.</p>	<p>Remote Sensing Method</p> <p>Estimates chlorophyll-a concentration using satellite or airborne sensor data.</p> <p>Principle: Based on the reflection of light from water bodies related to chlorophyll concentration.</p>
<p>All these methods are used to estimate chlorophyll-a concentration in aquatic systems for assessing algal biomass, primary productivity, and water quality.</p>			

It plays a vital role in capturing light energy and converting it into chemical energy during photosynthesis. Since phytoplankton form the base of aquatic food webs and contribute significantly to primary production, chlorophyll-a is widely used as an indicator of phytoplankton biomass, productivity, and the trophic status of aquatic ecosystems. Chlorophyll-a generally accounts for about 1–2% of the dry weight of phytoplankton cells, although its concentration may vary with species composition, nutrient availability, light intensity, and environmental conditions. The measurement of chlorophyll-a provides valuable information on the biological productivity and ecological health of water bodies. Higher chlorophyll-a concentrations are usually associated with increased phytoplankton abundance and nutrient-rich conditions, while lower concentrations indicate less productive waters.

Table 3. Types of Chlorophyll and Their Functions

Pigment	Occurrence	Function
Chlorophyll-a	All photosynthetic organisms	Primary photosynthetic pigment
Chlorophyll-b	Green algae and higher plants	Accessory pigment
Chlorophyll-c	Diatoms and brown algae	Accessory pigment
Chlorophyll-d	Red algae and some cyanobacteria	Adaptation to low-light environments
Chlorophyll-f	Certain cyanobacteria	Utilization of far-red light for photosynthesis

Several methods are available for chlorophyll-a estimation in aquatic systems, including spectrophotometric, fluorometric, high-performance liquid chromatography (HPLC), and remote sensing techniques. Among these, the spectrophotometric method is widely employed because of its simplicity, reliability, and cost-effectiveness.

Principle: Phytoplankton pigments are extracted using 90% acetone, and chlorophyll-a concentration is determined spectrophotometrically. Absorbance is measured before and after acidification. Acidification converts chlorophyll-a to pheophytin-a, allowing correction for degradation products and improving the accuracy of chlorophyll-a estimation. (Kumar et al 2015, 2020)

Materials Required

- Water samples containing phytoplankton
- Whatman GF/C glass fibre filters
- 90% acetone
- Saturated magnesium carbonate (MgCO₃) solution
- 1% hydrochloric acid (HCl)
- Mortar and pestle
- Graduated centrifuge tubes
- Centrifuge

Sample Filtration

1. Filter a known volume of water sample through a Whatman GF/C glass fibre filter.
2. During filtration, add a few drops of saturated magnesium carbonate (MgCO₃) solution to the filter.

- Magnesium carbonate prevents acidification during filtration and protects chlorophyll pigments from degradation.

Chlorophyll Extraction Procedure

1. Grinding

- Place the filter containing the retained phytoplankton in a clean mortar.
- Add approximately 10–15 mL of 90% acetone.

2. Cell Disruption

- Gently grind the filter using a pestle until the phytoplankton cells are completely ruptured.
- This facilitates the release of chlorophyll pigments into the solvent.

3. Extraction

- Transfer the resulting slurry into a graduated centrifuge tube.
- Seal the tube tightly and keep it in darkness at 4°C for 24 hours to ensure complete pigment extraction.

4. Centrifugation

- Centrifuge the samples at 2500 rpm for 15 minutes.
- Carefully collect the clear supernatant for spectrophotometric analysis.

Spectrophotometric Analysis

Measure the absorbance of the extracted pigment solution using a UV–Visible spectrophotometer.

Before Acidification: 750 nm (W) & 664 nm (X)

After Acidification

Add 1–2 drops of 1% HCl, mix gently, and allow the sample to stand for 2–3 minutes.

Measure absorbance at:

- 750 nm (Y)
- 665 nm (Z)

Significance of Measurement Wavelengths

Wavelength (nm)	Purpose
750	Correction for turbidity and background scattering
664	Measurement of chlorophyll-a in acetone extract
665 (after acidification)	Measurement of pheophytin-a

Calculation of Chlorophyll-a

Corrected Absorbance Values

Before acidification: $664b = X - W$

After acidification: $665a = Z - Y$

Formula

$$\text{Chlorophyll a } (\mu\text{g/L}) = \frac{26.7 \times (664b - 665a) \times V_1}{V_2 \times L}$$

Where:

- 26.7** = Absorption coefficient and conversion factor
- V₁** = Volume of acetone extract (L)
- V₂** = Volume of filtered water sample (m³)
- L** = Optical path length of cuvette (usually 1 cm)

Observation Table

Absorbance Measurements

Sample	750 nm (W)	664 nm (X)	664b = (X - W)	750 nm (Y)	665 nm (Z)	665a = (Z - Y)
Site 1						
Site 2						
Site 3						

Chlorophyll-a Calculation

Sample	664 b	665 a	V ₁ (L)	V ₂ (m ³)	L (cm)	Chlorophyll a (μg/L)
Site 1						
Site 2						
Site 3						

Precautions

- Perform all extraction procedures under low-light conditions.
- Use amber-coloured bottles to prevent photodegradation of pigments.
- Keep samples refrigerated during storage and transport.
- Ensure complete extraction of pigments by maintaining samples in acetone for 24 hours.

Preparation of Reagents

Preparation of 90% Acetone

To prepare 1 L of 90% acetone:

- Acetone = 900 mL

- Distilled water = 100 mL

Mix thoroughly and store in a tightly closed container.

Preparation of Saturated Magnesium Carbonate (MgCO₃) Solution

1. Add approximately 10 g MgCO₃ to 100 mL distilled water.
2. Stir thoroughly.
3. Allow the suspension to settle.
4. Use only the clear supernatant during filtration.

Preparation of 1% Hydrochloric Acid (HCl)

To prepare 100 mL of 1% HCl solution:

- Concentrated HCl = 1 mL
- Distilled water = 99 mL

Add acid slowly to water while stirring.

Caution: Always add acid to water, never water to acid.

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ARTICLE ID: 22**Microplastics:****The New Threat Lurking in Our Agri-Systems****1. Introduction**

In recent years, microplastics have gained attention as an emerging pollutant of global concern. These tiny plastic particles are being reported in agricultural soils, where they influence soil properties, plant development, and the sustainability of agroecosystems. Originally derived from the fragmentation of larger plastic materials or released directly from products such as packaging, synthetic textiles, and tyres. These particles are now widely detected beyond marine environments. Recent studies suggest that agricultural soils act as significant repositories for microplastics. Microplastics contribution is mainly due to the use of plastic-based farming materials, land application of sewage sludge and compost, contaminated irrigation water, atmospheric deposition, and the continuous breakdown of larger plastic items in the environment. Their persistence, mobility, and ability to adsorb toxic additives and co-contaminants are serious concerns. The occurrence and degradation differ from those of many available conventional pollutants. They may accumulate progressively in soil ecosystems. As a result, microplastics are no longer passive litter fragments but are active contaminants capable of influencing soil functioning, crop performance, and food-chain integrity.

2. Effects on Soil Health and Crop Production**Alteration of Soil Physical Properties**

Soil is the foundation of agricultural productivity. Its structure directly determines the availability of water, air, and nutrients to plants. The accumulation of microplastics can disrupt this balance by modifying bulk density, porosity, aggregation, and water-holding capacity. Such changes may alter infiltration and evaporation patterns, which alter soil moisture dynamics and root-zone conditions. In some cases, routine soil assessments of microplastics interfere with the estimation of soil organic carbon and nutrient status.

Disruption of Soil Biological Processes

Healthy soils depend on diverse microbial communities and fauna. These sustain nutrient cycling and organic matter decomposition. Microplastics may disturb these biological processes by altering microbial community structure and suppressing enzyme activity. Microplastics influence the behaviour of soil organisms such as earthworms and nematodes. Since these organisms contribute to soil aeration, aggregation, and fertility, their impairment may have long-term consequences for ecosystem stability and crop productivity.

Impacts on Plant Growth

The effects of microplastics on plants have become an important area of research. Particularly for staple food crops such as rice, wheat, and maize. Studies have reported that microplastic-contaminated soils show changes in seed germination, root elongation, biomass accumulation, and nutrient uptake in plants.

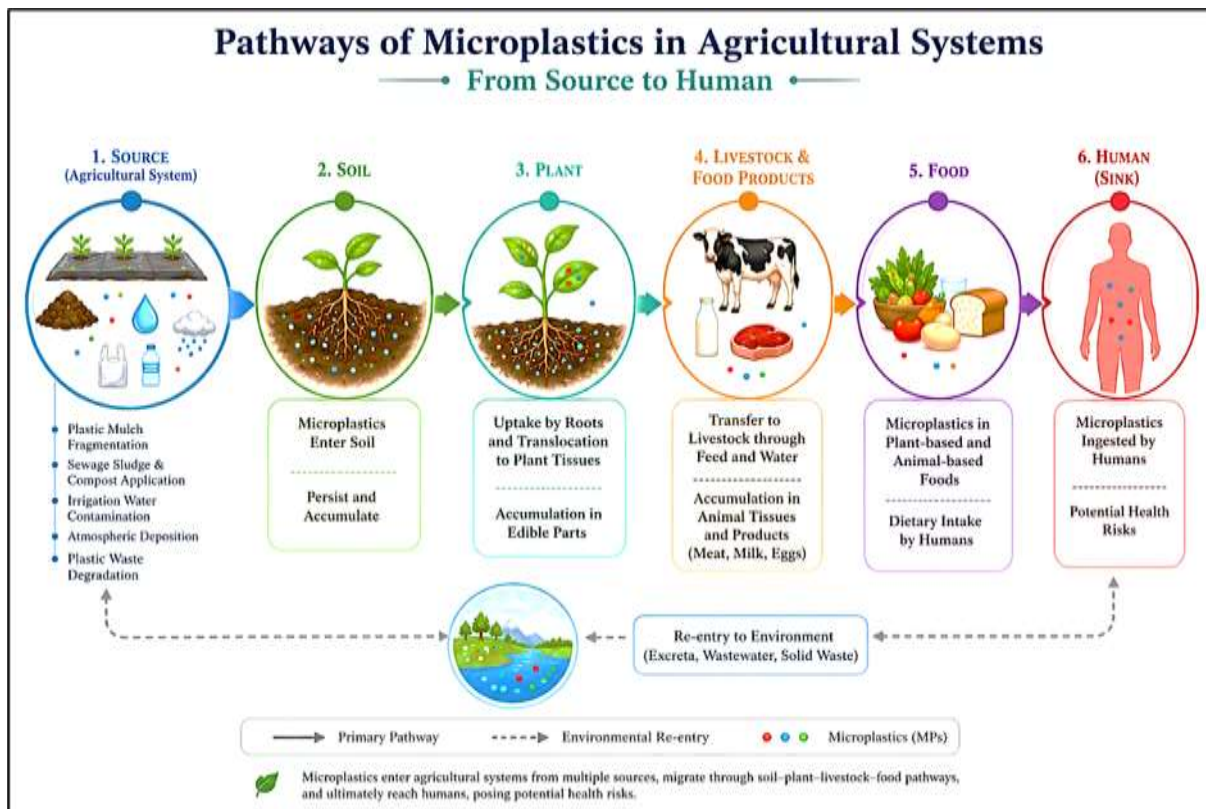


Fig. 1. Pathways of Microplastics in Agricultural Systems

The first point of contact with contaminated substrates appears to be vulnerable in root systems. Alterations in root architecture, tissue density, and root surface area may limit the plant’s capacity to absorb water and essential nutrients. In more severe cases, microplastic exposure has been associated with oxidative stress, stunted growth, and reduced yield potential.

3. Entry into the Food Chain

Uptake by Crops

A major concern regarding the presence of microplastics in agricultural environments is their ability to move from soil to plant tissues. The potential uptake and translocation represent a significant challenge in agricultural systems. This process transfers plastic particles through the food production to humans. Nanoplastics and microplastics enter root tissues through cracks, root tips, and other microscopic pathways. Following uptake, microplastic particles translocate within the plant via vascular pathways. This raises the possibility that microplastics can reach edible plant parts, thereby creating a direct route to human exposure.

Transfer to Livestock

Beyond crops, livestock can also contribute to the movement of microplastics through the food chain. When animals consume feed or water containing microplastics exposed not only to the particles but also to co-contaminated pollutants. This has generated growing concern about possible effects on animal health and the quality and safety of foods produced from these animals.

Human Exposure and Risk

The movement of microplastics in the food supply from soil to crops and livestock has direct adverse effects on human health. Although the full toxicological consequences remain under investigation. The presence of microplastics in agricultural produce raises serious concerns regarding chronic exposure and bioaccumulation. The issue is therefore not confined to environmental quality alone; it has become a matter of food security, public health, and sustainable development.

4. Mitigation Strategies

Improved management techniques, regulatory intervention, and technology innovation are all

necessary to address microplastic contamination in agriculture. One of the most important steps in reducing microplastic contamination is lowering the amount of plastic that enters agricultural areas. This can be accomplished by promoting the adoption of eco-friendly substitutes for traditional plastics, through improving agricultural plastic residue collection, recycling, and disposal methods. In order to reduce the spread of microplastics through treated irrigation water and sludge application, advancements in wastewater treatment technology are equally crucial. Adopting sustainable crop and soil management techniques also lessens the cumulative effects of environmental pollutants and preserves the resilience of agroecosystems. To track pollution levels, identify sensitive locations, and evaluate changes over time, agricultural soils, organic amendments, and irrigation water sources must be continuously monitored. Stricter regulations on the disposal of plastic waste, thorough guidelines for the use of sewage sludge in agriculture, and greater public awareness of the effects of microplastic pollution on the environment and food safety are all necessary for effective management.

5. Summary

Microplastic contamination has emerged as an important environmental challenge for agricultural systems. These particles can alter soil structure and biological activity, influence plant growth and development, and potentially enter food webs through crops and livestock. As a result, concerns are growing about their implications for soil fertility, agricultural productivity, and food safety. Although many aspects of microplastic behaviour in agroecosystems remain under investigation, current evidence indicates that their accumulation may pose long-term risks to both ecosystem functioning and sustainable food production. An integrated strategy that incorporates appropriate farm management techniques, successful legislative initiatives, and scientific research will be needed to address this problem. To lessen environmental pollution, safeguard ecosystem health, and guarantee food security for future generations, such coordinated actions are crucial.

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ARTICLE ID: 23

Kinnow: A Promising Fruit Crop in Northern Rajasthan

Abstract

Kinnow (*Citrus reticulata* Blanco) has become an important citrus fruit in Northern Rajasthan, offering significant opportunities for income and agricultural diversification. Well-suited to arid and semi-arid conditions, it tolerates temperature extremes and limited water. With high yield potential, early maturity and strong market demand, kinnow appeals to both small holder and commercial farmers. Improved varieties, better orchard management and integrated pest control have enhanced productivity and fruit quality. Although challenges like irrigation limitations, soil salinity and post-harvest handling remain, kinnow cultivation can boost rural livelihoods, support nutritional security and strengthen the region's economy. Focused research, policy support and farmer awareness are key to realizing its full potential as a sustainable crop in arid zones.

Keywords: *Citrus reticulata* × *Citrus deliciosa*, Northern Rajasthan, Crop Diversification, Horticulture and Fruit quality.

Introduction

Kinnow (*Citrus reticulata* Blanco) is a high-yielding mandarin hybrid, developed by crossing the “King” and “Willow Leaf” mandarin. Originating in California, USA in 1935 by H. B. Frost. The crop was later introduced to India in the 1940s and has since gained widespread popularity in northern states, including **Rajasthan, Punjab and Haryana**, due to its adaptability to arid and semi-arid climates. It is a commercially important citrus fruit valued for its juicy, sweet and tangy flavor, making it highly acceptable in domestic and export markets.

Nutritional Composition of Kinnow

Component	Content/100 g edible portion	Remarks
Water	85–88 g	Major component
Energy	40–50 kcal	Low-calorie fruit
Sugars	8–10 g	Glucose, Fructose
Proteins	0.7–1.0 g	Plant-based protein
Vitamin C (Ascorbic Acid)	40–60 mg	Antioxidant
Vitamin A (β-carotene)	10–15 µg	Supports vision
Calcium	40–45 mg	Bone health
Flavonoids	Hesperidin, Naringin	Antioxidant
Phenolic Compounds	Present	Antioxidant
Essential Oils	Limonene (mainly in peel)	Aromatic & bioactive properties

The crop demonstrates remarkable adaptability to arid and semi-arid regions, tolerating temperature extremes and water-limited conditions, which are typical of Northern Rajasthan districts such as **Sri Ganganagar, Hanumangarh and Bikaner**. Its early fruiting, high productivity and extended harvest period make it an attractive choice for smallholder and commercial farmers. Additionally, kinnow cultivation contributes to crop diversification, enhances rural livelihoods and strengthens regional agricultural economies. Despite challenges related to irrigation, soil salinity and post-harvest management, ongoing research and improved agronomic practices have further improved fruit quality and yield, reinforcing kinnow's role as a promising fruit crop in arid agro-ecological zones.



Climate and Soil

Kinnow is a subtropical citrus fruit well-adapted to the arid and semi-arid climate of Northern Rajasthan. Its growth, flowering, fruiting and fruit quality are influenced by temperature, rainfall, humidity and sunlight. Optimal temperatures for vegetative growth and fruit development range from 20–30°C, though the crop can tolerate extremes of 0°C in winter and 45°C in summer. It prefers low to moderate rainfall (500–750 mm annually), as excessive rain during flowering or fruiting can cause fruit drop, fungal infections and reduced quality. Moderate humidity (50–70%) is ideal, while high humidity favors diseases such as citrus canker and greening.

Kinnow thrives in well-drained sandy loam

to loamy soils with a slightly acidic to neutral pH (6.0–7.5). Deep soils (1.5–2 m) enriched with 1–2% organic matter support healthy root development, nutrient absorption and water retention. The crop tolerates low to moderate soil salinity, but electrical conductivity above 1.5–2 dS/m may negatively affect growth and yield.

Water requirements

Kinnow is moderately drought-tolerant but requires regular irrigation to ensure high yield and fruit quality. Young trees (1–3 years) are irrigated every 7–10 days, while mature trees require irrigation every 15–20 days, with more frequent watering in arid summers. **Drip irrigation** is preferred for efficiency, uniform water supply and reduced disease incidence, though basin or furrow methods may be used where drip systems are unavailable. Water quality is important, as high sodium or bicarbonate levels can reduce growth and yield. **Critical stages** for irrigation include flower initiation, fruit set and fruit enlargement. Irrigation water with a TDS level below 350 ppm is considered suitable for Kinnow cultivation, as it ensures optimal growth and minimizes the risk of salinity-related stress on plants.

Morphology and Botanical Characteristics

Kinnow is a medium-sized, evergreen citrus tree that typically attains a height of 3–5 meters under normal cultivation. The tree exhibits a dense, rounded, and spreading canopy, providing ample shade.



The flowers are small, white and fragrant, occurring singly or in small clusters in the leaf axils.

Flowering generally takes place during spring, between February and March. The flowers are bisexual (hermaphrodite), and insect-mediated pollination, particularly by honey bees, plays a major role in fruit set.

The fruit of Kinnow is a hesperidium, a type of modified berry characteristic of citrus species. Fruits

are medium to large in size, averaging 120–150 g, and undergo a color transition from green to deep orange upon ripening. They contain numerous polyembryonic seeds. In Northern India, the fruits typically reach maturity and are ready for harvest between December and February.

Planting

For Kinnow cultivation, healthy, disease-free and certified budded or grafted plants aged 1–2 years, with straight stems and well-developed root systems, are recommended for planting. Planting pits measuring 1 m × 1 m × 1 m are usually dug during May–June and left open for 2–3 weeks to allow soil sterilization. Approximately 15–20 days before planting, the pits are filled with topsoil along with 20–25 kg of well-decomposed farmyard manure (FYM), 1 kg of neem cake, and 100 g of termite-control dust, if required.

Planting is carried out between July and August with a spacing of 6 m × 6 m in standard orchards, and 5 m × 5 m in high-density plantings. The square planting system is most commonly used, although in some regions, rectangular arrangements are adopted. Proper spacing ensures adequate sunlight penetration and promotes optimal tree growth. In areas with sufficient irrigation facilities, spring planting is also practiced to take advantage of favorable soil moisture. Protect the young trees from frost in winter and from sunburn in summer.

Common Rootstocks: Rough lemon, Jatti Khatti and Carrizo citrange are most commonly used.

Nutrient management

Proper use of manures and fertilizers in Kinnow promote vegetative growth, ensure better flowering and fruit set, improve fruit size, quality, higher yield and longer orchard life. Balanced nutrition is essential for sustainable production.

Organic Manures: Apply 20–25 kg well decomposed FYM, 5–10 kg vermicompost and 1–2 kg Neem cake per plant per year per plant per year during the month of **December to January** just after the harvesting of fruits. Organic manures improves soil structure and water-holding capacity.



Chemical Fertilizer:

Recommended dose of fertilizers depends on plant age.

Age (Years)	Nitrogen (g)	Phosphorus (g)	Potassium (g)
1–3 Years	150–300	50–100	100–200
4–6 Years	400–600	150–200	300–400
7+ Years (Bearing)	800–1000	300–400	600–800

Fertilizer application in Kinnow orchards is typically carried out in two split doses. The first dose is applied during February–March, prior to flowering, to promote vegetative growth and flowering, while the second dose is administered during July–August to support fruit development. The basin method is the most commonly employed technique for fertilizer application. A circular basin is prepared around the tree, typically 60–90 cm from the trunk and fertilizers are applied uniformly, lightly mixed with the soil, followed by immediate irrigation to facilitate nutrient absorption.

An improved approach involves fertigation through drip irrigation, which enhances nutrient-use efficiency, minimizes fertilizer losses and ensures uniform distribution of nutrients to the root zone.

Micronutrient Management: Micronutrient deficiencies are commonly observed in citrus orchards. Foliar application of zinc sulphate (0.5%), ferrous sulphate (0.5%), manganese sulphate (0.3%) and borax (0.2%) during February–April and September–October, repeated 2–3 times at 15-day intervals, has been shown to enhance both fruit yield and quality.

Pest and Disease Management in Kinnow

Effective pest and disease management is essential for sustainable Kinnow production, as biotic stresses considerably influence plant health, fruit yield and quality. An integrated pest and disease management strategy combining cultural, biological and chemical approaches is recommended to ensure long-term orchard productivity.

1. Major Insect Pests and Their Management

1.1 Citrus Psylla (*Diaphorina citri*): Citrus psylla is a major sucking pest that damages young shoots and leaves and acts as a vector of citrus greening disease.

Management:

- Use disease-free planting material.
- Prune and destroy infested shoots.
- Apply systemic insecticides such as Imidacloprid or Thiamethoxam.

1.2 Leaf Miner (*Phyllocnistis citrella*): Larvae tunnel within young leaves, reducing photosynthetic efficiency and weakening plants.

Management:

- Timely pruning of affected shoots.
- Avoid excessive nitrogen fertilization.
- Spray abamectin or neem-based formulations.

1.3 Fruit Fly (*Bactrocera spp.*): Fruit flies lay eggs inside fruits, leading to internal damage and premature fruit drop.

Management:

- Regular collection and destruction of fallen fruits.
- Installation of pheromone traps.
- Foliar sprays of Malathion 50% EC, Dimethoate 30% EC and Spinosad 45 SC.

1.4 Scale Insects and Mealybugs: These pests suck sap and produce honeydew, resulting in sooty mould development.

Management:

- Maintain orchard sanitation.
- Use Chlorpyrifos under heavy infestation.

2. Major Diseases and Their Management

2.1 Citrus Greening: This is a destructive bacterial disease characterized by leaf mottling, poor fruit development and yield decline.

Management:

- Use certified disease-free planting material.

- Remove and destroy infected plants.
- Control psylla population by spraying the crop with Imidacloprid and Thiamethoxam.

2.2 Citrus Canker (*Xanthomonas citri*): Canker causes raised corky lesions on leaves, twigs and fruits leading to defoliation and fruit drop.

Management:

- Prune infected plant parts.
- Avoid overhead irrigation.
- Spray copper-based fungicides and Streptocycline at regular intervals.

2.3 Root Rot and Gummosis (*Phytophthora spp.*): These soil-borne diseases result in gum exudation, root decay and gradual decline of trees.

Management:

- Improve soil drainage.
- Avoid waterlogging.
- Apply Bordeaux paste on infected trunks.
- Drench soil with Ridomil gold, Metalaxyl and Mancozeb for effective control.

2.4 Powdery Mildew and Anthracnose: These fungal diseases affect flowers, leaves and fruits, reducing fruit set and marketability.

Management:

- Maintain proper spacing and aeration.
- Remove diseased plant part.
- Spray sulphur or systemic fungicides as recommended.

New improved variety of Kinnow by Punjab Agricultural University, Ludhiana

PAU Kinnow-1 is an improved low-seeded strain of the traditional Kinnow mandarin (*Citrus reticulata*), developed through mutation breeding at **PAU, Ludhiana** to address key limitations of conventional Kinnow (high seed content). It is specifically recommended for commercial cultivation and juice processing in Punjab and similar subtropical environments.

Fruit Quality Characteristics of PAU Kinnow-1 Variety:

- **Seed content:** Very low (average 3- 4 seeds per fruit), significantly reduced compared to traditional Kinnow.

- **Maturity:** Mid-season, typically matures in **January**.
- **Colour:** Deep orange peel at maturity.
- **Juice quality:** High juice content with **sweet flavour**, making it suitable for both fresh consumption and processing.
- **Total Soluble Solids (TSS):** Around **10.5–11 °Brix**, indicating good sweetness.
- **Acidity:** Approximately **0.7–0.9%**, contributing to balanced flavour.
- **Yield:** A five-year-old PAU Kinnow-1 tree yields approximately **45 kg of fruit per tree**, demonstrating strong bearing potential.

Yield and Productivity: In well-managed orchards under proper irrigation, Kinnow yields about **20–25 t/ha**.

Post-Harvest Management and Marketing

Harvesting of Kinnow is generally carried out between December and February, when fruits attain an orange-red coloration and a minimum juice content of 40%. Harvesting is performed using sharp clippers or secateurs to minimize mechanical injury. A short pedicel of approximately 0.5–1.0 cm is retained on the fruit to reduce the risk of fungal infection and post-harvest decay.



Storage: For storage, fruits are maintained at a temperature of 5–7 °C and a relative humidity of 85–90%, which allows safe storage for up to 4–6 weeks under optimal conditions.

Packaging is commonly done in ventilated corrugated cartons lined with suitable cushioning materials to prevent bruising and ensure safe transportation.

Handling and Transportation:

- Handle fruits carefully to minimize mechanical injury.
- Transport in crates or boxes with adequate ventilation.
- Avoid exposure to direct sunlight or high temperatures.

- Use refrigerated trucks for long-distance transport to maintain quality.

Post-Harvest Treatments:

- **Fungicidal Treatment:** Dip the fruit in **0.1% sodium orthophenyl phenol** to prevent fungal rot.
- **Wax Coating:** Food-grade wax improves shelf life, reduces water loss and enhances appearance.
- **Hot Water Treatment:** Dipping fruits at 50°C for 2–3 minutes to control pests like fruit fly.

Value Addition and Processing: **Kinnow can be processed into various products like** Kinnow juice, Squashes and nectars, Marmalade, jam, candied peels and essential oils.

Marketing of Kinnow:

Domestic Market: Delhi, Jaipur, Mumbai and other urban centers

- Marketing channels: Farmer → Commission agent → Retailer → Consumer

Export Market:

Gulf countries, Europe and Southeast Asia.

Export requires grading, waxing, packaging and phytosanitary certification.

Pricing Factors:

- Fruit size, color, TSS, seed content and supply-demand dynamics.
- Low-seeded varieties like PAU Kinnow fetch premium prices in market.

Economic Importance:

Aspect	Economic Importance
Income	₹3–5 lakh/ha/year from mature orchards
Employment	Seasonal & permanent jobs in farming, harvesting, processing
Processing	Juice, concentrate, jams & candies (value addition)
Export	Gulf countries, Europe, premium market prices
Cropping Diversification	Reduces risk from cereal crops, improves farm sustainability
Agro-industry	Development of local juice and food processing units

Challenges in Kinnow Cultivation in Northern Rajasthan

Kinnow is a major fruit crop in northern Rajasthan, but its cultivation faces several agronomic, climatic and economic challenges:

- Dependence on canal water and groundwater makes orchards vulnerable to drought and water shortages.
- Lack of timely management leads to yield and quality losses.
- Susceptible to nutrient deficiencies, salinity and poor water retention.
- Standard Kinnow has many seeds, reducing consumer preference and processing suitability while, Low-seeded varieties like PAU Kinnow are gradually replacing traditional types but are not yet widespread.
- Limited shelf life under high temperature and low humidity.
- Price fluctuations during harvest season and limited direct access to high-value markets for small farmers.
- High temperature, frost, water stress and hailstorms can damage flowers and fruits.

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Vegetable Biofortification: A Food Security Strategy for world

Abstract

Micronutrient malnutrition, or "hidden hunger," is a critical global health crisis affecting billions, driven by monotonous staple-based diets in developing nations. This review explores biofortification as a sustainable, cost-effective agricultural strategy to enhance essential nutrients like iron, zinc, and vitamin A directly within edible crop portions. Unlike post-harvest fortification, biofortification utilizes conventional plant breeding, agronomic practices, and genetic engineering during crop growth. Vegetable crops—including carrots, tomatoes, spinach, and sweet potatoes—serve as primary targets due to their natural nutrient density. Powered by modern biotechnology and genomic tools, the development of these nutrient-dense varieties directly addresses widespread deficiencies, offering a scalable pathway toward improved public health, enhanced food security, and sustainable food systems.

Keywords: Biofortification, Vegetable, Hunger, Deficiency, Agriculture, Food Security

1. Introduction

Micronutrient malnutrition, often referred to as "hidden hunger," is a major global health concern affecting more than two billion people worldwide. It occurs when individuals consume enough food to meet their energy needs but do not receive adequate amounts of essential vitamins and minerals such as iron, zinc, vitamin A, folate, and selenium. Hidden hunger is particularly common in developing countries where diets are largely based on staple foods and lack sufficient nutritional diversity. These nutritional disorders negatively affect public health, productivity, and economic development. Vegetables are important components of a healthy diet because they provide vitamins, minerals, dietary fiber, antioxidants, and various bioactive compounds. However, many commonly consumed vegetables do not contain sufficient quantities of certain micronutrients to Therefore, innovative needed to enhance the nutritional value of food crops.

Biofortification has emerged as a sustainable and cost-effective strategy to address micronutrient deficiencies. It involves increasing the concentration and bioavailability of essential nutrients in crops through conventional plant breeding, agronomic practices, or modern biotechnological techniques. Unlike conventional food fortification, which adds nutrients during processing, biofortification improves the nutritional quality of crops during their growth and development.

In vegetable crops, biofortification offers significant potential for improving nutritional security. Crops such as carrot, tomato, spinach, sweet potato, pumpkin, amaranth, and broccoli have been successfully targeted for nutrient enhancement. These biofortified vegetables provide higher levels of important nutrients such as iron, zinc, vitamin A, folate, and calcium, thereby contributing to improved human health and well-being.

With increasing concerns about malnutrition, population growth, and food security, biofortification is gaining importance as an integrated approach linking agriculture, nutrition, and public health. The development and adoption of biofortified vegetable crops can play a vital role in reducing hidden hunger and promoting sustainable food and nutritional security worldwide.

2. Concept of Biofortification

Biofortification is an agricultural and nutritional intervention aimed at increasing the concentration and bioavailability of essential micronutrients in food crops during plant growth and development. The term "biofortification" refers to the enhancement of nutritional quality through biological processes rather than the addition of nutrients during food processing. It represents an innovative and sustainable strategy for addressing micronutrient malnutrition by improving the nutrient composition of crops before harvest.

The fundamental concept of biofortification is based on developing crop varieties that naturally accumulate higher levels of vitamins, minerals, and other health-promoting compounds in their edible parts. These nutrient-rich crops are produced through conventional plant breeding, agronomic practices, or modern biotechnological approaches. When consumed regularly, biofortified crops provide improved nutritional benefits without requiring significant changes in dietary habits.

Traditional approaches such as dietary diversification, food supplementation, and industrial food fortification have contributed significantly to improving nutritional status. However, these approaches often face challenges related to cost, accessibility, infrastructure, and long-term sustainability. In contrast, biofortification delivers nutrients directly through agricultural production, making it particularly suitable for rural communities that depend largely on self-produced food.

One of the major advantages of biofortification is its ability to reach vulnerable populations in remote and resource-poor areas. Farmers can cultivate biofortified varieties using existing agricultural practices, while consumers benefit from improved nutrition through their daily diets. Once developed and adopted,

biofortified varieties can continue providing nutritional benefits over many years, making biofortification a cost-effective and sustainable intervention.

The effectiveness of biofortification depends not only on increasing nutrient concentration but also on improving nutrient bioavailability, which refers to the proportion of a nutrient that can be absorbed and utilized by the human body. Therefore, modern biofortification programs focus on enhancing both nutrient content and nutrient utilization to maximize health benefits.

Biofortification targets essential micronutrients commonly deficient in human diets, including iron, zinc, vitamin A, folate, calcium, selenium, and iodine. These nutrients play vital roles in growth, immunity, cognitive development, and overall health. By increasing their levels in food crops, biofortification helps reduce micronutrient deficiencies and improve nutritional well-being.

In vegetable crops, biofortification offers significant opportunities because vegetables are already important sources of vitamins, minerals, antioxidants, and dietary fiber. Crops such as carrot, tomato, spinach, pumpkin, sweet potato, broccoli, and amaranth can be enhanced to provide greater nutritional benefits and serve as effective vehicles for delivering essential micronutrients.

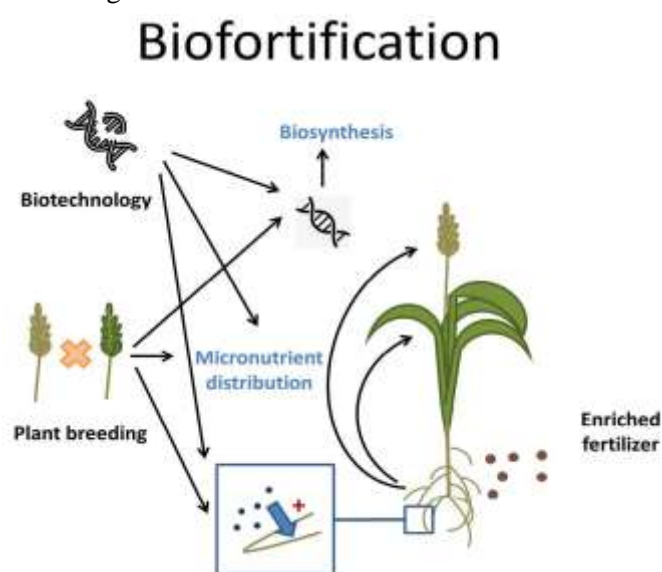


Figure 1. Conceptual framework of biofortification

Biofortification also supports the goals of sustainable agriculture and food security by linking crop improvement with nutritional objectives. By improving both food quality and nutritional value, it contributes to better public health and sustainable development. Therefore, biofortification is increasingly recognized as a practical and long-term solution for combating hidden hunger and improving global nutritional security.

3. Importance and Need of Biofortification

Micronutrient malnutrition, commonly known as hidden hunger, is a major global health problem affecting more than two billion people worldwide. It occurs when diets provide sufficient calories but lack essential vitamins and minerals required for normal growth, development, and body functions. Deficiencies of nutrients such as iron, zinc, vitamin A, folate, calcium, and selenium are particularly common in developing countries, where diets are often dominated by staple foods with limited nutritional diversity. Children, pregnant women, and elderly individuals are among the most vulnerable groups.

The health impacts of micronutrient deficiencies are significant. Iron deficiency is a leading cause of anemia and can result in fatigue, reduced work capacity, and impaired cognitive development. Zinc deficiency weakens the immune system and increases susceptibility to infections, while vitamin A deficiency can cause vision problems and increase the risk of illness, particularly among children. Similarly, folate deficiency during pregnancy may lead to developmental abnormalities in infants, and calcium deficiency can affect bone health and growth.

Several approaches such as dietary diversification, supplementation, and food fortification have been used to combat micronutrient deficiencies. Although effective, these methods often require continuous financial support, efficient distribution systems, and access to healthcare or food-processing facilities. In many rural and resource-poor regions, such services are limited, reducing the long-term effectiveness of these interventions.

Biofortification addresses this challenge by improving the nutritional quality of crops during plant growth. By increasing nutrient levels directly in food crops,

biofortification provides a sustainable and cost-effective solution that reaches populations through their regular diets. Once nutrient-rich varieties are developed and adopted, farmers can continue cultivating them without major additional costs, making biofortification a long-term strategy for improving nutrition.

Biofortification also contributes to food and nutrition security by enhancing the quality of commonly consumed crops. In vegetable crops such as carrot, spinach, tomato, sweet potato, pumpkin, broccoli, and amaranth, nutrient enhancement can significantly improve the intake of essential vitamins and minerals. As concerns about malnutrition, population growth, and food security continue to rise, biofortification has become an important approach for improving public health and supporting sustainable agricultural development.

4. Major Nutrients Targeted in Biofortification

The primary objective of biofortification is to increase the concentration and bioavailability of essential micronutrients that are commonly deficient in human diets. These nutrients are vital for growth, immunity, metabolism, and overall health. Modern biofortification programs mainly focus on iron, zinc, vitamin A, folate, calcium, and selenium due to their widespread deficiencies and significant impact on public health.

4.1 Iron (Fe)

Iron is an essential micronutrient required for the formation of hemoglobin, oxygen transport, energy metabolism, and cognitive development. Iron deficiency is the leading cause of anemia worldwide and can result in fatigue, weakness, impaired learning ability, and reduced immunity. Biofortification efforts focus on increasing iron levels in crops such as spinach, amaranth, and other leafy vegetables to help reduce iron deficiency and improve public health.

4.2 Zinc (Zn)

Zinc plays a crucial role in enzyme activity, protein synthesis, immune function, growth, and wound healing. Zinc deficiency can lead to impaired growth, weakened immunity, and increased susceptibility to infections. Biofortification through plant breeding and zinc fertilization has successfully enhanced zinc

concentrations in vegetables such as spinach, broccoli, and amaranth, improving dietary zinc intake.

4.3 Vitamin A (β -Carotene)

Vitamin A is essential for vision, immune function, and normal growth. Since plants contain provitamin A carotenoids rather than vitamin A itself, biofortification targets β -carotene-rich crops. Deficiency of vitamin A can cause night blindness and increased vulnerability to infections. Carrot, pumpkin, and orange-fleshed sweet potato are important examples of vitamin A biofortified crops.

4.4 Folate (Vitamin B9)

Folate is required for DNA synthesis, cell division, and fetal development. Deficiency may lead to anemia and neural tube defects in newborns. Increasing folate content in vegetables such as tomato, spinach, and lettuce can improve maternal and child health and contribute to better nutritional outcomes.

4.5 Calcium (Ca)

Calcium is important for bone and teeth development, muscle contraction, nerve transmission, and blood clotting. Inadequate calcium intake can result in weak bones and osteoporosis. Leafy vegetables such as amaranth, kale, and broccoli are considered suitable crops for calcium biofortification and can help improve bone health.

defense system. Agronomic biofortification through selenium fertilization has been used to increase selenium content in vegetables and other food crops.

Collectively, these micronutrients are the primary targets of biofortification programs worldwide. Enhancing their concentrations in vegetable crops can significantly improve nutritional quality, reduce hidden hunger, and contribute to better food and nutrition security.

5. Methods of Biofortification

Biofortification can be achieved through different approaches aimed at increasing the concentration and bioavailability of essential nutrients in food crops. The three major methods include conventional plant breeding, agronomic biofortification, and genetic engineering. Each method has unique advantages and applications depending on the crop, target nutrient, and available resources.

5.1 Conventional Plant Breeding

Conventional plant breeding is the most widely used and accepted method of biofortification. It involves identifying naturally occurring genetic variation for nutrient content and crossing nutrient-rich parent lines with high-yielding cultivars. The resulting progenies are evaluated over several generations to select plants with improved nutritional and agronomic traits.

One of the major advantages of this method is that it does not involve the introduction of foreign genes, making it widely accepted by consumers and regulatory authorities. In addition, once biofortified varieties are developed, farmers can cultivate them repeatedly without additional investment. Successful examples include provitamin A-rich sweet potato, zinc-enriched wheat, iron-rich beans, and nutrient-dense pearl millet. In vegetable crops, varieties of carrot, pumpkin, tomato, spinach, and amaranth have been developed with enhanced nutrient content. However, conventional breeding is often time-consuming and depends on the availability of sufficient genetic diversity within the crop species.

5.2 Agronomic Biofortification

Agronomic biofortification involves the use of fertilizers, soil amendments, and crop management practices to increase nutrient uptake and accumulation in edible plant parts. This method is particularly



Figure 2. Major micronutrients targeted through biofortification and their roles in human health.

4.6 Selenium (Se)

Selenium is a trace mineral that supports antioxidant activity, immune function, and thyroid hormone metabolism. Selenium deficiency may increase the risk of various health disorders and weaken the body's

effective for nutrients such as zinc, selenium, iron, and iodine, whose availability is strongly influenced by soil conditions.

Common techniques include soil application of micronutrient fertilizers, foliar sprays, seed treatments, and fertigation. Foliar application is especially effective because nutrients are directly absorbed through leaves and transported to edible tissues. Agronomic biofortification can be implemented quickly and often produces results within a single growing season. However, its effectiveness may vary depending on soil properties, environmental conditions, and crop type. Continuous fertilizer application may also increase production costs and require careful management to avoid environmental concerns.

5.3 Genetic Engineering and Transgenic Biofortification

Genetic engineering is an advanced approach that involves modifying a plant's genetic makeup to enhance nutrient synthesis, transport, or storage. This method allows researchers to introduce traits that may not naturally exist within a crop species and is particularly useful when conventional breeding is unable to achieve the desired level of nutrient enhancement.

A well-known example is Golden Rice, which was genetically engineered to produce β -carotene in the grain. In vegetable crops, genetic engineering has been used to increase the levels of vitamins, minerals, antioxidants, and other beneficial compounds. Recent developments in gene-editing technologies such as CRISPR-Cas9 have further improved the precision and efficiency of crop biofortification.

Despite its potential, genetic engineering faces challenges related to regulatory approval, public acceptance, and technical requirements. Nevertheless, it remains a powerful tool for addressing complex nutritional problems and developing nutrient-rich crop varieties.

Comparative Overview of Biofortification Methods

Each biofortification method contributes differently to improving crop nutritional quality. Conventional breeding offers a sustainable and widely accepted long-term solution, agronomic biofortification

provides rapid improvements through nutrient management, and genetic engineering enables precise enhancement of specific nutritional traits. The integration of these approaches, supported by advances in biotechnology and precision agriculture, is expected to strengthen future biofortification programs and help combat hidden hunger more effectively.

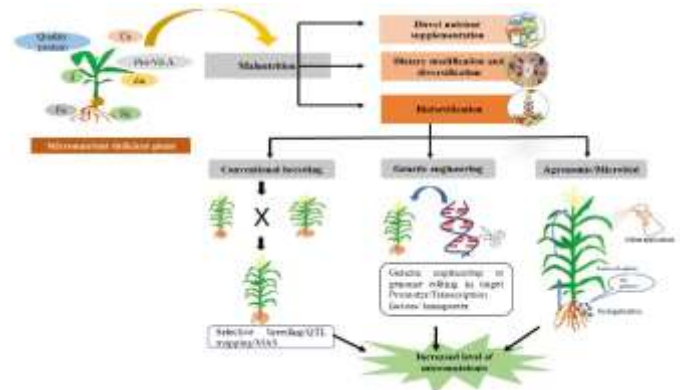


Figure 3. Major approaches used for crop biofortification.

6. Biofortification in Major Vegetable Crops

Vegetable crops are important components of a healthy diet as they provide essential vitamins, minerals, antioxidants, and dietary fiber. Due to their high nutritional value and regular consumption, vegetables have become major targets for biofortification programs aimed at reducing micronutrient deficiencies. Various breeding, agronomic, and biotechnological approaches have been used to enhance the nutritional quality of vegetables by increasing the levels of vitamins, minerals, and other health-promoting compounds.

6.1 Carrot

Carrot (*Daucus carota* L.) is one of the most successful biofortified vegetable crops due to its naturally high β -carotene content, which serves as a precursor of vitamin A. Breeding programs have developed varieties with enhanced carotenoid concentrations that help improve vision, immune function, and overall health. Regular consumption of biofortified carrots can contribute significantly to reducing vitamin A deficiency, particularly among children and pregnant women.

6.2 Tomato

Tomato (*Solanum lycopersicum* L.) is widely

consumed and is an excellent source of vitamin C, lycopene, and antioxidants. Biofortification efforts have focused on increasing folate, lycopene, iron, and other micronutrients. Enhanced tomato varieties provide additional nutritional benefits and are considered valuable functional foods that support human health and disease prevention.

6.3 Spinach

Spinach (*Spinacia oleracea* L.) is a nutrient-rich leafy vegetable containing iron, zinc, calcium, folate, and vitamins A and C. Through conventional breeding and agronomic practices, researchers have improved mineral accumulation in spinach leaves. Consumption of biofortified spinach can help reduce anemia, strengthen immunity, and improve overall nutritional status.

6.4 Sweet Potato

Orange-fleshed sweet potato (*Ipomoea batatas* L.) is one of the most successful examples of vitamin A biofortification. Its high β -carotene content helps improve vitamin A intake and reduce deficiency-related disorders. Biofortified sweet potato varieties have shown positive impacts on nutritional health, particularly among children and women in developing countries.

6.5 Pumpkin

Pumpkin (*Cucurbita* spp.) is naturally rich in carotenoids, vitamins, and antioxidants. Biofortification programs have focused on increasing β -carotene concentrations to improve vitamin A content. Regular consumption of nutrient-rich pumpkin varieties can contribute to better vision, immunity, and overall health.

6.6 Amaranth

Amaranth (*Amaranthus* spp.) is known for its high levels of calcium, iron, zinc, and other essential nutrients. Selection and breeding programs have identified varieties with superior mineral accumulation, making amaranth an important crop for addressing mineral deficiencies and improving nutritional security.

6.7 Broccoli and Other Cruciferous Vegetables

Broccoli (*Brassica oleracea* var. *italica*) and other cruciferous vegetables such as cabbage, cauliflower, and kale possess significant biofortification potential.

These crops are rich in calcium, folate, vitamin C, and antioxidants. Efforts to increase selenium, calcium, and folate concentrations have further enhanced their nutritional value and health benefits.

Current Status of Biofortified Vegetable Varieties
Several biofortified vegetable varieties have been developed through national and international crop improvement programs. Examples include Kashi Arun carrot, Arka Chandan pumpkin, Pusa Rohini tomato, and other nutrient-rich cultivars developed for improved nutritional quality. The continued development and adoption of biofortified vegetables can play an important role in reducing hidden hunger, improving public health, and strengthening food and nutrition security worldwide.

7. Benefits of Biofortification

7.1 Improvement of Human Health and Nutrition

Biofortification improves human health by increasing the intake of essential micronutrients such as iron, zinc, vitamin A, folate, calcium, and selenium through daily diets. Regular consumption of biofortified crops helps prevent nutritional deficiencies, strengthens immunity, supports growth and development, and enhances overall well-being.

7.2 Reduction of Hidden Hunger

Hidden hunger remains a major global nutritional challenge, particularly in developing countries. Biofortified crops provide higher concentrations of essential nutrients and help reduce micronutrient deficiencies through routine dietary consumption without requiring major changes in eating habits.

7.3 Cost-Effective Nutritional Intervention

Compared with supplementation and food fortification programs, biofortification is a cost-effective strategy. Once nutrient-rich varieties are developed and adopted, their nutritional benefits can be sustained for many years with minimal additional investment.

7.4 Sustainable and Long-Term Solution

Biofortification offers a sustainable approach to improving nutrition because biofortified varieties can be cultivated repeatedly by farmers. The enhanced nutritional traits are maintained through seed multiplication, ensuring long-term benefits for future generations.

7.5 Enhancement of Food and Nutrition Security

Biofortification contributes to both food security and nutritional security by improving the quality of commonly consumed crops. It helps ensure that

People receive essential nutrients

people while meeting their daily food requirements.

7.6 Benefits for Rural and Resource-Poor Communities

Rural populations often have limited access to fortified foods and nutritional supplements. Biofortified crops provide an effective means of delivering essential nutrients through locally grown foods, thereby improving health and livelihoods in resource-poor communities.

7.7 Environmental Advantages

Biofortification can support sustainable agricultural practices by improving nutrient-use efficiency and reducing dependence on excessive fertilizer applications. This contributes to better resource management and environmentally friendly crop production.

7.8 Contribution to Sustainable Development Goals

Biofortification supports global efforts to achieve sustainable development, particularly the goals related to zero hunger, good health, and improved nutrition. It represents an effective strategy for addressing malnutrition while promoting sustainable agricultural development.

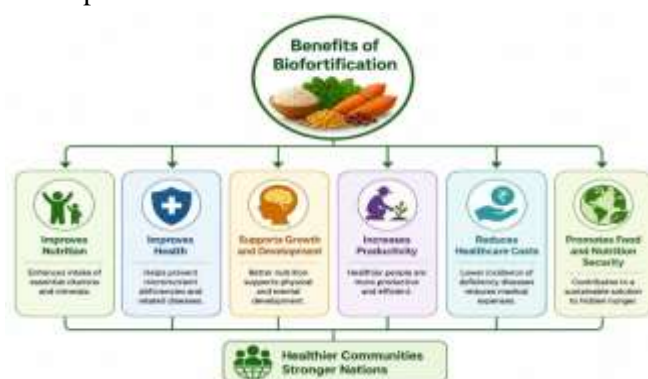


Figure 5. Contribution of biofortification to nutrition, food security, and sustainable development.

7.9 Strengthening Agriculture–Nutrition Linkages

Biofortification creates a direct link between agriculture and public health by integrating nutritional

objectives into crop improvement programs. This multidisciplinary approach helps develop healthier populations, resilient food systems, and improved nutritional outcomes.

8. Challenges and Limitations of Biofortification

Despite its numerous advantages, biofortification faces several scientific, technical, economic, and social challenges that can influence its effectiveness and large-scale adoption. Understanding these limitations is important for improving biofortification programs and maximizing their impact on global nutrition.

8.1 Limited Genetic Variability

The success of conventional breeding depends on the availability of natural genetic variation for nutrient content within crop species. In some crops, suitable genetic resources are limited, making the development of nutrient-rich varieties a time-consuming process.

8.2 Nutrient Bioavailability Constraints

Higher nutrient concentrations in crops do not always guarantee efficient absorption by the human body. Anti-nutritional compounds such as phytates can reduce the bioavailability of minerals like iron and zinc, limiting their nutritional benefits.

8.3 Environmental Influence on Nutrient Accumulation

The nutrient content of biofortified crops can be affected by soil fertility, climate, irrigation, and crop management practices. As a result, nutrient accumulation may vary across different growing environments.

8.4 Yield–Nutrition Trade-Offs

Plant breeders often face the challenge of improving nutrient content while maintaining high yield, disease resistance, and adaptability. Balancing these traits is essential for the successful adoption of biofortified varieties by farmers.

8.5 Consumer Acceptance and Market Preferences

Some biofortified crops may differ in color, taste, or appearance from traditional varieties. Consumer awareness and nutrition education are therefore important to encourage acceptance and adoption of nutrient-rich foods.

8.6 Farmer Adoption Challenges

Farmers are more likely to cultivate biofortified crops

if they provide good yields, market demand, and economic returns. Effective extension services, quality seed availability, and farmer training are essential for promoting adoption.

8.7 Regulatory and Policy Constraints

Biofortification programs, particularly those involving genetic engineering, often face regulatory and policy challenges. Lengthy approval procedures and public concerns regarding genetically modified crops can slow their commercialization.

8.8 Economic and Infrastructure Limitations

The development and dissemination of biofortified varieties require investments in research, breeding programs, seed production, and extension activities. Limited infrastructure and funding may restrict large-scale implementation, especially in developing countries.

8.9 Nutrient Losses During Processing and Cooking

Certain nutrients, especially vitamin A and folate, may be lost during storage, processing, and cooking. Therefore, proper post-harvest handling and food preparation practices are important for retaining nutritional quality.

8.10 Public Awareness and Knowledge Gaps

Limited awareness about micronutrient deficiencies and the benefits of biofortified crops remains a challenge in many regions. Public education and nutrition awareness programs are necessary to increase consumer demand and support adoption.

Although these challenges exist, continuous advances in plant breeding, biotechnology, agronomy, and nutrition science are helping to overcome many of these limitations. With coordinated efforts from researchers, policymakers, farmers, and consumers, biofortification can continue to play an important role in reducing hidden hunger and improving global nutritional security.

9. Future Prospects of Biofortification

Biofortification has emerged as an effective strategy for improving nutritional security and reducing micronutrient deficiencies worldwide. With growing concerns about hidden hunger, population growth, climate change, and food security, the importance of biofortification is expected to increase in the coming

years. Advances in agricultural and nutritional sciences are creating new opportunities to develop nutrient-rich crops with improved productivity and adaptability.

9.1 Advances in Plant Breeding Technologies

Modern breeding tools such as marker-assisted selection, genomic selection, and speed breeding are accelerating the development of biofortified crops. These technologies enable breeders to identify and transfer desirable nutritional traits more efficiently, reducing the time required to develop improved varieties.

9.2 Integration of Gene Editing Technologies

Gene-editing technologies such as CRISPR-Cas9 offer new possibilities for precise crop improvement. These tools can enhance nutrient content, improve nutrient utilization, and reduce anti-nutritional factors, making biofortification more effective and targeted.

9.3 Development of Multi-Nutrient Biofortified Crops

Future research is increasingly focused on developing crops enriched with multiple nutrients rather than a single micronutrient. Crops containing higher levels of iron, zinc, folate, and vitamins simultaneously could provide broader nutritional benefits and help address multiple deficiencies at once.

9.4 Climate-Resilient Biofortified Crops

Climate change poses significant challenges to crop production and nutritional quality. Therefore, future biofortification programs will focus on developing nutrient-rich varieties that can withstand drought, salinity, heat stress, and other adverse environmental conditions.

9.5 Precision Agriculture and Smart Farming

The adoption of precision agriculture technologies, including soil nutrient mapping, remote sensing, drones, and artificial intelligence, can improve nutrient management practices. These technologies will help optimize agronomic biofortification and increase nutrient accumulation in crops more efficiently.

9.6 Increased Focus on Vegetable Crop Biofortification

While early biofortification efforts mainly targeted staple crops, increasing attention is now being given

to vegetables because of their naturally high nutrient content. Crops such as tomato, carrot, spinach, broccoli, pumpkin, sweet potato, and amaranth offer considerable potential for further nutritional enhancement.

9.7 Strengthening Public Awareness and Consumer Acceptance

The success of biofortification depends on consumer awareness and acceptance. Nutrition education programs, public awareness campaigns, and community outreach activities will play important roles in increasing demand for biofortified foods and encouraging their adoption.

9.8 Policy Support and International Collaboration

Future progress in biofortification will require strong support from governments, research institutions, and international organizations. Collaborative efforts can facilitate research, seed distribution, technology transfer, and the large-scale adoption of biofortified crops.

9.9 Contribution to Sustainable Development Goals

Biofortification contributes directly to global goals related to zero hunger, good health, and sustainable agriculture. As nutrition-sensitive agricultural practices gain greater importance, biofortification is expected to become an integral component of sustainable food systems worldwide.

Overall, the future of biofortification is highly promising. Continued advances in plant breeding, biotechnology, precision agriculture, and nutrition science will support the development of nutrient-rich crops capable of addressing hidden hunger and improving food and nutrition security for future generations.

10. Conclusion

Micronutrient malnutrition, or hidden hunger, remains a major global challenge, particularly in developing countries where access to diverse and nutrient-rich foods is limited. Biofortification has emerged as a sustainable and cost-effective strategy to improve the nutritional quality of food crops by increasing the concentration and bioavailability of essential nutrients such as iron, zinc, vitamin A, folate, calcium, and selenium. Unlike supplementation and food

fortification programs, biofortification delivers nutrients directly through commonly consumed crops, making it especially beneficial for rural and resource-poor populations. Vegetable crops such as carrot, tomato, spinach, sweet potato, pumpkin, amaranth, and broccoli have shown great potential for biofortification due to their natural richness in vitamins, minerals, and antioxidants. The development of nutrient-rich vegetable varieties can significantly contribute to reducing micronutrient deficiencies, improving public health, and strengthening food and nutrition security. Although challenges related to nutrient bioavailability, environmental factors, consumer acceptance, and adoption still exist, ongoing advances in plant breeding, biotechnology, and agronomic practices continue to improve the effectiveness of biofortification programs. Overall, biofortification represents an important link between agriculture, nutrition, and public health. With continued research, supportive policies, farmer participation, and consumer awareness, biofortified crops can play a vital role in reducing hidden hunger and promoting sustainable food systems. Therefore, biofortification is expected to remain a key strategy for improving global nutrition and achieving long-term food and nutrition security.

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Institute, Karnal***ARTICLE ID: 25****Microplastics in Agriculture, Food Chain, and Human Health**

Plastic has undoubtedly been one of the most revolutionary inventions of modern times. Its affordability, durability, and versatility have made it indispensable across industries from packaging and construction to medicine and agriculture. However, these same properties have also turned plastic into a persistent environmental challenge. Unlike natural materials, plastic does not easily break down. Instead, it fragments into smaller and smaller pieces, creating a silent and long-lasting form of pollution.

While the image of plastic-choked oceans often captures public attention, a less visible but equally alarming issue is unfolding on land, particularly within agricultural systems. Tiny plastic particles, known as microplastics, are steadily accumulating in soils, finding their way into crops, livestock, and ultimately, the food we consume. This is not a sudden crisis, but a slow and cumulative one, deeply intertwined with the way modern agriculture functions.

What are Microplastics?

Microplastics are plastic particles smaller than 5 millimeters, many of which are so small that they cannot be seen with the naked eye. Even finer particles, known as nanoplastics, are increasingly being studied due to their potential to interact more actively with biological systems. These particles originate from two primary sources. Some are intentionally manufactured at microscopic sizes, such as synthetic fibers used in textiles or abrasives used in industrial processes. Others are formed through the gradual breakdown of larger plastic items viz., bags, bottles, or agricultural films under the influence of sunlight, temperature fluctuations, and mechanical stress. The persistence of microplastics particularly concerning. They do not biodegrade in the traditional sense. Instead, they continue to fragment, circulate, and accumulate across ecosystems, moving through air, water, soil, plants, animals, and eventually, humans.

How Do Microplastics Enter Agricultural Systems?

Modern agriculture relies heavily on plastic-based materials to improve efficiency and productivity. While these inputs offer short-term benefits, they also contribute significantly to long-term environmental contamination. Plastic mulching films, widely used for moisture conservation and weed control, gradually degrade in the field. Drip irrigation systems, greenhouse coverings, and protective tunnels also contribute plastic residues over time. Additionally, organic inputs like sewage sludge and compost can introduce microplastics when they are derived from urban waste streams contaminated with plastic debris. Irrigation water itself can act as a carrier, bringing microplastics from rivers, wastewater, or industrial discharge into agricultural fields. Even the air plays a role, tiny plastic fibers shed from clothing and packaging can settle onto soil surfaces through atmospheric deposition. Over repeated cycles of use, weathering, and inadequate disposal, these plastic materials fragment and become embedded within the soil profile, creating a growing but often unnoticed reservoir of contamination.

Microplastics in Soil: A Hidden Stress on Agroecosystems

Soil is far more than just a medium for plant growth, it is a dynamic, living system composed of minerals, organic matter, microorganisms, roots, and soil fauna. The introduction of microplastics disrupts this delicate balance in multiple ways. Physically, microplastics can alter soil structure, affecting porosity, aeration, and water-holding capacity. Biologically, they can interfere with the activity of beneficial organisms such as earthworms, fungi, and bacteria that are essential for nutrient cycling and soil fertility. Chemically, it acts as carriers for other pollutants. They can adsorb pesticides, antibiotics, and heavy metals, prolonging their presence in the environment and potentially increasing their bioavailability. Plants, too, respond to these changes. Studies have shown that microplastics can influence root development, nutrient uptake, and stress responses, ultimately affecting crop growth and productivity. In essence, microplastics introduce an artificial and persistent component into soils that evolved without such materials.

From Soil to Crop: Entry into the Food Chain

For a long time, it was assumed that plant roots would act as a barrier, preventing microplastics from entering plant tissues. However, recent research has challenged this assumption. Evidence now suggests that micro- and nanoplastics can be absorbed by plant roots and transported through vascular tissues to different parts of the plant, including leaves, fruits, and grains. Crops such as wheat, rice, and various vegetables have shown measurable uptake under both experimental and field conditions.

The issue does not stop at crops. Livestock feeding on contaminated fodder or grazing on affected soils can ingest microplastics, which may accumulate in their digestive systems and tissues. This creates an additional pathway for human exposure through animal-derived food products such as milk, meat, and eggs. Ultimately, microplastics move seamlessly along the soil–plant–animal–human continuum, making them a pervasive component of modern food systems.

What Happens When Microplastics Enter the Human Body?

Microplastics are a relatively new presence in human biology, and research is still evolving. However, early findings suggest that they are not biologically inert. Potential health concerns include inflammation and oxidative stress, particularly in the lungs and digestive system. Plastics often contain chemical additives, such as plasticizers and stabilizers that can leach out and cause toxicity. Some of these compounds are known to interfere with hormonal systems, raising concerns about endocrine disruption.

There is also growing evidence that microplastics may interact with the immune system, especially with long-term, low-level exposure. Alarmingly, microplastics have already been detected in human blood, lungs, intestines, and even placental tissues, suggesting exposure may begin before birth. Although scientific understanding is still developing, global health bodies emphasize the need for precaution. The absence of complete certainty should not delay action, particularly when potential risks are widespread and cumulative.

Why Agriculture Is Central to the Microplastics Challenge

Agriculture sits at the intersection of environmental sustainability, food production, and human health. When soils become contaminated, the effects go beyond crop yields, they influence food quality, safety, and long-term ecological stability. In regions already facing challenges such as climate variability, soil degradation, and water scarcity, microplastics add another layer of stress. Over time, this could compromise soil resilience, reduce productivity, and erode consumer confidence in food systems.

Microplastics represent a new form of agricultural pollution, one that is simultaneously physical, chemical, and biological. Addressing it requires a systems-level approach that considers the entire food chain.

How Can We Reduce Microplastics in Agriculture and Food Systems?

At the farm level, reducing dependence on single-use plastics is a critical first step. Alternatives such as biodegradable or plant-based mulches offer promise, but they must be carefully evaluated to ensure they truly break down without leaving harmful residues.

Strengthening systems for plastic collection, recycling, and responsible disposal is equally important. Improving the quality of compost and manure by ensuring they are free from plastic contamination can also help reduce inputs of microplastics into soils.

Consumers also have a role to play. Reducing plastic use, supporting sustainable farming practices, and choosing environmentally responsible products can collectively drive change across the food system.

A Bigger Perspective: Rethinking Our Relationship with Plastic

Microplastics serve as a reminder that pollution does not simply disappear, it transforms, spreads, and accumulates in unexpected ways.

A plastic sheet used in a field today may eventually reappear in water, food, or even within the human body. Addressing this issue is not just about finding alternatives to plastic. It requires a broader shift in how we produce, consume, and manage resources. It calls for renewed respect for soil as a living system and a finite resource that underpins food security and environmental health.

In many ways, microplastics represent one of the most subtle yet far-reaching challenges of our time. Their size may be small, but their impact is anything but. And if there is one place where meaningful action can begin, it is within agriculture at the very foundation of our food systems.

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ARTICLE ID: 26

Building Healthy Soils for Climate-Resilient Agriculture: The Role of Khet Bachao Abhiyan in Achieving Viksit Bharat @2047

Abstract

Soil health is fundamental to agricultural productivity, food security and environmental sustainability. However, Indian agriculture is increasingly challenged by declining soil fertility, excessive dependence on chemical fertilizers and pesticides, depletion of soil organic matter, water scarcity and the growing impacts of climate change. These challenges threaten sustainable agricultural production and rural livelihoods. Recognizing the urgent need to restore soil health and promote resilient farming systems, the Government of India launched the nationwide *Khet Bachao Abhiyan* from 1 June to 30 June 2026. This article examines the importance of soil health in sustainable agriculture and discusses the interlinkages among climate change, soil degradation, climate-smart soil management, Integrated Nutrient Management (INM) and agricultural sustainability. It further highlights the role of Khet Bachao Abhiyan in supporting the national vision of Viksit Bharat @2047 and contributing to the United Nations Sustainable Development Goals. Strengthening soil conservation through scientific interventions, institutional support and active farmer participation will be critical for building a resilient agricultural future.

Keywords: Soil health, Climate change, Sustainable agriculture, Integrated Nutrient Management, Khet Bachao Abhiyan, Viksit Bharat @2047

Introduction

Agriculture continues to be the backbone of India's economy and rural livelihoods, providing food, employment and income to millions of households. The agricultural sector not only ensures food and nutritional security but also supports economic growth and rural development. However, the long-term sustainability of Indian agriculture is increasingly under pressure due to declining soil fertility, imbalanced nutrient management, overuse of agrochemicals and climate-induced environmental stress. Sustainable agricultural development depends largely on the health of natural resources, especially soil. Healthy soils support crop productivity, improve resource-use efficiency and enhance resilience to environmental stresses. Therefore, restoring and maintaining soil health has become essential for ensuring long-term agricultural sustainability and farmer prosperity.

Importance of Soil in Sustainable Agriculture

Soil is one of the most valuable natural resources and serves as the foundation of agricultural production, ecological balance and human survival. It provides essential nutrients, water and physical support for plant growth while sustaining diverse microbial communities that regulate nutrient cycling and soil fertility (Brady & Weil, 2016). Healthy soil improves seed germination, root development, nutrient uptake and crop productivity. It also enhances water infiltration and moisture retention, reducing vulnerability to drought and floods. Beyond agriculture, soil contributes significantly to carbon sequestration, biodiversity conservation and climate regulation. Thus, soil health plays a central role in ensuring food security, environmental sustainability and resilient rural livelihoods.

Climate Change and Soil Degradation

Climate change has emerged as one of the most serious challenges facing global agriculture, particularly in developing countries such as India. Rising temperatures, erratic rainfall patterns, prolonged droughts, floods, heat waves and increased pest incidence are adversely affecting agricultural productivity and farm income.

Among natural resources, soil is particularly vulnerable to climate change. Elevated temperatures accelerate decomposition of soil organic matter, leading to reduced soil carbon and fertility. Heavy rainfall intensifies soil erosion and nutrient losses, while drought reduces microbial activity and nutrient availability. These processes accelerate soil degradation and reduce agricultural resilience (Lal, 2015).

Degraded soils become less productive, less biologically active and more vulnerable to environmental stress. Therefore, addressing soil degradation has become central to climate adaptation and sustainable agricultural development.

Need for Sustainable Agriculture

The growing challenges of climate change, resource degradation and rising input costs have increased the need for sustainable agricultural systems. Sustainable agriculture aims to enhance productivity while conserving natural resources, minimizing environmental damage and maintaining long-term ecological balance.

A sustainable farming system must improve soil fertility, increase water-use efficiency, reduce greenhouse gas emissions and strengthen resilience to climate variability. Achieving these goals requires adoption of scientific and resource-efficient agricultural practices.

Climate-Smart Soil Management

Climate-smart soil management focuses on maintaining and improving soil quality through practices that simultaneously enhance productivity, adaptation and mitigation capacity. Healthy soils form the basis of climate-resilient agriculture.

Practices such as organic farming, composting, green manuring, crop residue incorporation and biofertilizer application help replenish soil organic matter and

improve microbial activity. Increased soil organic carbon enhances soil aggregation, aeration and water-holding capacity, enabling crops to better withstand drought and heat stress.

Conservation agriculture practices including minimum tillage, residue retention, cover cropping and crop rotation further reduce soil erosion, conserve moisture and improve carbon sequestration (Food and Agriculture Organization, 2021). These practices improve resilience while reducing environmental degradation.

Role of Integrated Nutrient Management

Integrated Nutrient Management (INM) is a key component of sustainable agriculture and climate-smart soil management. INM involves the balanced and efficient use of chemical fertilizers along with organic nutrient sources such as farmyard manure, compost, vermicompost, green manures, crop residues and microbial biofertilizers (Tandon, 2013).

The major strength of INM lies in improving nutrient-use efficiency while reducing nutrient losses through runoff, leaching and volatilization. Excessive dependence on chemical fertilizers often causes nutrient imbalance and declining soil organic matter. In contrast, INM ensures gradual nutrient release and improved nutrient availability.

Organic inputs improve soil structure, enhance microbial activity and increase soil organic carbon. As a result, INM improves soil fertility, lowers production costs and strengthens resilience against climate stress. Thus, INM acts as a bridge between productivity, profitability and sustainability.

Khet Bachao Abhiyan: A National Response

Recognizing the growing challenge of soil degradation, the Government of India launched the nationwide Khet Bachao Abhiyan from 1 June to 30 June 2026 under the leadership of the Union Ministry of Agriculture and Farmers Welfare. Initiated from Ramasiya village in Madhya Pradesh's Raisen district, the campaign carries the message: "Save the Soil, Save Farming, Save Farmers."

The campaign aims to promote soil conservation, balanced nutrient management, climate-resilient agriculture and sustainable resource use. It represents a strategic policy response to address the interlinked

challenges of soil degradation, climate change and declining agricultural sustainability.

Key Features of Khet Bachao Abhiyan

Khet Bachao Abhiyan promotes a comprehensive package of scientific and sustainable farming practices aimed at restoring soil health and improving resource-use efficiency. Major interventions include:

- Soil testing and distribution of Soil Health Cards
- Balanced fertilizer application based on soil-test recommendations
- Promotion of green manures, organic amendments and biofertilizers
- Efficient irrigation and water conservation measures
- Crop diversification through pulses and oilseeds
- Improved seed treatment and modern sowing technologies
- Awareness regarding counterfeit agricultural inputs
- Farmer access to government support schemes

These interventions collectively promote sustainable productivity and climate resilience.

Role of Soil Health Cards and Scientific Outreach

A major component of the campaign is the promotion of Soil Health Cards, which provide farmers with information on soil nutrient status and fertilizer recommendations. Soil-test-based nutrient management helps reduce unnecessary fertilizer expenditure while improving nutrient-use efficiency and long-term soil fertility.

A distinguishing feature of the campaign is its strong grassroots outreach. Scientists from agricultural universities, Indian Council of Agricultural Research institutions and Krishi Vigyan Kendra centers provide technical guidance, demonstrations and farmer training. This helps bridge the gap between scientific knowledge and field-level adoption.

Contribution to Viksit Bharat @2047

India's vision of Viksit Bharat @2047 aims to transform the country into a developed, inclusive and sustainable economy by the centenary of independence. Agriculture will play a central role in achieving this vision.

Khet Bachao Abhiyan contributes directly to this national goal by improving agricultural productivity,

increasing farmer income, strengthening food security and conserving natural resources. Sustainable soil management and integrated nutrient management reduce input costs, improve resilience and support long-term rural prosperity.

Healthy soils are therefore foundational to building a resilient agricultural economy and achieving Viksit Bharat @2047.

Contribution to Sustainable Development Goals

Khet Bachao Abhiyan aligns closely with the United Nations Sustainable Development Goals (SDGs) by promoting sustainable soil management, climate-resilient agriculture and efficient resource utilization. The campaign contributes significantly to SDG 1 (No Poverty) by enhancing agricultural productivity and improving farmers' income, thereby strengthening rural livelihoods. It supports SDG 2 (Zero Hunger) by improving soil fertility and ensuring sustainable food production for long-term food and nutritional security. Through balanced fertilizer use, soil conservation and water-efficient agricultural practices, the initiative also advances SDG 6 (Clean Water and Sanitation) by reducing soil and water contamination. Furthermore, the promotion of integrated nutrient management and judicious input use contributes to SDG 12 (Responsible Consumption and Production) by encouraging sustainable resource management and minimizing environmental degradation. By enhancing carbon sequestration, reducing greenhouse gas emissions and strengthening climate resilience, Khet Bachao Abhiyan directly supports SDG 13 (Climate Action). In addition, the campaign contributes to SDG 15 (Life on Land) by protecting soil biodiversity, reducing land degradation and promoting sustainable land management practices. Thus, through its integrated approach to soil conservation and climate-smart agriculture, Khet Bachao Abhiyan simultaneously advances economic growth, social well-being and environmental sustainability.

Future Road Map

The long-term success of Khet Bachao Abhiyan requires sustained efforts beyond the campaign period through policy support, institutional strengthening and active farmer participation. Expanding soil-testing infrastructure and universal access to Soil Health

Cards should remain priorities.

Greater emphasis should be placed on increasing soil organic carbon through crop residue recycling, green manuring, composting, biofertilizers and agroforestry. Integration of precision farming, climate-smart agriculture, digital advisory services and efficient irrigation systems can further improve resource-use efficiency.

Stronger collaboration among agricultural universities, ICAR institutions, KVKs, extension agencies and farmer producer organizations will accelerate adoption of sustainable practices.

Conclusion

Climate change has made soil conservation an urgent agricultural and developmental priority. Sustainable agriculture depends fundamentally on healthy soils, efficient nutrient management and climate-resilient farming practices. Integrated Nutrient Management and climate-smart soil management offer practical pathways for restoring soil fertility and enhancing resilience. Khet Bachao Abhiyan represents a timely and strategic national initiative to address soil degradation and strengthen sustainable agriculture.

By integrating scientific soil management, farmer awareness and institutional support, the campaign can significantly contribute to agricultural resilience, rural prosperity and environmental sustainability. Protecting soil today will be essential for ensuring food security, farmer welfare and realizing the vision of Viksit Bharat @2047.

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ARTICLE ID: 27**Wearable Health Devices: Next-Gen Technology for Real-Time Monitoring of Dog Health****Abstract**

Dogs are not merely pets; they are family members, security guardians, partners in search and rescue operations, and vital companions providing therapeutic support. Therefore, maintaining their health is of paramount importance. Currently, diseases like heart disease, obesity, arthritis, diabetes, infections, epilepsy, and age-related ailments are rapidly increasing in dogs. In most cases, symptoms manifest only when the disease has significantly advanced. In such scenarios, early detection and continuous health monitoring become critical. Modern digital technology has introduced a new revolution in this direction, known as Wearable Health Devices. These devices are generally developed in the form of smart collars, smart harnesses, smart tags, or sensor-equipped jackets. The micro-sensors embedded in them continuously record vital information such as heart rate, respiratory rate, body temperature, daily activity, sleep patterns, energy expenditure, and location (GPS). The collected data is transmitted to mobile applications or cloud platforms for analysis, enabling the timely detection of subtle health variations. This facilitates early disease diagnosis, treatment monitoring, and swift decision-making during emergencies. In the future, the integration of artificial intelligence, biosensors, microfluidics, and biomarkers will make these devices even more advanced and precise. This will allow veterinarians to monitor canine health from remote locations and promote personalized healthcare for individual dogs. Wearable health devices are not only becoming a medium for early disease detection in modern veterinary medicine but are also playing a significant role in ensuring better health, longevity, and a qualitative life for dogs.

Keywords: Wearable Health Devices, Smart Collar, Canine Health, Real-Time Monitoring, Digital Veterinary Medicine

1. The Evolving Role of Dogs in Modern Society

For centuries, dogs served primarily as working animals guarding property, herding livestock, or assisting in hunts. In the modern era, however, their role has undergone a profound transformation. Today, canines are deeply integrated into human lives as cherished family members, military and police tactical assets, search-and-rescue partners, guide dogs for the visually impaired, and certified emotional support animals. Because our society relies so heavily on their well-being, maintaining canine health is no longer just a matter of basic animal welfare; it directly impacts human safety, emotional stability, and overall quality of life.

2. The Silent Threat of Chronic Canine Illnesses

While advancements in veterinary medicine, better nutrition, and shifting lifestyles have successfully extended the average lifespan of companion animals, this longevity has introduced a surge in chronic, age-related health conditions. Modern veterinary clinics are seeing unprecedented rates of:

- Cardiovascular diseases and congestive heart failure
- Metabolic disorders like diabetes mellitus and severe obesity
- Degenerative joint diseases such as osteoarthritis
- Chronic respiratory distress and neurological conditions like epilepsy

The most critical bottleneck in treating these ailments is that dogs possess an evolutionary instinct to mask weakness or pain. Consequently, early-stage symptoms are incredibly subtle minor changes in respiratory pacing, slight shifts in sleep cycles, or a faint reduction in daily movement. By the time a pet owner notices distinct clinical signs, the underlying pathology has usually progressed to an advanced, costly, and sometimes irreversible stage.

3. The Dawn of Digital Veterinary Surveillance

To bridge this critical communication gap between animals and humans, veterinary science is leveraging wearable health devices. These smart electronic systems engineered as ergonomic collars, harness attachments, lightweight tags, or bio-sensor jackets allow for continuous, non-invasive biometrics tracking without disrupting the animal's daily routine.

Unlike a traditional, stressful checkup at a veterinary clinic that only captures a single snapshot in time, wearables offer baseline, 24/7 longitudinal monitoring. This allows algorithms to easily differentiate between an animal's healthy baseline data and genuine physiological anomalies.

4. Core Biometric Indicators Captured by Wearables

Modern pet wearables integrate a suite of micro-sensors including photoplethysmography (PPG) modules, 3-axis accelerometers, and thermal sensors to continuously capture critical data points:

- **Vital Signs:** Continuous heart rate variability (HRV) and resting respiratory rates (RRR).
- **Thermoregulation:** Subtle fluctuations in core body temperature that indicate systemic inflammation or fever.

- **Behavioral Metrics:** Exact sleep architecture (deep sleep vs. restlessness), daily caloric burn, and overall scratch/itch frequencies.
- **Kinematics:** Advanced gait analysis to detect early lameness or joint stiffness before physical limping occurs.
- **Spatial Tracking:** Real-time GPS and cellular connectivity to prevent lost animals and monitor working dogs in active field environments.

All gathered data is transmitted via Bluetooth or Wi-Fi to cloud networks. When a parameter breaches safe thresholds, the system instantly alerts owners and veterinary teams via mobile applications.

5. Real-World Wearable Systems Currently in Use

This technology is not theoretical; several advanced wearable platforms are heavily utilized by pet owners, research institutions, and veterinary clinics globally today:

- **FitBark & Whistle Switch:** These lightweight collar attachments operate similarly to human fitness trackers. They are widely used to monitor dynamic activity levels, sleep quality, and dermatological issues (by tracking excessive scratching or licking behaviors).
- **Petpace Smart Collar:** A heavily validated medical-grade collar utilized by veterinarians to track continuous ECG-level heart rates, respiration, temperature, and pain scores. It is frequently deployed to monitor dogs recovering from major surgeries or managing congestive heart failure.
- **Invoxia Minitailz:** A cutting-edge smart pet tracker that utilizes micro-AI sensors to record advanced cardio-respiratory biometrics, acting essentially as a wearable stethoscope that can detect early signs of heart disease before visible symptoms appear.

6. The Preventative Power of Early Biometric Shifts

The primary clinical advantage of this technology lies in early diagnostic intervention. For example, a minor systemic infection or the onset of an arthritic flare-up

might initially cause a dog to simply look a bit lethargic. While a human observer might miss this, a wearable device will immediately flag a 15% spike in resting heart rate paired with a sudden drop in deep sleep. Recognizing these micro-changes allows veterinary practitioners to run targeted diagnostics early, starting therapies weeks before a medical crisis develops.

7. Future Horizons: Smarter, Personalized Veterinary Care

The trajectory of digital veterinary medicine points toward an ecosystem where wearables are integrated with advanced artificial intelligence, paper-based microfluidic diagnostics, and automated biomarker profiling. Future smart collars may eventually sync with in-home diagnostic tools to cross-reference real-time vitals with molecular data from biofluids. This shifts the entire paradigm of veterinary medicine away from reactive emergency treatments and toward fully automated, highly personalized, and predictive preventative care, ensuring our canine companions live longer, healthier, and more vibrant lives.

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ARTICLE ID: 28

**The Great Indian Organic
Renaissance to Blow Life into Dying Earth**

Abstract

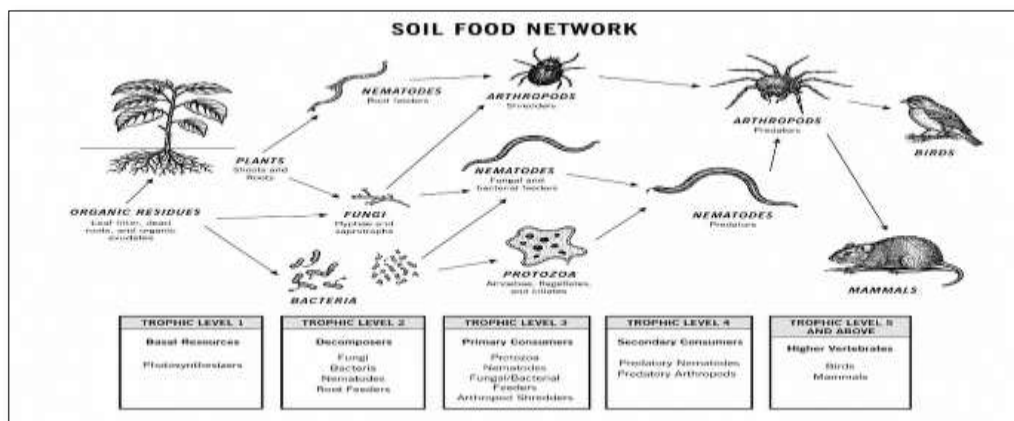
For over six decades, the Green Revolution ensured India’s food security but left a legacy of degraded soil, toxic ground water and health crises. This paper evaluates India’s “Organic Renaissance”, a transition from chemical-intensive agriculture to biological renovation. By scrutinizing the “Soil Food Web” and the recovery of ancient Vrikshayurveda through modern Zero Budget Natural Farming (ZBNF), the study highlights a shift from feeding plants to nurturing soil life. Through a relative analysis of Sikkim’s success and Sri Lanka’s downfall. Several studies suggest that while initial yields may drop, long term organic systems offer higher profitability, climate resilience and environmental sustainability. Eventually the paper advocates for regenerative agriculture as a vital second independence from chemical dependency.

Keywords: Regenerative Agriculture, Zero Budget Natural Farming (ZBNF), Vrikshayurveda, Sikkim Organic Mission, Sustainable Intensification.

Introduction: The silence of the skylarks

If you stand in the middle of orthodox wheat field in Punjab today, the first thing you observe is not what is there, but what is absent. The buzzing of bees has faded. The earthworms, those ancient soil engineers, are gone. The soil itself is often gray, hard and a grimy comatose medium kept on life support by intravenous drips of Urea and Diammonium Phosphate (DAP).

Over sixty years, India has been fighting a battle against hunger. In 1960s, the Green Revolution, led by Norman Borlaug and M.S. Swaminathan, was an indispensable marvel. It introduced high-yielding variety (HYV) seeds, irrigation canals and chemical inputs that saved a starving nation. But now the miracle becomes a burden on country’s future. We are perceiving the unraveling of the chemical age. The “Cancer Train” that departs from Bhatinda to Bikaner conveys the human cost of pesticide overuse. The groundwater tables fall down, contaminated with heavy metals and Nitrates. The soil organic carbon the heartbeat of fertility has dropped to sever low levels.



However, there is a new hope emerging. From the hazy terraced slopes of Sikkim to the drylands of Andhra Pradesh, a silent revolution is developing. India is returning to its roots, not out of nostalgia, but out of stipulation. This is the story of the organic resurgence.

Chapter 1: The science of resurrection

To understand why organic farming is vital, one must understand the violence of conventional agriculture. The soil is not only hungry for Nitrogen (N), Phosphorous (P), Potassium (K) but requires organic matter (Carbon) also.

Organic farming treats soil as dynamic ecological system rather than passive growth medium. A single teaspoon of organic soil contains more microbes than there are humans on earth. These microbes along with nematodes, arthropods and vertebrates create a “Soil food Web”.

- 1. The Fungal Network:** Mycorrhizal fungi attach to plant roots, extending them fetching water and nutrients. Chemical fungicide kills this network.
- 2. The Nitrogen Fixers:** Bacteria like Rhizobium pull nitrogen from air and fix it into the soil. Nitrogenous fertilizers make these bacteria lazy and eventually extinct.
- 3. The Carbon Sponge:** Organic matter rich in humus. Humus acts like a sponge and can hold

water 90 per cent of its own weight. In drought areas organic soil is a reservoir.

Hence when farmer switches to organic, they stop feeding to crop and start nurturing to soil.

Chapter 2: Ancient wisdom, Modern method

Organic farming is not new to India; we practiced it for 5000 years before the British arrived. The current movement is a revival of Vrikshayurveda (the science of plant life), adapted for 21st century. The movement in India is currently split into two main domains:

- 1. Certified Organic Farming (NPOP):** This is the export-oriented model. It follows strict international standards (USDA, EU). It allows bio-fertilizers and bio-pesticides purchased from the market. It is capital intensive but essential for global trades.
- 2. Zero Budget Natural Farming (ZBNF):** It was popularized by Subhash Palekar, for which he honored with Padmashri in 2016 (Anon., 2016). It contends that farmer should not buy anything from market no chemical or organic inputs sold by companies. It has basically four pillars (Palekar, 2014). These are:
 - **Jeevamrutha:** A fermented microbial culture made from cow dung, cow urine, jaggery and pulse flour. It not only provides nutrient but also acts as a catalyst that promotes the



activities of microorganisms and earthworm in soil.

- **Bijamrita:** A consortium of water, cow dung, cow urine, lime and just a hand full of soil. It protects the seedlings young roots from fungus as well as soil-borne and seed borne diseases.
- **Acchadana (Mulching):** It is the process of covering the top soil with crop waste or live cover crops. It conserves soil moisture by reducing evaporation, ceasing weed flora growth and adds organic matter to soil after decomposition.
- **Whapasa (Soil aeration):** It is the condition defined by the presence of both water and air molecule in the soil. It reduces the need of frequent irrigation.

Chapter 3: The Sikkim miracle

In 2016, Prime Minister Narendra Modi declare Sikkim the world's first fully organic state. This was not a coincidence; it was deliberate strategy led by Chief Minister Pawan Chamling.

How they did it:

1. **Phased Ban:** They didn't ban chemicals overnight. They slowly reduced the subsidy on chemical fertilizers while increasing supports for organic inputs.
2. **Education:** They introduced organic farming modules in school curriculums.
3. **Infrastructure:** They built automated bio-fertilizer units and soil testing labs.

The Result: Sikkim's cardamom and ginger are now global benchmarks. The state sees eco-tourism specifically for its farming practices. It proved that food security is not threatened by organic farming rather it is enhanced by it.

Chapter 4: The thorn in the rose

We must address the uncomfortable truth, Sri Lanka banned chemical fertilizers overnight. The result was catastrophic crop failure, food riots and economic collapse.

Sri Lanka failed because it was a political decision not an agricultural one. They banned the chemical fertilizer aiming to save roughly \$400 million USD in annual import cost. They did not prepare the soil; they

did not train the farmers and they did not have enough organic manure to replace the chemicals. From this India must learn that the transition must be:

- **Gradual:** Phased over 5-10 years.
- **Supported:** Farmers need income support during "conversion yield drop".
- **Scientific:** It cannot be based on pseudoscience; it requires rigorous soil testing and carbon management.

The Certification Nightmare: In India agriculture is mostly subsistence type. The farmers are poor and often face poverty. Thus, for a poor farmer getting a "USDA organic certificate" is expensive and involves mountains of paperwork. The "Third party certification" model is flawed for smallholders.

The Solution: "PGS (Participatory Guarantee System)"; this is a decentralized certification where groups of farmers certify each other. It is built on trust and paper review, recognized by the Indian government for the domestic market.

Chapter 5: Government Policy and the road ahead

The government of India has launched significant schemes that promote organic farming. These are:

1. Paramparagat Krishi Vikas Yojana (PKVY): PKVY was launched in 2015. It promotes sustainable organic farming through a cluster-based model. It provides farmers with ₹50,000 per hectare over three years, with ₹31,500 dedicated to organic input via Direct Benefit Transfer. The scheme focuses on improving soil health, reducing chemical dependency and ensuring chemical-free produce. Certification is managed through the Participatory Guarantee System (PGS), linking clusters directly to markets for better price realization and environmental conservation.

2. Mission Organic Value Chain Development for North Eastern State (MOVCDNER): This is a flagship initiative by the government to transform northeast Indian government to a transform Northeast India into an organic hub. It was launched in 2015, the scheme shifts focus from traditional subsistence farming to a sustainable, commercial model. It organizes local farmers into Farmer Producer Companies (FPCs) providing them with technical support, high quality seeds and third-party organic certification.

By funding processing units and cold storage, the mission bridges the gap between rural fields and global markets. This “farm-to-fork” approach ensures better income for growers while promoting eco-friendly agriculture across all eight north eastern states (i.e. Assam, Arunachal Pradesh, Manipur, Mizoram, Meghalaya, Nagaland, Tripura and Sikkim).

3. National Programme for Organic Production:

This program was launched in 2001 by Ministry of Commerce and Industry under government of India. It provides a robust framework for accrediting certification bodies, setting standards and certifying organic produce. It was implemented by APEDA (Agricultural and Processed Food Products Export Development Authority). It ensures organic integrity from farm to market through strict audited third-party certification. Guidelines require ecological production, excluding synthetic chemicals and GMOs and align with international standards for global market access.

4. National Project on Organic Farming (NPOF):

The National Project on Organic Farming (NPOF) was initiated in 2004 to promote sustainable agriculture by reducing chemical reliance. It centers on promoting bio-fertilizers, producing vermicompost and providing training for farmers. It focuses on capacity building, quality control of organic inputs and fostering low-cost certification systems (Participatory Guarantee System of India).

5. Capital Investment Subsidy Scheme Under Soil Health Management Scheme:

This is one of the government’s initiatives for promoting organic farming in India. Through this financial aid program existing units can receive support for technological upgrades and the expansion of their current capacity. The objectives of this scheme are:

- Pick up agricultural productivity while preserving soil health and environmental integrity.
- Reduce total reliance on chemical fertilizers and pesticides by increasing the approachability of high-quality bio-fertilizer and organic manure in the country.
- Foil pollution through appropriate use and diversion of organic waste.

The future of Indian agriculture is hybrid. We may not get 100 per cent organic like Sikkim everywhere, however the baseline must shift.

Conclusion: The second independence

The first struggle for Indian agriculture was starvation. The second struggle is independence from poison. The Indian farmer stands at a crossway. One path leads to a barren wasteland of salted soils and debt while the other one is the organic path which is difficult and steep. It requires patience, labor and a relationship with nature that we have forgotten.

As the sun sets over a natural farm the air smells fresh not like chemicals. It’s clear that farming is no longer just about food; it’s about future. The soil is not machine to be used; it’s our mother, and it is time we treated her with the reverence she deserves.

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Vector and Reservoir Control: A Strategy to Prevention of Vector Born Zoonotic Diseases

Vector born diseases account of more than 17 % of all infectious diseases all over the world. It involves managing insects (vectors like ticks, mosquitoes etc.) and animals (reservoirs like dog, rat, rodents, bats etc) to prevent the spread of infectious diseases such as dengue, malaria, ebola, and Zika. The key strategies include habitat modification, biological control, insecticide application and reducing human-animal contact through protective barriers.

Vector Control Methods:

Vector control targets creatures that transmit pathogens directly, such as mosquitoes, ticks, and fleas.

- **Environmental Management:** It involves the removing the breeding sites by draining stagnant water, covering water containers and cleaning up rubbish.
- **Chemical Control:** Using the chemicals like insecticide-treated nets, indoor residual spraying, and larvicides to kill mosquitoes.
- **Biological Control:** By introducing larvivorous fish like *Gambusia affinis* and *Poecilia reticulata* into water bodies to consume mosquito larvae.
- **Personal Protection:** Wearing long clothes, using repellent, and installing window screens.

Integrated Vector Management (IVM)

IVM is the recommended approach to enhance efficiency and sustainability:

- **Multi-sectoral Action:** Collaborating with agriculture, urban planning, and education sectors to manage environments sustainably.
- **Surveillance:** Monitoring vector populations to ensure timely, targeted interventions.
- **Community Engagement:** Involving local communities to maintain, for example, "weekly dry days" to destroy breeding spots.

Vector Control in Specialized Settings

- **Ports & Transportation:** Conveyances (ships, planes) and port areas (up to 400 m from terminals) must be kept free of vectors and reservoirs to prevent international spread, as mandated by the International Health Regulations (IHR 2005).
- **Urbanization & Climate:** Addressing the rising burden of disease, exacerbated by climate change and, frequently, urban planning that increases vector habitats.

Reservoir Control Strategies :

Reservoir control focuses on managing animals that harbor pathogens, such as dogs for leishmaniasis or rodents for plague.

- **Vaccination/Treatment:** Treating or vaccinating host animals to prevent them from carrying the disease.
- **Population Control:** Reducing the population of rodent reservoirs via trapping or culling in affected areas.
- **Management:** Keeping food and garbage in secure containers to discourage rodents from settling near homes.

Above all these practices helps in the control and management of vector born zoonotic diseases which have major public health significance and highly economic values. It is the primary defense against highly fatal vector born diseases for which specific medical treatments and vaccines may be limited or unavailable.

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ARTICLE ID: 30

Status of *Albizia*'s Genetic improvement in India: An overview

Abstract

This review synthesizes current knowledge on the genetic improvement of Indian *Albizia* species, patterns of natural genetic diversity, and the suite of conventional and molecular tools employed to date. Existing studies reveal considerable inter- and intraspecific variation but also highlight major gaps: limited provenance trials, sparse genomic resources, fragmented germplasm collections and few coordinated breeding programmes. Conventional approaches have yielded locally adapted planting material, yet progress is constrained by long juvenile periods, high heterozygosity and poor seed quality in many species. Recent applications of molecular markers and early efforts in tissue culture, somatic embryogenesis and cryopreservation show promise for accelerating selection and conserving elite germplasm in nutshell *Albizia* has been untapped for genetic improvement.

Keywords: *Albizia*, genetic improvement, molecular markers, provenance trials, Roadmap.

1. Introduction

Trees of the genus *Albizia* (Fabaceae: Mimosoideae) are fast-growing, nitrogen-fixing, multipurpose species with substantial ecological and economic value in India. They are used in agroforestry, afforestation, horticulture (shade, ornamentals), fodder, fuelwood, medicinal uses and reclamation of degraded lands. Despite wide planting and usefulness in agroforestry systematic tree breeding program on *Albizia* is still lagging behind major plantation species like Eucalyptus and Acacia. In current scenario the emphasis is given on the exotic species in India for agroforestry models like Eucalyptus, Populus, Casurina, etc in Haryana, Punjab, and Western Uttar Pradesh (Bijalwan *et al.*, 2014). Further the tree species like Acacia, Casuarinas, and Teak were promoted in agroforestry by private sector and forest department but these species does not gained popularity in central India and North Eastern states. But *Albizia* has potential to perform well in the agroforestry plantations and therefore can be promoted model in these states. Most of earlier reviews on *Albizias* focused on photochemistry and variability studies. so this review was drafted to highlights status of genetic improvement, future strategies and drafting of roadmap for genetic improvement of *Albizias* in India.

2. Usage of *Albizias*: Genus *Albizia* is very significant socially due to its wider utility in for forage, timber and medicinal plants (Joycharat, 2014).

2.1 Medicial use: Seeds of *A. lebeck* are astringent and given in piles (Singh, 1995). The flowers of *A. amara* have been applied to boils, eruptions, and swellings.

2.2 Agro forestry and restoration purposes: Like many legumes, *Albizia* species form symbiotic relationships with rhizobium bacteria, enriching soil fertility (Meenakshi *et al.* 2023).

2.3 corrosion inhibitor

The extract of *Albizia lebbek* pods and seeds has been used as a corrosion inhibitor for carbon steel in a saline medium (Aghani *et al.*, 2020).

3. Species of interest in India

Major *Albizia* taxa of practical importance in India:

Albizia lebbek — widely distributed; used for timber, poles, fodder and medicinal uses (Thakur *et al.*, 2014).

Albizia procera — fast-growing, used for light timber, fuelwood and agro forestry.

Albizia saman (rain tree) — shade tree, fodder, and soil-improving species in some regions.

Albizia chinensis-

Excellent for restoration of degraded lands, produces fuel and small timber, and its leaves form excellent fodder for cattle (Dhanai *et al.*, 2003).

Other local taxa and naturalized species with regional importance. For each species, improvement priorities differ: timber quality for *A. lebbek*, coppice and form improvement for *A. procera*, and shade/fodder traits for *A. saman*.

4. History of Albizia tree improvement in india

The history of genetic improvement of *Albizia* in India is a relatively recent but growing field of research, with efforts intensifying since the late 20th century.

Early/colonial to mid-20th century: Early silvicultural and provenance observations were recorded in forestry literature.

Late 20th century (1970s–1990s): ICFRE and its regional institutes began organized trials, provenance collections and plantation technique research for *Albizia* spp.

2000s–present: Continued ecological and provenance studies but few coordinated, long-term genetic improvement programmes specifically aimed at breeding superior *Albizia* cultivars have been published.

5. Key milestones in genetic improvement

5.1 Provenance studies and germplasm evaluation:

Collection of seed sources from diverse regions to identify fast-growing or site-adapted provenances—the usual first step in tree improvement. Recent

provenance/sampling work has been documented in preprints and region.

Toky *et al.*, 1990 in earlier germplasm evaluations: In a study under “Genetic Diversity in Three Important Agroforestry Tree Species of Dry Zone”, germplasm from multiple provenances (12-provenance of *A. lebbek*) were raised at Hisar, showing differences in growth, fodder quality and nitrogen fixation among provenances:

The recent preprint by Rajora *et al.*, 2024) showed high provenance variation in seed size, pod dimensions, seed germination among *A. lebbek* populations in northern India; correlations with bioclimatic variables (temperature, precipitation) suggest potential for ecotypic selection.

5.2. Variability Studies of POD and Seed Characteristics *Albizia* species

The populations of *Albizia chinensis* distributed in Himachal Pradesh and Uttarakhand (Dhanai *et al.* 2003a Dhanai *et al.*, 2003b) and *A. lebbek* (Uppal and Singh, 2010) from Garhwal Himalaya and Siwaliks, Uttaranchal, Uttar Pradesh were observed for pod and seed morphology and studied their genetic characters. (Tiwari *et al.*, 2018 determine the variation in pod and seed characteristics *Albizia procera* in five provenances of Chhattisgarh, India.

5.3Vegetative propagation / tissue culture: (Handa, *et al.*2003) showed that IBA at 200 ppm induced rooting of stem cuttings, with biochemical changes (e.g. sugar content, C/N ratio) being important during rooting. This demonstrates potential for vegetative multiplication.

5.4 Molecular genetics and diversity

High within-population variation; low–moderate among-population differentiation is commonly reported for *Albizia* species — most molecular variance tends to be within populations rather than among them (common for outcrossing, insect/avian-pollinated trees). Marker choice matters: studies comparing markers (RAPD, ISSR, SCOT, and DAMD) find differences in polymorphism detection and clustering; AFLP gave good resolution in multi-species work. Recent SNP-based work (outside India but relevant) shows much finer resolution and can reveal subtle structure or historical bottlenecks.

Applications so far: germplasm characterization, provenance/provenance trial support, genetic-fidelity of micropropagated plants, and baseline data for conservation/breeding programs.

a. AFLP, RAPD, — the earliest and most common markers used to evaluate species- and population-level diversity and relationships in Albizia (*A. procera*, *A. lebbeck*, *A. kalkora*, *A. odoratissima* etc.). *AFLP was used for multi-species comparisons* of Albizia species; by **Aparajita and rout, 2010** for conservation strategies.

b. SSR (microsatellites), SCOT, ISSR — used in some comparative marker-efficiency studies and population work; SSRs give co-dominant information (useful but no case studies available for Albizia in India). (.

c. Chloroplast genomes & SNPs / genomics —case studies on SNP are limited in Indian .but very recent global work by (**Park et al.,2024**) is appearing for some Albizia species, opening the door to high-resolution population genomics .

d. Assessment of gene diversity

Case studies on genetic diversity are limited in India, but recently some global case studies by (**Aguirre-Morales et al., 2019, An et al., 2024**) are appearing for some Albizia species.

6. Main constraints to genetic improvement in India

Limited molecular/genomic resources: Very few studies using molecular markers; no reference genome or transcriptome publicly available in many cases. Without this, marker-assisted selection, genomic selection remain difficult.

Inadequate provenance and progeny trials: Existing provenance trials are localized (Himachal Pradesh, mid-Himalayas, etc.), and do not always cover full ecological range. Few progeny trials exist to estimate heritability under varied environments.

Propagation limitations: Vegetative propagation is species/provenance/age dependent; juvenile material roots better. Mature trees often difficult. Clonal propagation protocols are not scaled up or standardized.

Proposed Roadmap / Phased Plan (5- to 10-year Framework)

Phase	Key Objectives	Activities	Outputs / Milestones
Phase 1 (Years 1-2)	Germplasm collection & baseline evaluation	Collect germplasm from diverse provenances; set up common garden & provenance trials in 4-6 agro-climatic zones; characterize seed/pod traits; begin molecular marker discovery (e.g. SSR, GBS pilot)	Germplasm repository; data on seed/pod and growth trait variation; a set of molecular markers; identification of promising provenances/clones
Phase 2 (Years 3-5)	Propagation and selection of elite genotypes; beginnings of improved material deployment	Progeny trials; vegetative propagation / micropropagation of selected clones; development of seed orchards; refinement of clonal propagation protocols; germplasm conservation (cryopreservation)	Elite clones with known performance; reliable propagation protocols; initial deployment in demonstration plantations; seed orchards producing improved seeds; clear seed/stock certification guidelines
Phase 3 (Years 5-10)	Advanced breeding; scaling up; genomic tools integration	Perform controlled crosses; apply marker-assisted / genomic selection; screen for stress tolerance; expand propagation infrastructure;	Released improved genotypes (provenanced/clonal); expanded adoption by forestry/agroforestry sectors; improved resilience; increased economic returns;

Phase	Key Objectives	Activities	Outputs / Milestones
		integrate feedback from farmers; monitor long-term performance	policies supporting using improved material
Phase 4 (Ongoing)	Monitoring, evaluation, capacity building, policy alignment	Regular monitoring of plantations; socio-economic impact assessments; continuous training; policy advocacy; knowledge dissemination	Adjustment of breeding objectives; enhanced stakeholder participation; institutionalization of improved practices; sustainable impact

Seed quality, supply and certification: Seed sources are often of unknown provenance; seeds may have variable germination, infestation, defect; seed certification and nursery standards are weak.

Ecological and climate risks: As climatic zones shift, drought, heat stress, pest/disease incidence may increase; improvement programs need to build resilience.

Taxonomic uncertainties: Some species/taxa are poorly described; synonymies or misidentifications exist (e.g. newly described *A. arunachalensis*). This hampers accurate germplasm management.

7. Strategies and plans for *Albizia* improvement network

In order to develop strategies for improvement and breeding of *Albizia* an in-depth knowledge of biodiversity, habitat, systematic, population structure, geneecology, flowering and seed biology, mating system are much needed.

Future research thrusts/priorities

1. To conduct Provenance trial
2. Propagation and cryopreservation techniques for elite clones.
3. Establishment of seed orchard/germplasm bank for top provenances.

4. Study of genetic markers in genetic diversity analysis and association mapping for traits of interest.

Encourage nurseries, NGOs and farmer networks to maintain and multiply elite planting stock; community seed banks can preserve locally adapted material.

Conclusion

Albizia species in India, especially *A. lebbeck*, *A. procera*, *A. amara*, have substantial untapped potential for genetic improvement. Existing studies show good phenotypic variability in growth, seed/pod and seed quality traits, high heritability for some key traits, and possibilities for vegetative propagation. A coordinated, sustained programme combining conventional breeding, genomics/biotechnology, and strong seed/nursery systems, aligned with policy and stakeholder needs, can deliver improved *Albizia* genotypes that meet both ecological and economic needs in India.

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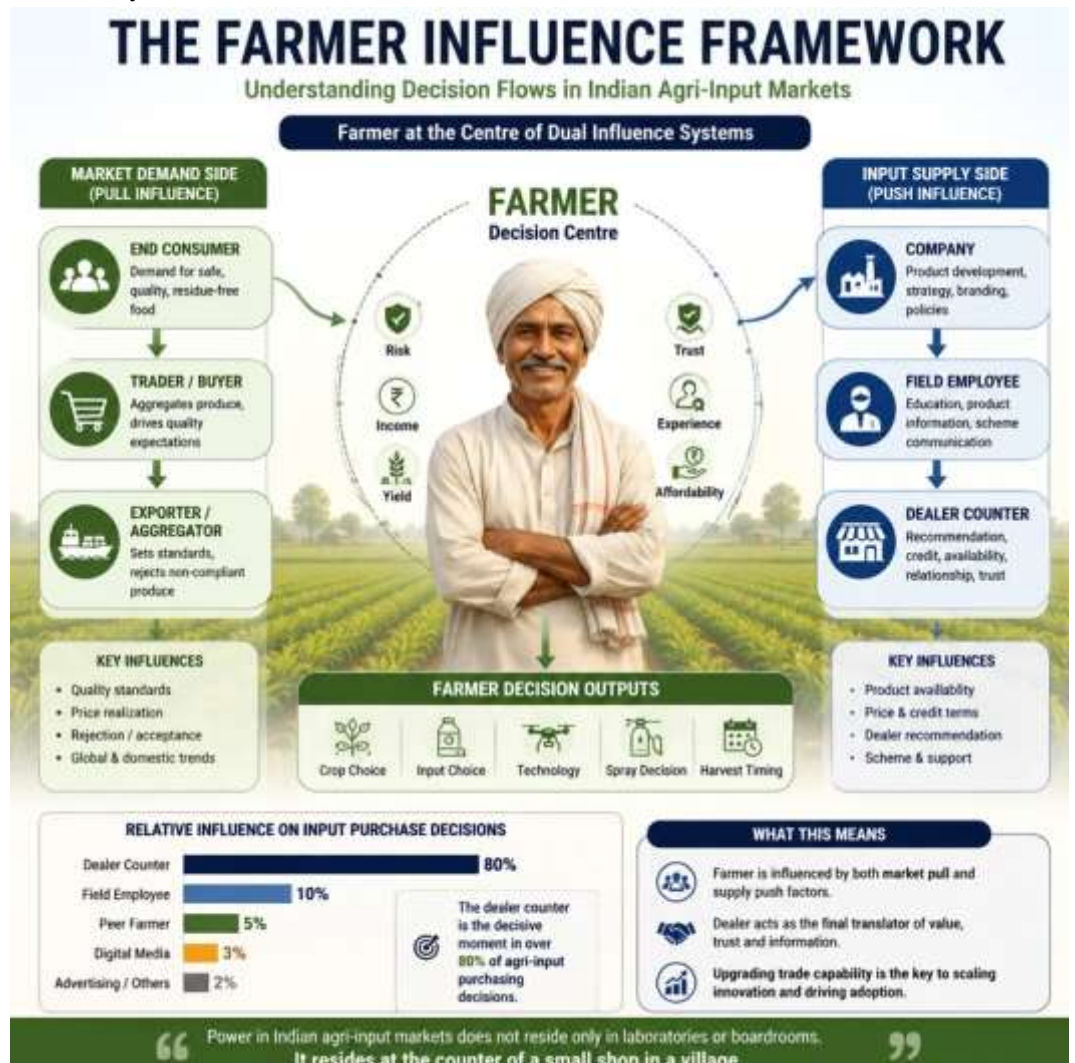
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**The Real Power Center in Indian Agri-Inputs:
Why Trade Shapes the Farmer's Decision**

In Indian agriculture, we often assume that the farmer is the ultimate decision maker. Technically, that is true. The farmer chooses what to sow, what to spray, and what to buy. But in practice, the decision-making ecosystem is far more layered.

When it comes to agri-input purchasing whether chemical pesticides or biological solutions the Indian farmer is deeply influenced, and often dependent, on the trade channel: dealers, distributors, and local retailers. Unless companies recognize this structural reality, even the most promising innovations will struggle to scale.

The Farmer Sits in the Middle, Not at the Edge

The Indian farmer occupies a powerful yet constrained position. He is the producer of food, the ultimate buyer of agricultural inputs, and the largest voter base in the country. Yet structurally, he sits between two dominant forces.



On one side lies evolving consumer demand of safe food, residue-free produce, organic cultivation, premium quality. On the other lies the input industry companies, brands, technologies, and marketing machinery.

However, the farmer does not have direct leverage over either. Urban consumer preferences reach him indirectly. Corporate strategies rarely engage him at scale without intermediaries. Between these two ends stands one consistent actor: trade.

How Consumer Signals Actually Travel

When urban consumers begin demanding safer or residue-free food, the signal does not move directly from city to farm. It travels through a layered supply chain.

The pathway looks something like this: Consumer to bulk buyer or mandi trader, then to exporter or aggregator, and finally to farmer. If buyers start rejecting produce with high residue levels, farmers gradually adapt their production practices.

This shift is especially visible in fruits, vegetables, and horticulture crops where quality differentiation carries market value. As farmers move toward safer output, they begin exploring safer inputs. That is where biologicals enter the conversation.

Yet consumer influence explains only part of the story. Because when it comes to choosing specific products, another force exerts greater control.

The Counter Moment That Shapes 80% of Decisions

In India, more than 80 percent of agri-input purchase decisions are influenced by the local dealer. Recommendation, relationship, credit availability, and stock visibility matter far more than corporate advertising campaigns.

Digital content exists. Government advisories exist. Peer farmer discussions happen. But the final decision moment still unfolds at the dealer's counter.

That moment determines which brand moves, which technology penetrates, and which innovation remains on the shelf.

And critically, the farmer cannot easily bypass this channel.

Why the Dealer Is Structurally Indispensable?

India has nearly three lakh agri-input retail shops. Each typically serves hundreds of farmers across a

defined geography. These outlets operate at village and small-town level, embedded within local social and economic networks.

E-commerce penetration in agri-inputs remains negligible compared to overall trade volumes. Government cooperatives contribute, but not at transformative scale. Direct-to-farmer models remain limited by logistics, credit, and advisory constraints.

The dealer performs multiple roles simultaneously: last-mile distributor, credit provider, informal agronomic advisor, local influencer, and risk buffer. In many cases, he carries inventory risk and working capital exposure that companies prefer not to absorb.

This makes him not merely an intermediary, but a structural pillar.

Why Companies See Trade as a Bottleneck?

Despite this reality, many companies describe dealers as obstacles. The complaints are familiar. Dealers push high-margin products. They delay payments. They promote competing brands. They negotiate aggressively. They demand incentives and schemes.

There is some truth in these frustrations. But there is also an uncomfortable counterpoint: companies helped design this system.

When a dealer is treated primarily as a warehouse for targets, a dumping ground for schemes, or a credit shock absorber, he optimizes for short-term financial survival. He behaves like what he is—a business owner.

Unlike a sales employee, the dealer carries personal capital risk. His decisions reflect working capital cycles, credit exposure, and return on investment. Expecting him to behave otherwise is structurally unrealistic.

The Collective Strength of Trade

Dealers are not isolated actors. They are organized into associations at village, taluka, district, and state levels. They collectively serve the country's largest political constituency—farmers.

This embedded positioning gives them bargaining strength and resilience. They are not a temporary channel awaiting disruption. They are institutionally woven into the rural economy.

The more relevant question, therefore, is not how to bypass trade. It is how to upgrade it.

WHY THE DEALER COUNTER REMAINS THE CENTRE OF FARMER DEPENDENCE

The Dealer Solves Multiple Real-World Needs for the Farmer—Right Where He Is.



IN INDIAN AGRICULTURE, THE DEALER COUNTER IS NOT JUST A DISTRIBUTION POINT. IT IS THE MOST ACCESSIBLE, TRUSTED AND RELIABLE AGRI-SOLUTIONS HUB FOR THE FARMER.

From Channel Partner to Business Partner

For sustainable growth in Indian agri-input markets, companies must shift mindset. The dealer cannot be viewed merely as a channel partner executing distribution tasks. He must be treated as a strategic business partner.

That shift requires structural reforms, not motivational speeches.

Digital enablement is one pillar. Inventory tracking, sell-out visibility, farmer advisory logs, and transparent credit data can reduce friction and build mutual trust.

Commercial alignment is another. Balanced margins, structured incentives, predictable payment cycles, and reduced forced linking create stability.

Risk-sharing mechanisms are equally critical, particularly for biological products. Partial buy-back structures, structured consignment in pilot clusters, and inventory protection linked to execution quality can encourage responsible experimentation without moral hazard.

Capability building is the final piece. Biological product education, soil health literacy, regulatory

awareness, and advisory skills transform the dealer from a product seller into a solution provider.

Profitability Must Align, Not Compete

Companies celebrate revenue growth. But rarely do they ask whether dealer return on investment has improved. Has working capital efficiency increased? Has turnover expanded sustainably? Has risk exposure declined?

If company growth outpaces dealer sustainability, friction becomes inevitable.

Both company and dealer are service providers. The ultimate business owner in the ecosystem is the farmer. When the farmer succeeds, the dealer grows. When the dealer grows, the company scales. When the farmer fails, contraction spreads across the system.

The Road Ahead

Trade is not disappearing. Digital platforms will expand. Direct models will evolve. But village-level dealer networks will remain central for decades because they solve trust, credit, and advisory gaps simultaneously.

The next phase of agricultural transformation in India will not be driven solely by superior products or larger

marketing budgets. It will be driven by governance—clear frameworks, transparency, aligned incentives, and structured accountability across the channel.

When the dealer becomes a true business partner, products move faster, payments stabilize, farmer trust deepens, and biological adoption accelerates.

Final Reflection

Power in Indian agri-input markets does not reside only in laboratories or boardrooms. It resides at the counter of a small shop in a village.

Whoever understands that ecosystem—and chooses to strengthen it rather than fight it—will shape the future of agricultural innovation in India.