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Impacts of Climate Change on Inland Fisheries in India

Article ID: 74000

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Abstract

India's inland fisheries sector plays a crucial role in supporting fish production, maintaining aquatic biodiversity and sustaining rural livelihoods; however, climate change is increasingly threatening its water security and long-term sustainability. Elevated temperatures lower the solubility of oxygen in water, increase physiological stress in fish, and ultimately affect reproduction and growth rates in both cultivated and wild species, and can cause death. Increased monsoon variation would result in floods and droughts, hence destruction or deterioration of habitats and limited water supply, which would wash away all the eggs, larvae and fingerlings. Water acidification, influx of nutrients in coastal water, enhances the harmful algal blooms, disturbs the water system, thereby mainly causing death of fish and also affects the biodiversity. Fish yield diminishes, and thus the livelihood of people involved is also affected, resulting in loss of food and nutrition security. Various implications of climate change in Indian inland fishery are described in this paper, and in turn, adaptation measures such as heat-tolerant species, rain-harvesting, polyculture and ecosystem-based management were emphasised to sustain the fishery production.

Keywords: Climate change, inland fisheries, fish production, biodiversity, adaptation strategies, rural livelihoods, India.

Introduction

In India, inland fisheries play a significant role in ensuring food and nutrition security, contributing 14 million livelihoods and providing affordable animal protein to more than 200 million people, primarily in rural India (FAO, 2022; Fisheries Office, 2023). India's freshwater fish production is largely supported by diverse inland water resources, including the Ganga and Brahmaputra River systems, reservoirs, wetlands, floodplain lakes, ponds, and aquaculture facilities, which together contribute substantially to the country's total freshwater fish output. The reservoir, wetland, flood plain lakes and aquaculture pond also form the base for the aquaculture industry, a growing sector in the country. (ICAR-CIFA, 2021; FAO, 2022). Pre-existing fishing and aquaculture populations have co-existed with the spatial variability in water availability and productivity, and the ecological relationships in the aquatic environment. In recent times, however, climate change has already established itself as a profound threat to the productivity and sustenance of inland fisheries in India. Changes in water quality brought by rising temperature reduced dissolved oxygen, altered metabolic rates, and adversely affected growth, reproduction and survival of indigenous and cultured species, including Mahseer and Pangasius (et al., 2007; De Silva & Soto, 2009). Altered monsoon patterns worsen droughts, which shrink aquatic habitats or floods, which dislodge and destroy eggs, larvae and juveniles, leading to losses of 15-40% in climate-sensitive areas such as the Indo-Ganges plains and Eastern Ghats (Handisyde et al., 2017; IPCC, 2023). Water acidification, nutrient run-offs, and eutrophication, coupled with climate change, degrade the quality of water bodies through promoting algal bloom, fish mortality, reduction in species diversity, and a threat to fish safety (Boyd & Tucker, 2012; IPCC, 2023). Such environmental transformations promote invasive species, shift the ecological balance and threaten the livelihood of millions of small-scale fishers and fish farmers whose resilience and adaptive capacity are not adequately strong. Inland fisheries are extremely vulnerable to climate shocks up to the point that the inland community is exposed (Lynch et al., 2016). It can thus be seen that climate change exerts considerable influence on the inland fisheries of India in various contexts, from fish physiology and the dynamics of ecosystems to household income and regional food security.

Impacts of Climate Change on Inland Fisheries and Adaptation Strategies in India

Rising water temperatures: Water temperature can be a determining factor in the growth, metabolism, reproduction and survival of fish. Water temperature is a key factor affecting the metabolism, growth, reproduction and survivorship of fish. Over the last three decades, the temperature of the waters (encompassing numerous Indian rivers, reservoirs, and aquaculture ponds) has risen by around 1-2 C, which has affected aquatic ecosystems substantially (et al., 2007; IPCC, 2023). As with any chemical, higher temperatures lead to lower solubility of oxygen. Water bodies during summer often drop out in their dissolved oxygen concentrations below the 5 mg/L mark, and experience chronic physiological stress, increased feeding stress, lower reproductive capacity, and even mass mortalities of the fish (Boyd & Tucker, 2012). Amongst the fisher Asian Himalayas, the coldwater-adapted species such as the Golden Mahseer (*Tor putitora*) are suffering increasing threat from the rise in temperature levels, while warmwater and exotic species such as the Nile tilapia are extending their ranges, and thereby disturbing diverse local citizens and livelihoods (Das et al., 2021).

Changing rainfall patterns and water availability: Alterations in precipitation and water resources. Due to the role of climate change in altering monsoon patterns, monsoon rains are becoming more unpredictable, leading to extreme floods and extended periods of drought (IPCC 2023). Floods are identified as the cause of the destruction of pond dams, predation of eggs, larvae and young fish and damage to aquaculture infrastructure in a number of eastern Indian states (Handisyde et al., 2017). However, drought reduces the proportion of available water in reservoirs and constricts the size of aquatic habitats, with consequent overshoots, competitive exclusion and increased predation and cannibalism (Handisyde et al., 2017). Drought conditions result in a failure of productivity, leading to less investment in aquaculture development.

Disturbance of reproductive and migratory behaviour: Disruption of reproductive and migratory behaviour. Freshwater fish species in India depend on certain environmental triggers like temperature, flow of water, and duration of light in initiating their reproductive and migratory behaviour. However, alterations in climate triggers have adverse effects on their reproductive cycles and hatchling success (De Silva and Soto, 2009). Hilsa Shad, Rohu (Labeo rohita), is sensitive to alterations in river runoff. Destruction of the distributional range through filtering runoff may negatively impact the migration routes, and thus imperative species is threatened.

Decline in water quality and disease outbreaks: Increasing temperature and rich runoff into the water lead to increased eutrophication, and consequently, dangerous algal blooms. These blooms lead to a quick decline in dissolved oxygen, resulting in the death of the fish (Boyd & Tucker, 2012). Higher temperatures also result in an increase in water pathogens such as Aeromonas, which in turn leads to greater and more intense disease outbreaks and dependence on antibiotics and increased costs.

Adaptation and Mitigation Strategies for Climate-Resilient Inland Fisheries

Addressing the impacts of climate change on India's inland fisheries sector can occur by integrating technological advancements, environmental management practices and support systems to enhance adaptability and resilience. However, how these elements will interact is yet to be fully understood.

Farming climate-resistant fish varieties: Developing climate-resistant fish species. Agriculture strategies have focused on breeding fish that tolerate both high temperatures and low dissolved oxygen levels, such as Rohu and Pangasius (Gjedrem & Baranski, 2009). The adaptation of climate-resistant species helps sustain yields even under difficult environmental conditions. Polyculture of fish such as carp, shrimp, and Tilapia helps mitigate risk as there is species diversity.

Improved water and habitat management: Optimising water and habitat management. Low-cost practices such as rainwater harvesting, pond excluders and optimising water use provide sustainable supplies of water during dry spells (FAO, 2022). Restoration of floodplains and wetlands, especially around the Brahmaputra River, provides breeding and nursery habitats for fish.

Advanced aquaculture technologies: Integrating innovative aquaculture technologies. The adoption of technologies such as Biofloc technology (BFT) and Recirculating aquaculture systems (RAS) allows the reduction of water consumption and increased control over temperature and water quality parameters. These enable year-round fish production regardless of unfavourable climate conditions (Emerenciano et al., 2017).

Early warning and climate information services: Building climate and early warning information systems. A considerable support for the farmers is achieved when combined weather forecasts from the Indian Meteorological Bureau are disseminated using mobile advisory services such as Kisan Suvidha to advise on suitable periods for planting, harvesting and management practices. A fish-based integrated farming systems approach (e.g., integrating fish with ducks or rice) has the potential to maximise the resource use and income streams and enable adaptation when the climate has something unpleasant to offer.

Disease management and biosafety: Enhancing disease management and biosafety. Disease management and biosecurity aim at having a preventative approach. Increased use of probiotics, phytogetic immunostimulants, disease monitoring, and effective biosecurity measures are critical for reducing disease outbreaks when temperatures increase.

Policy support and capacity building: Strengthening policy support and capacity building. At the policy level, institutions such as the National Fisheries Development Board and Indian Council of Agricultural Research need to strengthen the promotion of climate-smart practices, provide risk management tools, and train and empower scientists and extension agents for collaborative efforts, enabling the smooth flow of adaptive measures to beneficiaries.

Conclusion

India's inland fisheries are now experiencing growing impacts of climate change. Climate change affects both water quality and fish health, as well as displacing biodiversity. Fish populations and catch are declining due to increasing temperatures and erratic, heavy rainfall, putting the lives of millions of fishermen and fish farmers at risk not only from their livelihoods but from the fact that they and many others are dependent upon fish to sustain them. The situation is not without hope, however. We can mitigate some of these effects if intelligent adaptation strategies are put into

practice on an appropriate time scale, such as breeding fish with greater climate tolerance, better management of the water resources and implementation of technologies such as Recirculating Aquaculture Systems or Biofloc. Complementary tools like early warning systems and insurance will also help. Collaboration between researchers, policymakers, advisors and the local communities will truly make a difference in ensuring the health and sustainability of inland fisheries.

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Rheological Behaviour of Foods and its Importance in Food Processing

Article ID: 74001

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Abstract

Rheology is the science that studies the flow and deformation behaviour of materials under applied stress. In food systems, rheological behaviour significantly influences texture, consistency, stability, processing characteristics, and consumer acceptance. Most food materials exhibit complex rheological properties due to their heterogeneous composition and structural organization. Understanding food rheology is essential for optimizing food processing operations such as mixing, pumping, extrusion, heating, cooling, filling, and storage. Rheological parameters including viscosity, elasticity, viscoelasticity, and yield stress are widely used for quality evaluation and process design. Rheological studies are extensively applied in dairy, bakery, beverage, confectionery, meat, and fruit-processing industries. Modern rheological analysis also supports development of functional foods, plant-based products, and novel food structures. This article discusses the rheological behavior of foods, major rheological properties, measurement techniques, industrial applications, and their importance in food processing and quality control.

Keywords: Rheology, Food processing, Viscosity, Texture, Viscoelasticity, Flow behavior, Food quality.

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Introduction

Rheology is derived from the Greek words *rheo* meaning “flow” and *logos* meaning “study.” It is defined as the science of deformation and flow of matter under applied forces (Rao, 2014). In food science, rheology plays an important role because food materials exist in various forms including liquids, semi-solids, gels, emulsions, suspensions, foams, and viscoelastic materials. The rheological behaviour of food affects its processing performance, sensory characteristics, texture, appearance, stability, and consumer acceptability (Steffe, 1996).

The food industry increasingly depends on rheological analysis for designing processing equipment, improving quality control, and optimizing product formulation. Parameters such as viscosity, consistency, elasticity, and yield stress are important for evaluating food behaviour during processing and storage (Singh and Heldman, 2014). Texture attributes such as creaminess, smoothness, chewiness, and spread ability are closely associated with rheological properties.

Understanding rheological behaviour is also important in modern food product development, especially for functional foods, low-fat products, plant-based alternatives, and 3D food printing technologies (Tabilo-Munizaga and Barbosa-Cánovas, 2005).

Fundamentals of Food Rheology

1. Viscosity: Viscosity is the internal resistance of a fluid to flow and is one of the most important rheological parameters in food processing (Steffe, 1996). It influences pumping, heat transfer, filling operations, mixing efficiency, and sensory perception.

For example:

- High viscosity improves suspension stability in sauces.
- Beverage viscosity affects mouthfeel and drinking quality.
- Dough viscosity influences baking performance.

2. Elasticity and Viscoelasticity: Many food materials exhibit both viscous and elastic characteristics and are therefore termed viscoelastic materials. Dough, cheese, gels, meat emulsions, and confectionery products show viscoelastic behaviour (Fellows, 2017).

Elasticity determines the ability of a material to recover its shape after deformation, while viscosity reflects flow resistance.

3. Yield Stress: Yield stress refers to the minimum force required to initiate flow in a material. Foods such as chocolate, ketchup, and mayonnaise exhibit yield stress behavior. Yield stress is important for designing pumps, pipelines, and packaging systems.

4. Texture and Consistency: Texture is one of the most critical quality attributes influencing consumer acceptance. Rheological analysis helps evaluate texture parameters such as firmness, smoothness, spreadability, chewiness, and cohesiveness.

Importance of Rheology in Food Processing

1. Equipment Design and Process Optimization: Rheological properties are essential for designing food processing equipment including pumps, mixers, heat exchangers, extruders, evaporators, and pipelines (Singh and Heldman, 2014). Knowledge of flow behaviour helps optimize processing efficiency and reduce energy consumption.

For example:

- Pump performance depends on fluid viscosity.
- Heat transfer rates are influenced by food consistency.
- Extrusion quality depends on dough rheology.

2. Quality Control and Product Consistency: Rheology is widely used for quality assurance in food industries. Rheological measurements help maintain batch-to-batch consistency and desired product quality (Rao, 2014).

Examples include:

- Viscosity control in ketchup and beverages.
- Gel strength evaluation in yogurt and cheese.
- Dough consistency monitoring in bakery products.

3. Texture and Sensory Evaluation: Consumer perception of foods is highly dependent on texture and mouthfeel. Rheological studies provide objective measurements that correlate with sensory evaluation (Steffe, 1996).

Creaminess in ice cream, smoothness in yogurt, thickness in soups, and spreadability in butter are directly related to rheological properties.

4. Shelf Stability and Storage: Rheological behavior significantly influences food stability during storage. Sedimentation, syneresis, phase separation, and crystallization are affected by viscosity and viscoelasticity (Fellows, 2017). Hydrocolloids and stabilizers are commonly used to improve rheological stability and extend shelf life.

5. Heat and Mass Transfer Operations: Food rheology affects heat transfer during pasteurization, sterilization, drying, and evaporation processes. Highly viscous foods generally show lower heat transfer coefficients, affecting processing time and efficiency.

Rheological Measurement Techniques

1. Viscometers: Viscometers are used to determine viscosity of liquid foods. Rotational and capillary viscometers are widely applied in food industries.

2. Rheometers: Rheometers are advanced instruments used to measure viscoelastic properties, yield stress, and dynamic rheological behavior.

3. Texture Analyzers: Texture analyzers measure mechanical properties such as hardness, cohesiveness, adhesiveness, and chewiness, which are closely related to rheological behavior.

Applications of Rheology in Food Industries

1. Dairy Industry: Rheology is important in milk, yogurt, cheese, and ice cream processing. Viscosity and gel strength influence texture, stability, and consumer acceptance.

2. Bakery Industry: Dough rheology determines bread quality, loaf volume, texture, and gas retention properties.

3. Fruit and Vegetable Processing: Consistency and flow properties are critical in ketchup, jam, puree, sauce, and juice processing.

4. Confectionery Industry: Chocolate flow behavior, candy texture, and syrup consistency are controlled through rheological analysis.

5. Meat and Seafood Products: Rheological properties influence texture, emulsification, and gel formation in processed meat products.

Table 1: Applications of Rheology in Various Food Industry Sectors and Their Significance

Food Sector	Industry	Rheological Property Studied	Application	Importance/Benefit
Dairy Industry		Viscosity, Elasticity, Gel Strength	Evaluation of milk, yogurt, cheese, ice cream, and dairy desserts	Ensures desired texture, consistency, and consumer acceptability
Bakery Industry		Dough Viscoelasticity, Extensibility	Assessment of dough handling, proofing, and baking performance	Improves bread volume, crumb structure, and product quality

Beverage Industry	Flow Behavior, Viscosity	Characterization of fruit juices, smoothies, syrups, and functional beverages	Enhances processing efficiency and mouthfeel
Confectionery Industry	Yield Stress, Viscosity	Processing of chocolates, candies, and caramel products	Controls coating, molding, and texture development
Sauce and Dressing Industry	Shear-Thinning Behavior, Consistency	Formulation of ketchup, mayonnaise, salad dressings, and gravies	Provides stability, pourability, and consumer satisfaction
Meat and Poultry Industry	Texture, Elasticity, Firmness	Quality assessment of processed meats, sausages, and meat emulsions	Improves product structure and sensory characteristics
Fruit and Vegetable Processing	Viscosity, Pulp Consistency	Processing of purees, pastes, jams, and concentrates	Optimizes pumping, mixing, and packaging operations
Frozen Food Industry	Viscoelastic Properties, Ice Crystal Effects	Evaluation of frozen desserts and ready-to-eat foods	Maintains texture and stability during storage
Cereal and Grain Products	Pasting Properties, Gelatinization Behavior	Analysis of flour, starch, noodles, and breakfast cereals	Supports product development and process optimization
Food Emulsion Industry	Emulsion Stability, Yield Stress	Production of cream, mayonnaise, dressings, and spreads	Prevents phase separation and enhances shelf life
Extrusion Processing	Melt Rheology, Flow Characteristics	Manufacturing of snacks, pasta, and textured proteins	Improves expansion, shape retention, and product uniformity
Infant and Clinical Nutrition Foods	Viscosity and Flow Properties	Formulation of liquid and semi-solid nutritional products	Ensures ease of consumption and nutrient delivery
Packaging and Filling Operations	Flow Behavior, Yield Stress	Design of pumping, mixing, and filling systems	Enhances production efficiency and reduces processing losses
Functional and Novel Foods	Viscoelasticity, Texture Profile	Development of plant-based foods and fortified products	Improves sensory quality and consumer acceptance

Conclusion

Rheological behavior plays a vital role in food processing, product development, quality control, and sensory evaluation. Rheological properties such as viscosity, elasticity, viscoelasticity, and yield stress significantly influence processing operations, equipment design, texture, storage stability, and consumer acceptance. Understanding food rheology enables food industries to optimize manufacturing operations, improve product consistency, and develop innovative food products with desirable texture and functionality. With growing demand for high-quality and functional foods, rheology will continue to remain an essential aspect of modern food science and technology.

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Extraction of Natural Colorants from Food Waste: Sustainable Approaches, Technologies, and Applications

Article ID: 74002

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Abstract

The growing demand for clean-label foods and sustainable processing has increased interest in natural colorants derived from food waste. Food processing by-products such as fruit peels, pomace, vegetable trimmings, and seeds are rich in bioactive pigments including anthocyanins, carotenoids, betalains, chlorophylls, and curcuminoids. Recovery of these pigments supports waste valorization, environmental sustainability, and circular bioeconomy. Various extraction methods such as solvent extraction, ultrasound-assisted extraction, microwave-assisted extraction, enzyme-assisted extraction, supercritical fluid extraction, and pulsed electric field extraction are used for efficient pigment recovery. The stability of natural colorants is influenced by factors such as pH, temperature, oxygen, light, and storage conditions. Encapsulation technologies further improve pigment stability and bioavailability. Natural colorants from food waste have wide applications in food, pharmaceutical, cosmetic, textile, and nutraceutical industries.

Keywords: Natural colorants, Food waste valorization, Anthocyanins, Carotenoids, Green extraction, Circular economy, Bioactive pigments.

Acknowledgement

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Introduction

Color is a key quality attribute influencing consumer acceptance of foods and beverages (Martins et al., 2016). Although synthetic colorants are widely used due to their stability and low cost, concerns regarding their health and environmental impacts have increased demand for natural alternatives (Rodriguez-Amaya, 2016). Food processing wastes such as fruit peels, pomace, seed coats, and vegetable residues are rich sources of natural pigments including anthocyanins, carotenoids, betalains, and chlorophylls (Pathak et al., 2017). Recovery of these pigments supports waste valorization and environmental sustainability (Singh et al., 2020). Advanced green extraction methods such as ultrasound-assisted, microwave-assisted, enzyme-assisted, and supercritical fluid extraction improve pigment recovery while reducing environmental impact (Chemat et al., 2017; Saini and Keum, 2018). Modern stabilization techniques like microencapsulation further enhance pigment stability and shelf life.

Types of Natural Colorants Present in Food Waste

1. Anthocyanins: Anthocyanins are water-soluble pigments responsible for red, blue, and purple colors in fruits and vegetables (Khoo et al., 2017). They are commonly found in grape pomace, berry residues, purple cabbage waste, and black rice bran. These pigments possess strong antioxidant properties and are sensitive to pH, temperature, oxygen, and light. Anthocyanins are widely used in beverages, confectionery, and dairy products.

2. Carotenoids: Carotenoids are lipid-soluble pigments that produce yellow, orange, and red colors (Rodriguez-Amaya, 2016). Major sources include tomato peels, carrot pomace, pumpkin residues, and mango peels. Important carotenoids such as β -carotene and lycopene exhibit antioxidant activity and are extensively used in food products. Their extraction commonly involves non-polar solvents (Saini and Keum, 2018).

3. Betalains: Betalains are pigments mainly obtained from beetroot and cactus pear wastes. They include red-violet betacyanins and yellow betaxanthins. Beetroot pomace is a major source of betalains, which are increasingly used as natural alternatives to synthetic red dyes.

4. Chlorophylls: Chlorophyll pigments provide green coloration and are recovered from spinach waste, broccoli leaves, pea pods, and other leafy residues. Although nutritionally valuable, chlorophylls are unstable under acidic conditions and high temperatures.

5. Curcuminoids and Other Pigments: Turmeric residues contain curcuminoids with bright yellow color and antioxidant properties. Onion skins and pomegranate peels also contain valuable pigment compounds suitable for food and pharmaceutical applications (Gullón et al., 2016).

Sources of Food Waste for Natural Colorant Extraction

1. Fruit Processing Waste: Fruit processing wastes such as peels, pomace, seeds, and pulp residues are rich in natural pigments. Grape pomace contains anthocyanins, while mango and citrus peels are rich in carotenoids and polyphenols (Pathak et al., 2017).

2. Vegetable Processing Waste: Vegetable wastes including carrot peels, beetroot pomace, spinach stems, and tomato skins are important sources of natural pigments. Tomato peels are particularly rich in lycopene, while beetroot pomace contains betalains.

3. Cereal and Pulse By-products: Colored cereal brans and pulse husks contain anthocyanins, carotenoids, tannins, and polyphenols. Black rice bran, purple corn bran, sorghum bran, chickpea seed coats, and kidney bean husks are widely explored for functional food and natural colorant applications.

4. Agro-industrial By-products: Tea waste, coffee husk, cocoa shells, and flower residues also contain bioactive pigments and antioxidants suitable for natural dye production (Mussatto et al., 2012).

Extraction Techniques for Natural Colorants

1. Conventional Solvent Extraction: Conventional solvent extraction is one of the most commonly used methods for pigment recovery. The process involves mixing food waste material with suitable solvents under controlled temperature and agitation conditions. Advantages of solvent extraction include simplicity, low equipment cost, and ease of operation. However, disadvantages include high solvent consumption, longer extraction time, and possible degradation of heat-sensitive pigments.

2. Ultrasound-Assisted Extraction (UAE): Ultrasound-assisted extraction utilizes ultrasonic waves to disrupt plant cell walls and enhance mass transfer (Chemat et al., 2017). Cavitation generated during ultrasound treatment improves solvent penetration and pigment release.

UAE offers several advantages including shorter extraction time, reduced solvent usage, improved extraction yield, and lower processing temperature. This technique is widely used for extraction of anthocyanins, carotenoids, and phenolic compounds (Tiwari and Mason, 2012).

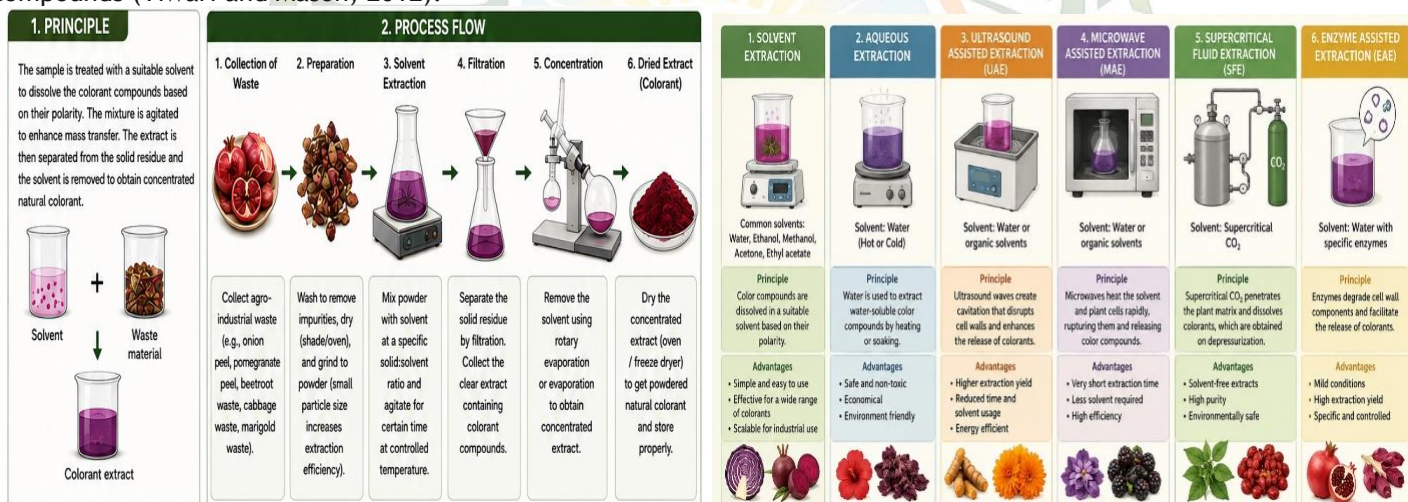


Fig 1: Conventional and Modern Extraction Techniques for Natural Colorants

3. Microwave-Assisted Extraction (MAE): Microwave-assisted extraction uses microwave energy to rapidly heat the sample-solvent mixture (Saini and Keum, 2018). The process enhances cell rupture and improves extraction efficiency.

MAE significantly reduces extraction time and energy consumption. However, optimization of microwave power and exposure time is necessary to prevent pigment degradation.

4. Enzyme-Assisted Extraction (EAE): Enzyme-assisted extraction employs enzymes such as cellulase, pectinase, and hemicellulase to degrade plant cell wall components and release intracellular pigments. EAE is considered environmentally friendly and highly effective for extraction from fruit peels and pomace. The technique improves extraction yield while preserving pigment quality.

5. Supercritical Fluid Extraction (SFE): Supercritical fluid extraction commonly uses supercritical carbon dioxide as the extraction medium. The technique is especially effective for extraction of non-polar pigments such as carotenoids. SFE offers advantages including solvent-free extracts, high purity, and minimal thermal degradation. However, high equipment cost limits its widespread industrial adoption.

6. Pulsed Electric Field (PEF) Extraction: Pulsed electric field treatment enhances pigment extraction by increasing cell membrane permeability. PEF is considered an emerging non-thermal technology with promising industrial applications.

Factors Affecting Stability of Natural Colorants

Natural pigments are generally less stable than synthetic colorants. Several environmental and processing factors influence pigment stability.

- 1. Temperature:** High temperatures accelerate pigment degradation, particularly for anthocyanins and betalains. Thermal processing may lead to color fading and loss of antioxidant activity.
- 2. pH:** Anthocyanins are highly sensitive to pH changes (Khoo et al., 2017). Acidic conditions stabilize red coloration, whereas alkaline conditions may result in pigment degradation.
- 3. Light and Oxygen:** Exposure to light and oxygen promotes oxidation and degradation of natural pigments. Packaging materials with oxygen and light barriers are therefore important for improving stability.
- 4. Water Activity:** Water activity significantly affects storage stability of natural pigments. Lower moisture levels generally improve shelf life.
- 5. Encapsulation:** Microencapsulation and nanoencapsulation techniques improve pigment stability by protecting colorants from environmental stress. Encapsulated pigments show improved storage stability, bioavailability, and controlled release properties.

Applications of Natural Colorants

1. Food Industry: Natural colorants are extensively used in beverages, dairy products, confectionery, bakery products, snacks, sauces, jams, and functional foods (Yusuf et al., 2017). Consumers increasingly prefer clean-label products containing naturally derived ingredients.

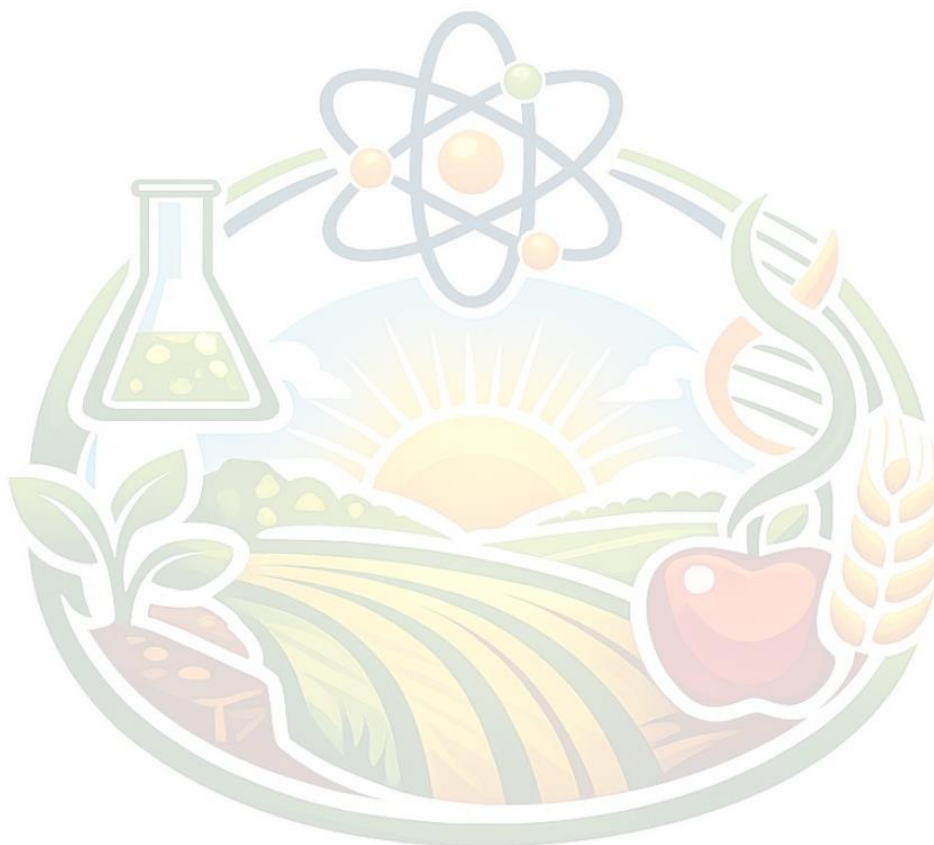
Anthocyanins are used in beverages and candies, carotenoids in dairy and bakery products, betalains in yogurts and desserts, and chlorophylls in sauces and health drinks.

- 2. Pharmaceutical Industry:** Natural pigments possess antioxidant, anti-inflammatory, antimicrobial, and anticancer properties (Giampieri et al., 2018). These bioactivities make them suitable for nutraceutical and pharmaceutical formulations.
- 3. Cosmetic Industry:** Natural pigments are increasingly utilized in lipsticks, creams, soaps, shampoos, and skincare products due to consumer preference for plant-based ingredients.
- 4. Textile Industry:** Food waste-derived pigments are also explored as eco-friendly textile dyes. Natural dyes reduce environmental pollution associated with synthetic textile colorants (Yusuf et al., 2017).

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Biochar Application in Agriculture: Impacts on Soil Health and Crop Yield

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Abstract

Biochar is a carbon-rich material produced through the pyrolysis of biomass under limited oxygen conditions. In recent years, biochar has gained significant attention as a sustainable soil amendment due to its ability to improve soil health, enhance crop productivity, and contribute to climate change mitigation through carbon sequestration. Biochar application influences soil physical, chemical, and biological properties, leading to improved nutrient availability, water retention, microbial activity, and crop growth. This article reviews the effects of biochar on soil health and crop yield and discusses its potential role in sustainable agriculture.

Keywords: Biochar, Soil Health, Crop Yield, Carbon Sequestration, Sustainable Agriculture, Soil Fertility.

Introduction

The increasing demand for food production, coupled with declining soil fertility and climate change challenges, necessitates the adoption of sustainable agricultural practices. Continuous cultivation, excessive fertilizer use, and soil degradation have negatively impacted agricultural productivity worldwide. Biochar has emerged as a promising soil amendment that can enhance soil quality while providing environmental benefits.

Biochar is produced from organic materials such as crop residues, wood chips, animal manure, and agricultural waste through pyrolysis at temperatures ranging from 300-700°C. Due to its porous structure and high carbon content, biochar can improve soil properties and promote sustainable crop production.

Production and Characteristics of Biochar

1. Feedstocks Used for Biochar Production:

- Crop residues (rice husk, wheat straw, maize stalks)
- Wood waste and sawdust
- Animal manure
- Sugarcane bagasse
- Coconut shells
- Forestry residues

2. Important Characteristics:

- High carbon content
- Large surface area
- High porosity
- Low bulk density
- High water-holding capacity
- Enhanced cation exchange capacity (CEC)

Impact of Biochar on Soil Health

1. Improvement in Soil Physical Properties

- Soil Structure:** Biochar enhances soil aggregation and improves soil structure, leading to better root development and aeration.
- Water Retention:** The porous nature of biochar increases soil water-holding capacity, particularly in sandy soils.
- Bulk Density:** Biochar reduces soil bulk density and improves soil porosity, facilitating root penetration.

2. Improvement in Soil Chemical Properties

- Nutrient Availability:** Biochar helps retain essential nutrients such as: Nitrogen (N) Phosphorus (P) Potassium (K) Calcium (Ca) Magnesium (Mg)
- Soil pH Regulation:** Biochar generally has an alkaline nature and can help neutralize acidic soils.
- Cation Exchange Capacity (CEC):** Biochar increases CEC, improving nutrient retention and reducing nutrient leaching.

3. Enhancement of Soil Biological Properties

- Microbial Activity:** Biochar provides habitat for beneficial soil microorganisms and stimulates microbial diversity.

b. Enzyme Activity: Studies have reported increased enzyme activities involved in nutrient cycling after biochar application.

c. Earthworm Population: Improved soil conditions often support greater earthworm abundance and activity.

Effects of Biochar on Crop Yield

1. Direct Effects:

- Enhanced nutrient uptake
- Improved root growth
- Better water availability
- Reduced plant stress

2. Indirect Effects:

- Improved soil fertility
- Increased microbial activity
- Reduced nutrient losses

Yield Improvements in Various Crops:

Crop	Yield Increase (%)
Rice	10-30
Wheat	8-25
Maize	10-35
Soybean	12-28
Vegetables	15-40

Yield response varies depending on soil type, biochar source, crop species, and environmental conditions.

Table: Effects of Biochar Application on Soil Health and Crop Yield:

Study	Feedstock Source	Soil Type	Crop	Biochar Rate (t ha ⁻¹)	Major Findings
Major et al. (2010)	Wood waste	Oxisol	Maize	8-20	Increased maize yield by 28% over four years and improved soil fertility.
Agegnehu et al. (2016)	Eucalyptus wood	Nitisol	Wheat	10	Increased grain yield by 22% and improved soil organic carbon.
Liu et al. (2013)	Crop residues	Paddy soil	Rice	20	Increased rice yield and reduced methane emissions.
Biederman and Harpole (2013)	Various feedstocks	Multiple soils	Various crops	5-50	Meta-analysis showed average crop productivity increase of 11%.
Jeffery et al. (2017)	Various feedstocks	Global dataset	Various crops	Variable	Yield increase averaged 13% in degraded soils.
Steiner et al. (2007)	Charcoal + fertilizer	Tropical soil	Rice and Sorghum	11	Improved nutrient-use efficiency and crop productivity.
Glaser et al. (2002)	Charcoal	Highly weathered tropical soil	Various crops	10-100	Improved soil fertility and nutrient retention.
Uzoma et al. (2011)	Cow manure biochar	Sandy loam	Maize	10-30	Increased water retention and crop yield.
Vaccari et al. (2011)	Wood biochar	Mediterranean soil	Wheat	30	Increased wheat biomass and soil carbon content.
Laird et al. (2010)	Corn stover biochar	Mollisol	Maize	5-20	Improved soil water-holding capacity and nutrient retention.

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Biochar and Climate Change Mitigation

Carbon Sequestration: Biochar is highly stable and can remain in soil for hundreds to thousands of years, effectively storing carbon and reducing atmospheric CO₂ levels.

Reduction of Greenhouse Gas Emissions

Biochar application has been shown to:

- Reduce nitrous oxide (N₂O) emissions
- Lower methane (CH₄) emissions in flooded rice fields
- Improve fertilizer-use efficiency

Challenges and Limitations:

- High Production Cost:** Large-scale biochar production requires investment in pyrolysis technology.
- Variable Quality:** Biochar properties vary depending on feedstock and production conditions.
- Limited Farmer Awareness:** Adoption remains low in many developing countries due to lack of knowledge and technical support.
- Site-Specific Responses:** Biochar effectiveness varies according to soil type, climate, and crop management practices.

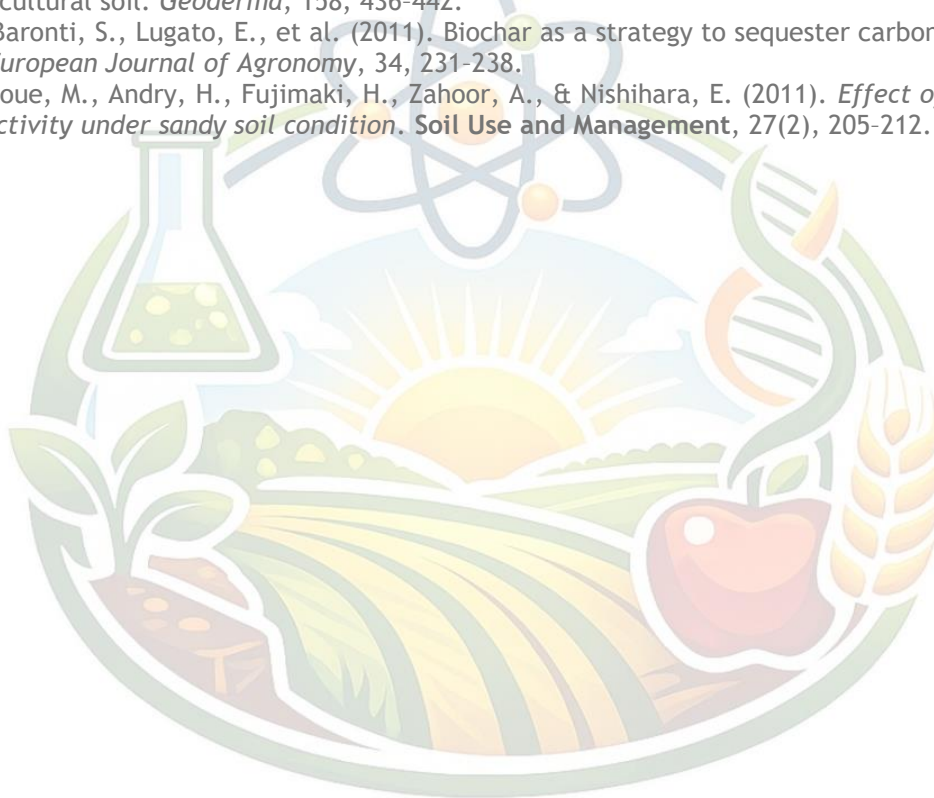
Conclusion

Biochar represents a promising tool for sustainable agriculture by improving soil physical, chemical, and biological properties. Its application enhances nutrient retention, water-holding capacity, microbial activity, and crop productivity while contributing to carbon sequestration and climate change mitigation. Although challenges related to production cost and variability exist, continued research and technological advancements can facilitate wider adoption. Integrating biochar into soil management practices offers significant potential for improving soil health, increasing crop yields, and promoting long-term agricultural sustainability.

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Greenhouse Technology: Advancing Modern Agriculture

Article ID: 74004

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Abstract

Greenhouse technology has emerged as a pivotal innovation in modern agriculture, offering solutions for sustainable crop production, climate resilience, and efficient resource utilization. By providing a controlled environment for plant growth, greenhouses enable higher yields, year-round cultivation, and optimized management of water, nutrients, and energy. This article presents a comprehensive review of greenhouse technology, examining its types, environmental controls, advantages, limitations, recent innovations, and future prospects in the context of sustainable agriculture.

Introduction

Agriculture faces unprecedented challenges in the twenty-first century, including climate variability, land scarcity, and increasing global food demand. Traditional farming methods are often constrained by seasonal fluctuations and environmental uncertainties, leading to inconsistent yields. Greenhouse technology addresses these challenges by offering a controlled environment that mitigates the effects of adverse weather and optimizes conditions for plant growth.

A greenhouse, defined as a structure enclosed with transparent or translucent materials, functions to regulate internal temperature, light intensity, humidity, and carbon dioxide concentration. Historically, rudimentary greenhouses date back to Roman horticulture, but contemporary greenhouse systems integrate advanced engineering and automation to maximize productivity. By providing a stable environment, greenhouses support intensive cultivation of high-value crops such as vegetables, flowers, and medicinal plants.

Types of Greenhouses

Greenhouse designs vary according to climatic conditions, crop requirements, and economic considerations.

- 1. Glass Greenhouses:** Glass greenhouses are characterized by high light transmission and structural durability. They are particularly suitable for regions with high solar radiation, allowing maximal photosynthetic efficiency. However, glass structures are associated with higher initial investment and maintenance costs.
- 2. Polyethylene Film Greenhouses:** These structures utilize plastic films as covering material. They are lightweight, cost-effective, and flexible in design. Polyethylene film greenhouses are widely adopted for small and medium-scale farming, although films require periodic replacement due to wear and UV degradation.
- 3. Polycarbonate or Plastic Greenhouses:** Polycarbonate panels combine durability with good thermal insulation. Such greenhouses provide moderate cost options and can maintain internal temperatures effectively, reducing energy demand for heating.
- 4. High-Tech Greenhouses:** High-tech or “smart” greenhouses incorporate advanced technologies including sensors, automated climate control systems, and precision irrigation. Integration with artificial intelligence (AI) and the Internet of Things (IoT) allows real-time monitoring and optimization of environmental parameters, enabling highly efficient and resource-conserving crop production.

Environmental Control in Greenhouses

The primary advantage of greenhouses lies in the ability to manipulate environmental factors critical to plant growth.

- 1. Temperature Control:** Greenhouse heating systems, cooling pads, and ventilation mechanisms help maintain optimal temperatures for various crops, mitigating the effects of external weather fluctuations.
- 2. Light Management:** Supplemental lighting, particularly LEDs, can enhance photosynthesis and extend photoperiods, improving growth rates and crop quality.
- 3. Humidity Regulation:** Fogging systems and dehumidifiers maintain appropriate moisture levels, reducing fungal disease incidence and enhancing plant metabolism.
- 4. CO₂ Enrichment:** Increasing carbon dioxide concentration inside the greenhouse accelerates photosynthesis, resulting in higher biomass accumulation and yields.
- 5. Soil and Nutrient Management:** Modern greenhouses often integrate hydroponic, aeroponic, or fertigation systems, enabling precise nutrient delivery while minimizing waste and soil degradation.

Advantages of Greenhouse Farming

Greenhouse technology offers numerous benefits that enhance agricultural productivity and sustainability:

- 1. Increased Yield:** Controlled environmental conditions minimize plant stress, thereby improving productivity per unit area.
- 2. Extended Growing Season:** Year-round cultivation becomes feasible regardless of climatic limitations, enabling multiple crop cycles.
- 3. Resource Efficiency:** Precision management reduces water and fertilizer usage, contributing to sustainable farming practices.
- 4. Pest and Disease Management:** Physical barriers and controlled conditions reduce exposure to pests, while integrated pest management can further enhance crop protection.
- 5. Crop Diversification:** Greenhouses facilitate the cultivation of high-value or off-season crops, providing farmers with new economic opportunities.

Challenges and Limitations

Despite the advantages, greenhouse farming faces several challenges:

- 1. High Capital Investment:** Initial construction, climate control systems, and automation equipment require significant financial resources.
- 2. Energy Consumption:** Heating, cooling, and lighting systems can result in high energy demand, necessitating the use of renewable energy sources for sustainability.
- 3. Technical Expertise:** Effective greenhouse management requires knowledge of crop physiology, environmental monitoring, and system maintenance.
- 4. Environmental Considerations:** Dependence on non-renewable energy or excessive plastic use can contribute to environmental degradation if not properly managed.

Recent Innovations in Greenhouse Technology

Advances in technology are continuously improving greenhouse efficiency and sustainability:

- 1. Smart Greenhouses:** Integration of IoT sensors, automated climate control, and AI algorithms allows real-time optimization of environmental factors, increasing productivity while reducing labor requirements.
- 2. Soilless Cultivation:** Hydroponics and aeroponics facilitate soil-less crop production, conserving water and eliminating soil-borne diseases.
- 3. Renewable Energy Integration:** Solar panels, geothermal heating, and biomass energy reduce reliance on fossil fuels.
- 4. LED Spectrum Lighting:** Tailored light spectra optimize photosynthesis at various crop growth stages, enhancing both yield and quality.

Case Studies

- 1. Netherlands:** Known for high-tech greenhouse vegetables, combining advanced climate control with precision irrigation and automation to maximize yield in limited land areas.
- 2. India:** Low-cost polyhouse technology has enabled small farmers to grow vegetables and flowers year-round, improving income and food security.
- 3. Israel:** Precision greenhouse technology addresses water scarcity, employing drip irrigation, sensors, and controlled environments for sustainable cultivation in arid regions.

Future Prospects

The future of greenhouse technology is closely linked to sustainability, urban agriculture, and technological innovation:

- 1. Integration with Vertical Farming:** Urban greenhouses can combine vertical farming techniques to maximize space efficiency.
- 2. Climate-Resilient Crops:** Development of crops specifically adapted to controlled environments will further enhance productivity.
- 3. Artificial Intelligence and Robotics:** Predictive analytics, automated monitoring, and robotic harvesting will reduce labor dependency and improve resource efficiency.

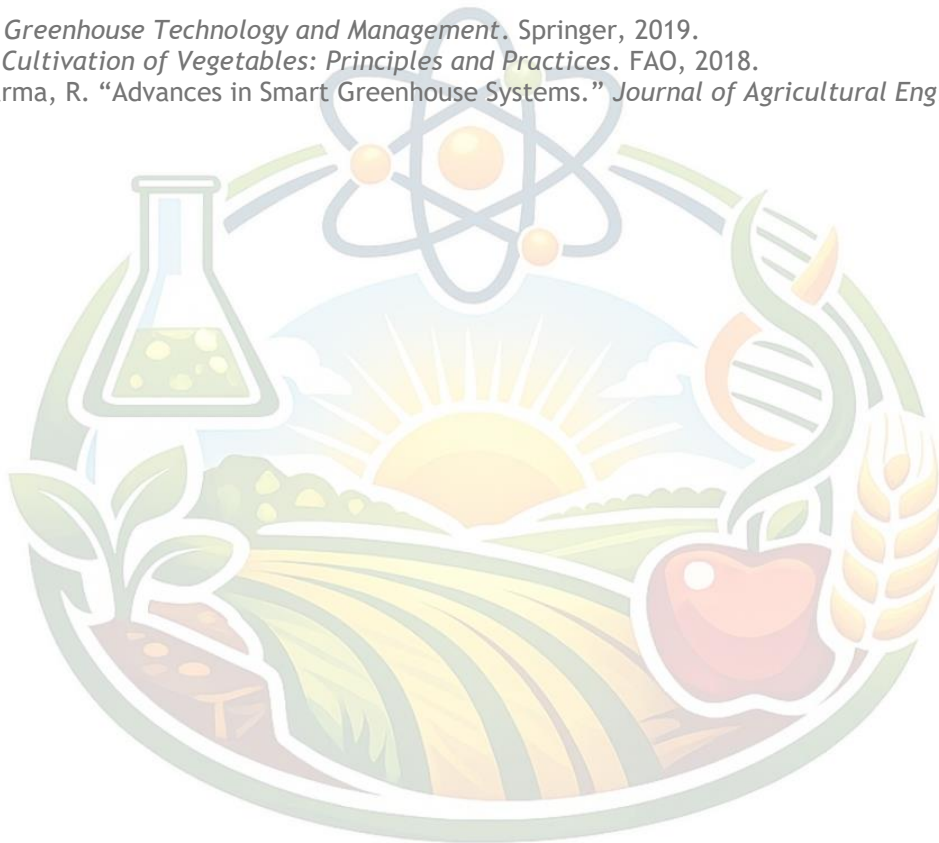
4. Circular Economy Practices: Reuse of water, recycling of plastic coverings, and renewable energy utilization will reduce environmental impact.

Conclusion

Greenhouse technology represents a transformative approach to modern agriculture, providing solutions for food security, resource efficiency, and climate resilience. By leveraging controlled environments, automation, and advanced cultivation techniques, greenhouses enable high-yield, year-round production while mitigating the risks associated with traditional farming. Continued innovation and integration with renewable energy, smart systems, and sustainable practices will ensure that greenhouse farming remains a key driver of agricultural progress in the coming decades.

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Small-Scale Processing & Value Addition of Medicinal Plants

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Introduction

Medicinal plants have been an essential part of human healthcare systems for centuries, forming the backbone of traditional practices such as Ayurveda, Unani, and Siddha. In recent years, the global demand for herbal and natural products has increased significantly due to growing awareness of their therapeutic benefits and fewer side effects.

However, most medicinal plants are sold in raw form, which often results in low economic returns for farmers and collectors. Raw materials are also highly perishable and prone to quality deterioration due to improper handling, storage, and transportation.

Small-scale processing refers to the conversion of raw medicinal plant materials into semi-processed or finished products using simple, low-cost techniques. These processes include cleaning, drying, grinding, extraction, and packaging. When these activities are combined with value addition, the economic worth of the plant materials increases significantly.

Value addition involves transforming raw herbs into products such as powders, extracts, essential oils, herbal teas, and formulations that are more convenient, stable, and marketable. This not only enhances the shelf life and quality of the products but also opens up new opportunities for income generation and entrepreneurship, especially in rural areas.

Small-scale processing and value addition play a crucial role in:

- Reducing post-harvest losses
- Improving product quality and safety
- Increasing farmers' income
- Promoting sustainable use of medicinal plant resources

Thus, developing skills and knowledge in this area can empower farmers, self-help groups (SHGs), and rural entrepreneurs to participate in the rapidly growing herbal industry and contribute to both economic development and healthcare systems.

Importance of Small-Scale Processing

Small-scale processing of medicinal plants plays a vital role in improving the economic, social, and practical value of herbal resources, especially for farmers, self-help groups (SHGs), and rural entrepreneurs.

1. Increases Income:

- Raw medicinal plants have low market value
- Processing (drying, powdering, extraction) significantly increases price
- Enables farmers to earn more from the same produce.

2. Reduces Post-Harvest Losses:

- Fresh plant materials are highly perishable
- Processing (especially drying) prevents spoilage
- Minimizes losses due to moisture, pests, and microbial growth

3. Enhances Shelf Life:

- Properly processed products can be stored longer
- Reduces wastage and allows year-round availability

4. Improves Quality and Safety:

- Cleaning and proper handling remove contaminants
- Controlled processing preserves active ingredients
- Ensures better medicinal effectiveness

5. Generates Employment:

- Creates jobs in rural areas
- Involves activities like sorting, drying, grinding, packaging
- Encourages participation of women and SHGs

6. Promotes Rural Entrepreneurship:

- Low investment and simple technologies required
- Suitable for small businesses and startups

c. Supports local herbal industries

7. Adds Value to Raw Materials:

- a. Converts raw herbs into:
 - i. Powders
 - ii. Extracts
 - iii. Herbal teas
 - iv. Oils
- b. Value-added products fetch higher market prices

8. Supports Traditional Healthcare Systems:

- a. Ensures availability of quality raw materials for systems like Ayurveda
- b. Maintains medicinal properties through proper processing

9. Expands Market Opportunities

- a. Processed products are easier to transport and sell
- b. Access to local, national, and export markets

10. Encourages Sustainable Use:

- a. Reduces waste of plant resources
- b. Promotes efficient utilization of medicinal plants

Stages in Processing of Medicinal Plants

1. Collection & Harvesting:

- a. The stage of maturity at which medicinal plants are harvested plays a crucial role in determining their quality, potency, and therapeutic effectiveness. Medicinal plants contain active compounds (phytochemicals) that vary in concentration during different stages of growth. Harvesting at the correct stage ensures that these bioactive constituents are present in their maximum concentration.
- b. If plants are harvested too early, they may lack sufficient active ingredients, while over-mature plants may show reduced potency or degradation of compounds. Therefore, understanding the right maturity stage—whether it is leaves, roots, flowers, seeds, or bark—is essential for maintaining the efficacy and market value of medicinal plant products.
- c. Proper timing of harvest not only improves product quality and shelf life but also enhances the overall success of small-scale processing and value addition.

2. Cleaning & Sorting: Cleaning and sorting are essential preliminary steps in the processing of medicinal plants, ensuring the quality, safety, and purity of the final product. After harvesting, plant materials often contain unwanted substances such as soil, dust, insects, stones, and other foreign matter that can affect their medicinal value.

Cleaning involves the removal of these impurities using methods such as washing, brushing, or manual picking, depending on the type of plant material. Sorting is the process of separating healthy, usable plant parts from damaged, diseased, or inferior materials, as well as grading them based on size, color, and quality.

Proper cleaning and sorting help to:

- a. Prevent contamination and microbial growth
- b. Maintain the active medicinal constituents
- c. Improve the appearance and market acceptability
- d. Ensure compliance with quality standards

These steps form the foundation for further processing like drying, grinding, and extraction, making them critical for successful small-scale processing and value addition of medicinal plants.

3. Drying: Drying is one of the most important steps in the processing of medicinal plants, as it directly affects the quality, shelf life, and medicinal value of the final product. Freshly harvested plant materials contain high moisture, which can lead to spoilage, microbial growth, and loss of active compounds if not properly dried.

The main objective of drying is to reduce moisture content to a safe level, preventing deterioration while preserving the plant's color, aroma, and bioactive constituents. Proper drying ensures that medicinal plants retain their therapeutic properties and remain suitable for storage and further processing.

Different drying methods are used depending on the type of plant material:

- a. **Shade drying:** Protects sensitive compounds and is commonly used
- b. **Sun drying:** Simple and cost-effective
- c. **Mechanical drying:** Faster and more controlled

Improper drying, such as excessive heat or prolonged exposure to sunlight, can cause loss of essential oils, discoloration, and reduced potency. Therefore, adopting appropriate drying techniques is critical for maintaining high-quality value-added products in small-scale processing.

4. Size Reduction: Size reduction is an important step in the processing of medicinal plants that involves cutting, crushing, or grinding plant materials into smaller pieces or powder. This process is essential for improving the efficiency of further processing and enhancing the overall quality of the final product.

Reducing the size of plant materials increases their **surface area**, which helps in better drying, efficient extraction of active compounds, and uniform mixing in formulations. It also makes handling, packaging, and storage easier.

Common methods of size reduction include:

- a. Cutting and slicing (for roots, stems, bark)
- b. Crushing
- c. Grinding or pulverizing into powder

Proper size reduction ensures:

- a. Faster and more effective extraction
- b. Uniform product quality
- c. Better utilization of medicinal properties

However, excessive grinding may lead to loss of volatile compounds and heat generation, which can reduce the medicinal value. Therefore, appropriate techniques and equipment should be used to maintain the quality and potency of medicinal plants.

5. Extraction: Extraction is a key step in the processing of medicinal plants, involving the separation of active medicinal compounds (phytochemicals) from plant materials using suitable solvents. These bioactive constituents are responsible for the therapeutic properties of the plant.

The main purpose of extraction is to concentrate and preserve the active ingredients in a usable form, making them more effective and easier to incorporate into herbal products such as syrups, oils, capsules, and tinctures.

Common extraction methods used in small-scale processing include:

- a. **Water extraction** (infusion and decoction)
- b. **Alcohol extraction** (tinctures)
- c. **Oil extraction** (for essential oils and herbal oils)

Proper extraction improves:

- a. Potency and effectiveness of medicinal products
- b. Shelf life and stability
- c. Ease of use and dosage control

However, the choice of solvent, temperature, and extraction time must be carefully controlled, as improper methods can lead to loss or degradation of active compounds.

Thus, extraction is a crucial step in value addition, transforming raw medicinal plants into high-value, marketable herbal products.

6. Packaging & Storage: Packaging and storage are critical final steps in the processing of medicinal plants, ensuring the quality, safety, and shelf life of the finished products. After processing, medicinal plant materials are highly sensitive to environmental factors such as moisture, light, air, and temperature, which can lead to deterioration and loss of active compounds.

Packaging involves placing the processed material in suitable containers that protect it from contamination and environmental damage. Common packaging materials include:

- a. Airtight containers
- b. Glass bottles
- c. Plastic or laminated pouches
- d. Paper bags (for short-term storage)

Proper storage conditions are equally important to maintain the potency and effectiveness of medicinal products. Key storage practices include:

- a. Keeping products in a cool, dry place
- b. Protecting from direct sunlight
- c. Avoiding exposure to humidity and pests
- d. Proper labeling (product name, date, batch number)

Effective packaging and storage help to:

- a. Extend shelf life
- b. Preserve medicinal properties
- c. Maintain product quality and hygiene
- d. Improve market value and consumer trust.

Thus, appropriate packaging and storage are essential for successful small-scale processing and value addition of medicinal plants.

Value Addition Techniques

Primary Value Addition:

- a. Cleaning
- b. Drying
- c. Grading
- d. Powdering

Secondary Value Addition:

- a. Extracts (liquid, dry)
- b. Essential oils
- c. Herbal teas
- d. Capsules and tablets

Advanced Value Addition:

- a. Standardized herbal formulations
- b. Nutraceuticals
- c. Cosmetics

Value addition ensures products meet pharmacopoeial and market standards.

Examples of Value-Added Products

From a single medicinal plant, multiple products can be developed:

1. Powder (e.g., Ashwagandha powder)
2. अर्क (extracts)
3. Herbal tea
4. Essential oils
5. Ointments and syrups

This diversification increases profitability.

Quality Control & Standards

To ensure safety and effectiveness:

1. Follow **Good Agricultural and Collection Practices (GACP)**
2. Follow **Good Manufacturing Practices (GMP)**
3. Check:
 - a. Moisture content
 - b. Purity
 - c. Active ingredients

Quality control is essential for export and commercial success.

Equipment for Small-Scale Units

Basic equipment required:

1. Drying trays / solar dryers
2. Pulverizer (grinder)
3. Sieves
4. Distillation unit (for oils)
5. Packaging machine

Low-cost technologies are suitable for rural setups.

Challenges in Small-Scale Processing

1. Lack of technical knowledge
2. Poor storage facilities
3. Inconsistent quality

4. Limited market access
5. Lack of standardization
6. Training and awareness can address these issues.

Opportunities

1. Growing demand for herbal products
2. Export potential
3. Government support (AYUSH, NMPB, TRIFED)
4. Scope for entrepreneurship

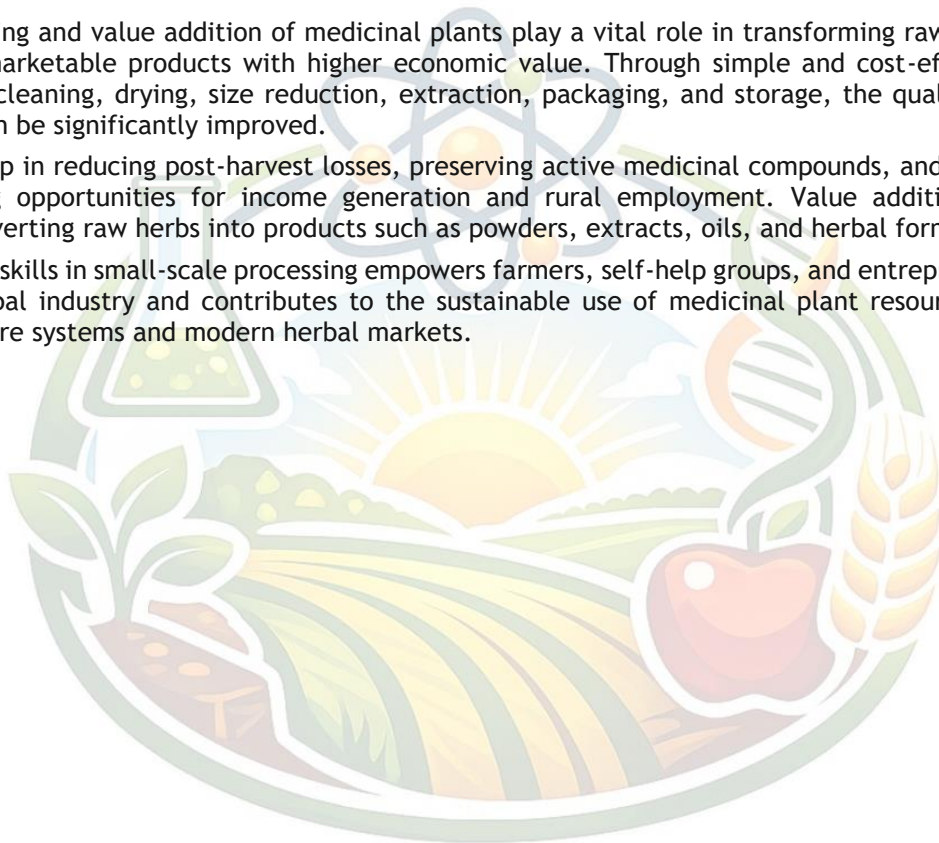
Value-added medicinal plant products have strong global demand.

Conclusion

Small-scale processing and value addition of medicinal plants play a vital role in transforming raw plant materials into safe, stable, and marketable products with higher economic value. Through simple and cost-effective steps such as proper harvesting, cleaning, drying, size reduction, extraction, packaging, and storage, the quality and usefulness of medicinal plants can be significantly improved.

These processes help in reducing post-harvest losses, preserving active medicinal compounds, and enhancing shelf life, while also creating opportunities for income generation and rural employment. Value addition further increases profitability by converting raw herbs into products such as powders, extracts, oils, and herbal formulations.

Overall, developing skills in small-scale processing empowers farmers, self-help groups, and entrepreneurs to participate in the growing herbal industry and contributes to the sustainable use of medicinal plant resources while supporting traditional healthcare systems and modern herbal markets.

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Strengthening Fisheries Value Chains through Effective Extension Interventions

Article ID: 74006

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Abstract

Fisheries value chains are crucial for food security, livelihoods and economic growth, especially in developing countries such as India. However, inefficiencies in production, post-processing, and marketing often limit their full potential. This article examines the role of enlargement measures in improving fisheries value chains through increased productivity, reduced losses and improved market access. It highlights the role of capacity building, technology dissemination, institutional support and digital innovation for the efficiency of the value chain. The discussion also includes government programs such as Pradhan Mantri, Matsya, Sampada Yojana and support from the National Fisheries Development Board. The study concludes that effective, participatory and technology-driven expansion systems are essential to develop resilient, inclusive and sustainable fisheries value chains.

Keywords: Fisheries Value Chain, Extension Services, Aquaculture, Market Linkages, Value Addition, Livelihood, India.

Introduction

Fisheries provide major contributions to nutrition, jobs and income worldwide. This sector provides employment to millions of fishers, fish farmers and allied workers in India. Fisheries are an important sector but are challenged by fragmented supply chains, post-harvest losses and limited access to modern technologies and markets. Such constraints often create inefficiencies in the fisheries value chain, which encompasses all steps from the provision of inputs to final consumption.

Extension services are critical to close gaps in knowledge, skills and institutional linkages. Extension interventions have the potential to greatly enhance the efficiency and profitability of fisheries value chains through the promotion of improved practices and increased stakeholder coordination.

Concept of Fisheries Value Chain

A fisheries value chain is the full range of activities that get fish from production systems to final consumers. It includes input supply (seed, feed), production, harvesting, processing, storage, transport and marketing. Each stage adds value to the product but inefficiencies can lead to losses and lower revenue.

The successful value chain provides quality, minimizes waste and guarantees fair returns to all stakeholders. Strengthening these chains requires a combination of technical, institutional and market-oriented interventions where extension services play a key role.

Role of Extension Services in Fisheries Value Chains

1. Production Enhancement: Extension services promote scientific fish farming practices like better breeding, feed management, water quality control and disease management. Training programmes, demonstrations and field visits give fish farmers practical knowledge that improves productivity and reduces risks.

2. Post-Harvest Management and Value Addition: Fish is highly perishable and hence post-harvest handling is critical. Interventions for extension include hygienic handling, cold chain management and processing methods like drying, smoking and pickling. Such practices reduce the losses and give value to the product and finally give higher income to the stakeholders.

3. Market Linkages and Information Dissemination: Extension services help fishers access real-time market information, understand consumer preferences, and identify profitable markets. Formation of cooperatives and producer groups strengthens collective marketing and bargaining power. Digital tools further enhance connectivity between producers and consumers.

4. Capacity Building and Skill Development: the purpose of fisheries extension services for capacity building and skills development is to strengthen the knowledge, skills, capacity and productivity of fishers and fish farmers. Farmers are provided with skills-technical, managerial, entrepreneurship-through different extension methods like training, demonstration and awareness programs; in areas such as fish culture, resource management, processing and marketing. These programs enable farmers to achieve high production and income and to apply and practice modern and sustainable

techniques in fisheries. Focusing specifically on the need for empowering women and youth is important to ensure inclusive development, self-employment and generation of livelihood.

Institutional and Policy Support

The development of the fisheries value chains is also largely dependent upon the Government's policy and institutions. Pradhan Mantri Matsya Sampada Yojana aims to upgrade infrastructure, add value and increase production of fish. The National Fisheries Development Board focuses on capacity building, technology adoption and infrastructure development.

Extension services are an important linkage that connects these institutions with the bottom level stakeholders.

Role of Technology in Strengthening Value Chains

Fisheries extension and value chains transformations following new technologies: ICT. Provides latest up dated information through tools/ services like mobiles, web based advisory services and online market information system and, in that sense, makes fishers informed decision regarding production. Other innovations are in storage, transportation, packaging.

Challenges in Fisheries Value Chains

Fisheries value chains still face the above problems despite all achievements.

1. Poor infrastructure: lacking of refrigeration and transport facilities cause spoilage of the product and post-harvest losses.
2. Lack of access to credit and financial institutions does not allow the fisher to have modern techniques to improve their production.
3. Market fragmentation and multiple middlemen lead to loss of producers' share of profit.
4. Climate change and environment issues affect fish production and availability.

Recommendations

Improving extension services using participatory approaches and ICT and the establishment of good infrastructure is essential to strengthen value chains in fisheries. Cooperatives promotion, access to credit and empowerment of women and youth will lead to increasing opportunities in livelihoods. Also, the use of sustainable and climate resilient practices of fisheries is important to increase production for sustainability.

Conclusion

The contribution of extension intervention is important for fisheries value chain development. Extension services improve livelihood, increase production, reduce losses and market access in fisheries value chain which can be used for the improvement of living standards. A good and coordinated information flow from extension service that leads to development of fisheries sector is also required to realize sustainable and inclusive growth.

A planned, technology-oriented, farmer-driven, and participative extension system should be designed to achieve the resilience of fisheries value chain development. This can be supported through enhancing coordination between government sectors, research institutes, NGOs and the community members to assure the sustainable and improved livelihood in fisheries sector.

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Physiological Disorders of Cauliflower

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Abstract

Cauliflower (*Brassica oleracea* var *botrytis*) is an economically important cole crop cultivated widely under tropical and subtropical climatic conditions. The crop is highly sensitive to environmental fluctuations and nutritional imbalances, which frequently result in several physiological disorders affecting curd quality and yield. Physiological disorders are non-pathogenic abnormalities induced by unfavorable environmental factors, nutrient deficiencies, improper agronomic practices, and genetic susceptibility. Important disorders of cauliflower include buttoning, riceyness, whiptail, browning, blindness, and leafiness. These disorders adversely influence market acceptability and storage quality of curds. Proper understanding of their etiology, symptomatology, and management practices is essential for sustainable cauliflower production.

Introduction

Cauliflower is one of the most important winter vegetable crops belonging to the family Brassicaceae. The edible portion of cauliflower is the immature proliferated inflorescence known as the curd. Successful curd development depends upon optimum temperature, adequate soil moisture, balanced nutrient supply, and proper varietal adaptation.

Physiological disorders are abnormalities caused by disturbances in normal physiological and metabolic activities of plants rather than by pathogens or pests. These disorders develop due to nutrient deficiencies, temperature stress, moisture imbalance, or unsuitable cultivation practices. In cauliflower, physiological disorders directly affect curd initiation, curd compactness, and overall plant growth, thereby reducing yield and commercial value.

Major Physiological Disorders of Cauliflower

1. Buttoning: Buttoning is characterized by the formation of miniature premature curds before adequate vegetative growth is attained. It occurs when the plant undergoes early reproductive transition under unfavorable environmental or nutritional conditions.

Scientific Causes:

- Transplanting over-aged seedlings
- Nitrogen deficiency during vegetative phase
- Exposure of young plants to low temperature
- Use of early cultivars under late sowing conditions
- Restricted root growth and moisture stress.

Physiological Basis: Insufficient vegetative development reduces photosynthetic surface area and carbohydrate accumulation. Consequently, the plant shifts prematurely from vegetative to reproductive stage, resulting in undersized curd formation.

Symptoms:

- Small compact button-like curds
- Poor foliage development
- Reduced marketable yield



Management:

- Use healthy seedlings of 4-6 weeks age
- Maintain optimum nitrogen nutrition
- Adopt recommended sowing schedule
- Ensure adequate irrigation and spacing.

2. Riceyness: Riceyness refers to the development of elongated floral buds on the curd surface, causing granular appearance and loss of compactness.

Scientific Causes:

- High temperature during curd development
- Excessive nitrogen fertilization
- High relative humidity
- Delayed harvesting

Physiological Basis: Elevated temperature accelerates floral differentiation and internodal elongation within the curd tissue. Excess nitrogen further stimulates rapid cell division and floral proliferation, leading to separation of flower primordia.

Symptoms:

- Loose and velvety curd surface
- Elongated floral buds
- Reduced compactness and quality



Management:

- Timely planting according to cultivar requirement
- Balanced nutrient application
- Harvest curds at proper maturity stage.

3. Whiptail: Whiptail is a nutritional disorder primarily associated with molybdenum deficiency and is common in acidic soils.

Scientific Causes:

- Deficiency of molybdenum (Mo)
- Soil pH below 5.5
- Reduced availability of micronutrients

Physiological Basis: Molybdenum is an essential component of nitrate reductase enzyme involved in nitrogen metabolism. Deficiency impairs nitrate reduction and protein synthesis, resulting in abnormal leaf lamina development.

Symptoms:

- Narrow, strap- like leaves
- Distorted lamina
- Poor curd formation
- Stunted plant growth.



Management:

- Apply sodium molybdate at recommended dose
- Maintain soil pH around 6.0-6.5
- Lime acidic soils before transplanting.

4. Browning (Brown Rot): Browning is caused mainly by boron deficiency and leads to necrosis of internal tissues.

Scientific Causes:

- a. Boron deficiency
- b. Drought stress
- c. Excessive liming
- d. Low organic matter content.

Physiological Basis: Boron plays a vital role in cell wall formation, carbohydrate transport, and meristematic activity. Deficiency disrupts cellular integrity, causing tissue breakdown and oxidation of phenolic compounds.

Symptoms:

- a. Brown discoloration of curd tissues
- b. Hollow stem development
- c. Water-soaked lesions
- d. Bitter taste in curds.



Management:

- a. Apply borax or boric acid sprays
- b. Maintain adequate soil moisture
- c. Avoid excessive liming.

5. Blindness: Blindness is the failure of plants to develop curds due to destruction or absence of the apical growing point.



Scientific Causes:

- a. Mechanical injury during transplanting
- b. Insect damage to terminal bud
- c. Frost injury

Genetic abnormalities Physiological Basis: The terminal bud contains actively dividing meristematic cells responsible for curd initiation. Damage to this growing point inhibits reproductive development and curd differentiation.

Symptoms:

- a. Absence of curd formation
- b. Excessive vegetative growth
- c. Formation of multiple side shoots

Management

- a. Careful handling of seedlings
- b. Protection against insect attack
- c. Avoid exposure to frost injury.

6. Leafiness: Leafiness is characterized by the development of small green leaves within the curd.

Scientific Causes:

- a. High temperature during curd development Excess nitrogen supply
- b. Cultivar susceptibility.

Physiological Basis: Under high temperature conditions, floral primordia partially revert to vegetative growth. This abnormal differentiation results in leaf emergence among curd tissues.



Symptoms:

- a. Presence of leaves in curd
- b. Loose and unattractive curds.
- c. Reduced market quality.

Management:

- a. Use climate-suitable varieties
- b. Maintain optimum temperature conditions
- c. Balanced fertilization practices.

General Management Practices

1. Selection of suitable cultivars according to season
2. Maintenance of optimum soil pH
3. Balanced macro and micronutrient application
4. Timely irrigation and drainage management
5. Proper transplanting and spacing
6. Regular monitoring of crop growth conditions.

Conclusion

Physiological disorders in cauliflower are primarily associated with disturbances in plant metabolic and developmental processes caused by environmental stress and nutrient imbalance. These disorders significantly reduce curd quality, yield, and economic returns. Scientific crop management practices including balanced fertilization, proper irrigation scheduling, optimum temperature management, and timely cultural operations are essential for minimizing physiological abnormalities and achieving higher productivity in cauliflower cultivation.

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Lotus: The Sacred Flower with Scientific Wonders

Article ID: 74008

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Lotus (*Nelumbo nucifera*) is one of the oldest and most admired aquatic flowering plants in the world. Popularly known as the sacred lotus or Indian lotus, it belongs to the family Nelumbonaceae and grows naturally in ponds, lakes and wetlands. Lotus has attracted human attention for centuries because of its beauty, purity and remarkable adaptability.



The lotus plant is unique in every aspect. Its leaves float gracefully above water, while its large attractive flowers bloom brilliantly under sunlight. The plant produces edible rhizomes and nutritious seeds, making it valuable not only as an ornamental flower but also as a food and medicinal plant. Scientists now consider lotus as an emerging horticultural model plant because of its exceptional biological features and increasing importance in modern plant research.



Cultural and Economic Importance

Lotus holds deep cultural and spiritual significance in many countries. In India, the lotus is regarded as the **National flower** and symbolizes purity, wisdom and prosperity. Apart from its cultural value, lotus has enormous economic importance. Different parts of the plant are utilized for various purposes. The flowers are cultivated for ornamental

decoration in gardens, parks and water landscapes. The rhizomes, commonly called lotus roots, are widely consumed as vegetables in Asian cuisine. They are rich in starch, vitamins and dietary fibre. Lotus seeds are also edible and highly nutritious. Both fresh and dried seeds are used in desserts, traditional dishes and herbal preparations. In addition, lotus leaves, flowers and embryos are widely used in traditional medicine systems.



Amazing Scientific Features of Lotus

One of the reasons lotuses fascinate scientists is its extraordinary biological properties. The plant possesses several unique features rarely found in other species.

1. Exceptional Seed Longevity: Lotus seeds are famous for their incredible longevity. Researchers discovered that lotus seeds buried for more than 1,000 years were still capable of germination. This remarkable survival ability is mainly due to the strong seed coat, antioxidant compounds and heat-stable proteins present in the seeds. Scientists believe that studying lotus seed longevity may help improve seed preservation techniques in agriculture and biological sciences.



2. The “Lotus Effect”: Another fascinating feature is the “lotus effect,” which refers to the self-cleaning property of lotus leaves. The surface of the leaf contains tiny waxy structures that repel water completely. Water droplets roll off the leaf surface while carrying dust and dirt particles away. This superhydrophobic nature keeps the leaves clean and dry even in muddy water conditions.



3. Floral Thermoregulation: Lotus flowers also possess the rare ability of thermoregulation. During flowering, certain floral parts can produce heat and maintain a stable temperature. This heat production helps attract insect pollinators and supports successful pollination. The process is controlled by special respiratory pathways present within the floral tissues. Such a feature is uncommon among flowering plants and has become an important topic in plant physiological research.



Ornamental and Medicinal Value

Lotus is among the most beautiful ornamental plants cultivated worldwide. The flowers occur in different colours including white, pink, red and yellow. Plant breeders have developed numerous cultivars with diverse petal arrangements, flower shapes and colour combinations. Double-petalled and multi-coloured lotus varieties are especially popular in landscaping and water gardening.



The beauty of lotus flowers is mainly due to natural pigments such as anthocyanins and carotenoids. Besides its ornamental importance, lotus is widely recognized for its medicinal properties. Almost every part of the plant has therapeutic value. Lotus leaves, flowers, seeds and rhizomes contain numerous bioactive compounds including flavonoids, alkaloids and phenolic acids.



Traditional medicine systems have used lotus for centuries to treat various ailments. Lotus leaves are commonly used to reduce body fat and manage blood lipid levels. Certain alkaloids present in lotus leaves, especially nuciferine, have shown antioxidant and medicinal activities. Lotus seed embryos are also known for their health-promoting properties.

Conclusion

Lotus is far more than a beautiful aquatic flower. It is a plant of immense cultural, economic, ornamental and scientific importance. From its sacred symbolism and nutritional value to its extraordinary biological features such as seed longevity and self-cleaning leaves, lotus continues to amaze both researchers and the general public.

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Hi-Tech Nursery: A Smart Way to Produce Quality Plant

Article ID: 74009

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Abstract

Agriculture and horticulture are essential sciences because they fulfill the fundamental need for food. Both the quality and quantity of food depend on healthy plants, which can only be grown from strong and vigorous seedlings or saplings. Most seedlings are highly vulnerable to damage from both biotic and abiotic stress factors, leading farmers to suffer significant losses in terms of yield and quality. Healthy seedlings are crucial for the successful growth and development of crops in the main field. Therefore, establishing and maintaining a Hi-tech nursery is a fundamental requirement in horticulture. A high-tech nursery incorporates advanced features such as computerized management, micro-irrigation systems, precise fertilization, and modern plant propagation techniques. The integration of modern technology has become essential for improving productivity. Higher levels of production cannot be achieved without the availability of uniform, high-quality planting material of the desired type. Therefore, adopting hi-tech nursery management is crucial for producing superior planting material and ensuring its supply to nurserymen across the country. These modern nurseries enhance key physiological functions in plants, enabling them to grow and perform more efficiently. This article explores the mechanics behind hi-tech nurseries, the specific technologies driving them, and why the shift from traditional to smart nurseries is a necessary evolution for modern agriculture, which helps farmers to build quality Seedlings.

Keywords: Hi-tech nursery, Quality planting material, Seedling production, Modern horticulture.

Introduction

A nursery is a place where young seedlings are raised under suitable conditions, with proper nutrients and timely irrigation to support their healthy growth. It is used to nurture plants during their early stages until they are strong enough to withstand conditions in the main field. Raising crops in a nursery helps save time and labor during field cultivation. The primary objective of nursery raising is to produce high-quality plants suited to specific regions and for successful transplantation. Nursery management is a fundamental component of horticultural production, as the quality of seedlings directly determines the growth, productivity, and overall success of crops in the field. In traditional nursery systems, seedlings are generally raised under open field conditions, where they are exposed to fluctuating environmental factors such as temperature, humidity, rainfall, and wind. These uncontrolled conditions often result in poor germination, uneven seedling growth, higher susceptibility to pests and diseases, and significant mortality rates. Additionally, soil-borne pathogens, nutrient imbalances, and inefficient water management further reduce the quality and uniformity of planting material. With the increasing demand for high-quality produce, rapid urbanization, and shrinking agricultural land resources, there is a growing need to adopt advanced technologies that can enhance productivity and ensure efficient resource utilization. Climate change and erratic weather patterns have further intensified the challenges faced by conventional nursery practices, making them less reliable and economically risky for farmers and commercial growers.

Hi-tech nurseries have emerged as an innovative and sustainable solution for the production of healthy, uniform, and disease-free seedlings. A hi-tech nursery is a specialized facility where seedlings are raised under controlled environmental conditions using modern technologies such as protected structures (greenhouses, polyhouses and shade net houses), soilless growing media, pro-tray systems, and automated irrigation and fertigation systems. These technologies allow precise control over temperature, humidity, light, and nutrient supply, thereby creating optimal conditions for seed germination and seedling development. The adoption of hi-tech nursery techniques not only improves germination rates and seedling vigor but also ensures uniform growth, reduces transplanting shock, and enhances field establishment. Moreover, it enables year-round production of seedlings, efficient use of water and nutrients, and minimization of pest and disease incidence. As a result, hi-tech nurseries play a crucial role in modern horticulture, particularly in the cultivation of high-value vegetable, fruit and ornamental crops.

Therefore, the transition from traditional nursery practices to hi-tech nursery systems represents a significant step toward sustainable and precision agriculture.

Objectives of High-Tech Nursery

1. To produce healthy, vigorous, and high-quality planting material
2. To supply uniform and true-to-type seedlings and saplings
3. To ensure year-round availability of planting materials

4. To raise disease-free and pest-free nursery plants
5. To improve seed germination and propagation success
6. To increase survival rate after transplanting
7. To promote faster growth and early crop establishment
8. To use water, nutrients, and space efficiently
9. To reduce production losses caused by adverse weather
10. To meet the increasing demand for quality plants
11. To increase profitability of nursery enterprises
12. To support modern horticulture and sustainable agriculture.

Major Components of High-Tech Nursery

1. Protected Cultivation Structures: High-tech nurseries are developed with specialized protected structures that create favourable microclimatic conditions for seed germination, rooting, and seedling growth. These include Greenhouse, Polyhouse, Glasshouse, Shade Net House, Mist Chamber, and Hardening Chamber. Such structures help regulate temperature, humidity, light intensity, and ventilation, protecting young plants from adverse weather and promoting healthy, uniform growth. Instead of open fields, plants are raised inside these specifically designed structures. These structures physically block out extreme weather, heavy winds, and larger pests.



Fig 1: Polyhouse



Fig 2: Glasshouse



Fig 3: Shade net house

2. Soilless Growing Media: Soilless growing media are alternative substrates used for raising plants without natural soil, mainly to provide physical support, water, air, and nutrients to the roots. These media are widely used in nurseries, greenhouse cultivation, and hydroponic systems for better root development and efficient crop management. They are generally sterile, lightweight, and free from many soil-borne pests and diseases. Selecting a suitable growing medium is

essential for effective nursery management, as it directly influences all other cultural practices such as irrigation scheduling, nutrient supply, and fertilizer application.

a. Cocopeat is a natural growing medium obtained after extracting fibre from coconut husk. It is widely used in nurseries and protected cultivation because of its excellent physical properties. Cocopeat has a very high moisture retention capacity, holding nearly 600-800 per cent of its dry weight in water. It also provides good aeration, with air-filled pore space ranging from 11 to 53 per cent, along with low bulk density (about 0.18 g/cc), making it light and easy to handle. In addition, it has a high cation exchange capacity (CEC) of around 20-30 meq/100 g, which helps in retaining nutrients for plant uptake.

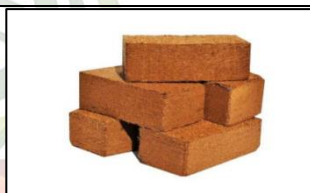
b. Vermiculite is one of the most commonly used growing media components due to its sterile nature and light weight. It is mainly used to improve the water-holding capacity of the growing medium, as it can retain about three to four times its own weight in water. Its pH generally ranges from neutral to slightly alkaline (6.3 to 7.8). Vermiculite also contains useful nutrients such as K, Mg and Ca which can support plant growth.

c. Perlite is a volcanic rock that is crushed and rapidly heated to a high temperature of about 1000°C, causing it to expand into a white, lightweight material with high pore space. It is commonly added to growing media to improve aeration and drainage, although its water-holding capacity is relatively low. Perlite is chemically inert and has a neutral pH.

Soilless Culture

1. Hydroponics: In hydroponics, plants are grown without soil in a nutrient-enriched water solution, where all essential minerals are supplied directly to the roots. This system allows precise control over nutrient levels, efficient use of water, faster plant growth, and reduced risk of soil-borne diseases. It is widely used for producing vegetables, herbs, and leafy greens under protected conditions.

2. Aeroponics: In aeroponics, plant roots are suspended freely in the air and periodically misted with a nutrient-rich solution. This method provides excellent oxygen availability to the roots, enhances nutrient uptake, promotes rapid growth, and uses very little water. It is considered an advanced cultivation technique suitable for high-value crops, seed production, and research purposes.

		
Vermiculite	Perlite	Cocopeat

3. Pro-Trays (Plug Trays): Seeds are sown into multi-celled plastic trays filled with inert growing medium rather than flat beds. This means every single seed gets its own dedicated space, nutrients, and water. When it's time to transplant, the sapling is pulled out with its root ball completely intact, eliminating "transplant shock" and ensuring the plant continues growing immediately after transplanting to main field.



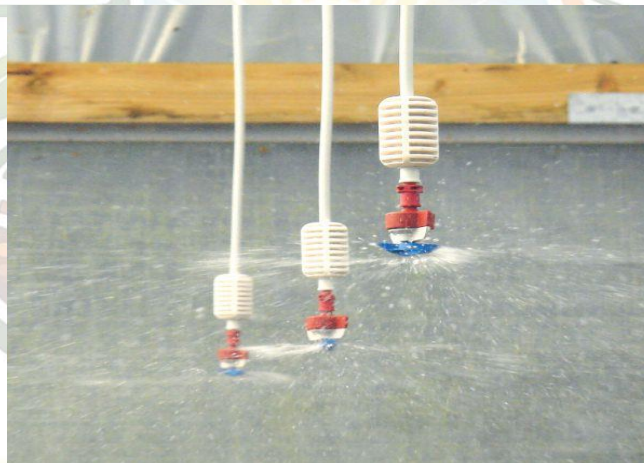
4. Automated Micro-Irrigation and Fertigation:

Automated irrigation technologies are widely used in hi-tech nurseries to provide precise and timely water application, ensuring healthy seedling growth while saving water and labour. These systems are designed to maintain optimum moisture levels in the growing media and can be operated through timers, sensors, or computer-controlled units. Watering plants with a hose is incredibly inefficient. Hi-tech nurseries use overhead micro-sprinklers or boom irrigation systems. Furthermore, fertilizers are dissolved directly into the water supply (fertigation). Sensors monitor the moisture levels in the trays, and automated systems deliver the exact amount of water and micro-nutrients required, exactly when the plants need it.

- a. Drip Irrigation:** Water is supplied directly to the root zone through emitters at a controlled rate. It minimizes water loss, improves water-use efficiency, and is suitable for container-grown plants and polybags.
- b. Sprinkler Irrigation:** Water is sprayed over plants in the form of fine droplets, simulating rainfall. It is commonly used for irrigating nursery beds, lawns, and young seedlings.
- c. Mist Irrigation / Fogging Systems:** These systems release very fine water droplets or mist to maintain high humidity and prevent moisture loss from tender cuttings and seedlings. They are especially useful in propagation chambers and greenhouse nurseries.
- d. Micro-sprinklers:** These provide low-volume water application over a small area and are ideal for potted plants and nursery containers. They ensure uniform moisture distribution.
- e. Smart Irrigation:** Advanced nurseries use computerized systems connected with sensors and weather data to control irrigation according to crop need, temperature, humidity, and evapotranspiration.



Drip irrigation



Overhead Sprinklers



Mist irrigation/Fogging System

Advantages of High-Tech Nursery

- 1. Production of Quality Planting Material:** High-tech nurseries produce healthy, vigorous, true-to-type, and disease-free seedlings with better survival rate after transplanting.
- 2. Year-round Production:** Controlled environmental conditions such as temperature, humidity, and light allow continuous production of seedlings throughout the year.
- 3. Uniform Growth of Seedlings:** Scientific management practices ensure uniform germination, growth, and development of nursery plants.
- 4. Efficient Use of Resources:** Advanced systems like drip irrigation, misting, and fertigation help in efficient use of water, fertilizers, and other inputs.
- 5. Protection from Pests and Diseases:** Use of protected structures such as greenhouses, net houses, and sterilized media reduces incidence of pests, diseases, and weeds.
- 6. Faster Growth and Early Availability:** Improved growing conditions promote faster growth, enabling early supply of seedlings to farmers.
- 7. Higher Survival after Transplanting:** Well-developed root systems and hardened seedlings establish quickly in the main field with higher success rate.
- 8. Labour Saving and Automation:** Automated irrigation, fertigation, and climate control systems reduce labour requirement and operational cost.
- 9. Better Space Utilization:** Plug trays, vertical systems, and organized nursery layouts allow maximum use of available space.
- 10. Higher Income and Entrepreneurship Opportunities:** High-tech nurseries create scope for commercial seedling production, employment generation, and profitable agribusiness ventures.

Conclusion

Raising healthy seedlings in the nursery has become an urgent requirement, making it essential to adopt scientific nursery management practices. Greater emphasis is now being placed on protecting seedlings from both biotic and abiotic stresses. Innovative and modern techniques used in hi-tech nurseries help in producing superior quality seedlings that fetch better market prices. High-tech nursery systems also support year-round and off-season production of vegetable seedlings, often under soilless media, on a commercial scale. High-tech nursery management plays a vital role in modern horticulture by ensuring the production of healthy, uniform, and quality planting material required for higher productivity. The use of protected structures, soilless media, automated irrigation, fertigation, and advanced propagation techniques improves seedling growth, resource-use efficiency, and crop establishment. It also reduces losses caused by pests, diseases, and adverse climatic conditions. Therefore, adoption of hi-tech nursery systems is essential for sustainable horticultural development, increased farmer income, and meeting the growing demand for quality horticultural crops.

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Soft Computing in FTS for Biological Stage Prediction (Lepidoptera)

Article ID: 74010

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Introduction

Applying Fuzzy Time Series (FTS) to model and predict aspects of the butterfly Life-Cycle involves using fuzzy logic to handle the uncertainties and variability inherent in biological systems. In this article, a structured approach to using fuzzy time series for modeling different stages of the butterfly Life-Cycle, such as egg development, larval growth, pupation, and adult emergence.

Data Collection and Preparation

1. Gather Butterfly Lifecycle Data: Collect historical data on butterfly development stages and related variables. Key data might include:

- a. Duration of each lifecycle stage (egg, larva, pupa, adult)
- b. Environmental factors (temperature, humidity)
- c. Food availability
- d. Mortality rates and survival rates at each stage

2. Pre-process Data: Clean the data by addressing missing values, outliers, and inconsistencies. Normalize or standardize data as needed to ensure consistency across different data types.

The stages can also be represented mathematically as: $E_t \rightarrow L_t \rightarrow P_t \rightarrow A_t$

where: E_t = Egg stage, L_t = Larval stage, P_t = Pupal stage, A_t = Adult stage

Each stage duration depends on environmental conditions such as climate and food supply.

Fuzzification

1. Define Fuzzy Sets: Create fuzzy sets to categorize data related to the butterfly lifecycle. For example:

- a. Egg Development Time: "Short", "Medium", "Long"
- b. Larval Growth Rate: "Slow", "Moderate", "Fast"
- c. Pupal Stage Duration: "Short", "Medium", "Long"
- d. Environmental Conditions: "Low", "Optimal", "High"

2. Develop Membership Functions: Define membership functions for these fuzzy sets. For instance, you might define the membership function for egg development time as:

A triangular function where "Short" might cover 1-3 days, "Medium" 4-7 days, and "Long" 8-12 days.

Construct Fuzzy Time Series

1. Transform Data into Fuzzy Sets: Convert historical lifecycle data into fuzzy sets. For example, if historical data shows that egg development times range from 5 to 8 days, this can be classified into "Medium" with varying degrees of membership.

2. Identify Relationships: Determine how fuzzy sets at one stage relate to fuzzy sets at subsequent stages. For example: "If the temperature is 'Optimal' and food availability is 'High', then the larval growth rate is likely to be 'Fast'."

Develop Fuzzy Rules

1. Formulate Fuzzy Rules: Develop rules based on the relationships observed. Examples might include:

- a. If (Temperature is 'Optimal') and (Food Availability is 'High'), then (Larval Growth Rate is 'Fast').
- b. If (Larval Growth Rate is 'Slow') and (Temperature is 'Low'), then (Pupal Stage Duration is 'Long').

2. Create a Rule Base: Compile these rules into a fuzzy inference system. Each rule should relate current conditions to predictions about future lifecycle stages.

Fuzzy Inference System

1. Select a Fuzzy Inference Method: Choose a fuzzy inference system, such as Mamdani or Sugeno.

- a. Mamdani: Uses fuzzy sets for both inputs and outputs, applying fuzzy rules to produce fuzzy outputs.

b. **Sugeno**: Uses fuzzy sets for inputs and precise functions (e.g., linear functions) for outputs.

2. **Apply Inference**: Use the fuzzy inference system to apply the rules to current data and predict future lifecycle stages. This involves combining fuzzy rules with input data to generate fuzzy outputs.

Defuzzification

1. **Convert Fuzzy Outputs to Crisp Values**: Transform the fuzzy outputs into precise numerical values. Common methods include:

a. **Centroid Method**: Calculates the center of gravity of the fuzzy set.

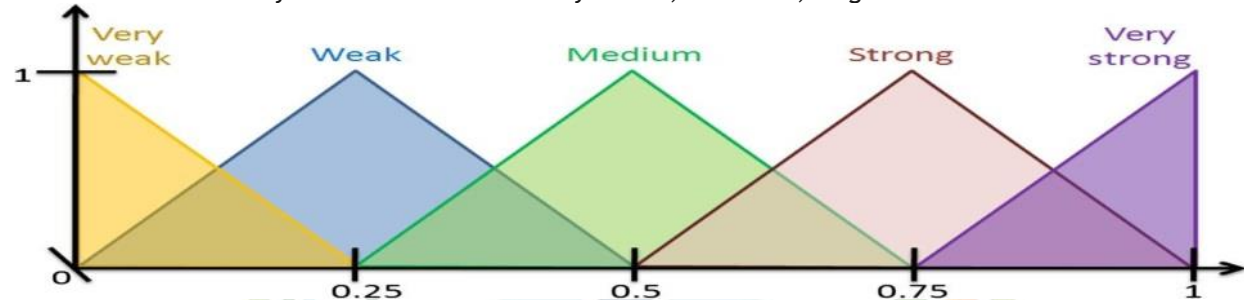
b. **Weighted Average**: Computes the weighted average of the fuzzy set values.

Example for Application: To predict the duration of the pupal stage based on temperature and food availability.

a. **Fuzzification**:

i. Define fuzzy sets for temperature: "Low", "Optimal", "High".

ii. Define fuzzy sets for food availability: "Low", "Medium", "High".



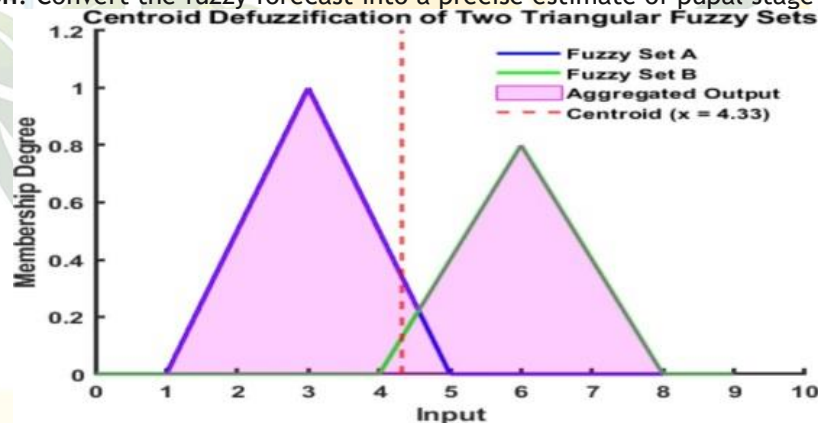
b. **Rules**:

i. If (Temperature is 'Optimal') and (Food Availability is 'High'), then (Pupal Stage Duration is 'Short').

ii. If (Temperature is 'High') and (Food Availability is 'Low'), then (Pupal Stage Duration is 'Long').

c. **Inference**: Apply these rules to current temperature and food availability data to predict the duration of the pupal stage.

d. **Defuzzification**: Convert the fuzzy forecast into a precise estimate of pupal stage duration.



Conclusion

Using fuzzy time series to model the butterfly Life-Cycle allows accounting for uncertainties and variabilities in biological processes, providing more flexible and robust predictions that can aid in understanding and managing butterfly populations.

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Adoption of Integrated Pest Management (IPM) in Pulses by Indian Farmers

Article ID: 74011

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Abstract

Pulses are majorly grown in Indian conditions. India is largest producer, consumer and importer of pulses. Since usage of chemicals like synthetic insecticides and fungicides for the management of insects and disease in pulses have the high risk of environmental pollution and loss of biological diversity, we for an ecofriendly approach called IPM (integrated pest management) to manage all the insects and disease in pulses. Integrated Pest Management (IPM) offers an eco-friendly, economically viable approach to managing pests in pulse crops. IPM strategy includes cultural, mechanical, biological, and chemical methods as its components. This review synthesizes literature on the adoption of IPM for major pulses in India (pigeonpea, chickpea, mungbean, blackgram, lentil), identifies socio-economic and institutional drivers and constraints, evaluates impacts on yields and pesticide use, and provides recommendations to increase adoption. The review draws on >30 peer-reviewed papers, extension reports, national IPM program documents and recent studies (2010-2025).

Keywords: Integrated Pest Management; pulses; adoption; pigeonpea; chickpea; mungbean; India; extension; constraints.

Introduction

Pulses are a cornerstone of Indian agriculture and nutrition. Pulses are an important source of dietary protein for human and animals because of their richness with proteins, essential minerals, vitamins and dietary fibers. The protein content of grain legumes is double that of wheat and three times that of rice. Therefore, pulses as a complement to cereals, make one of the best solutions to protein-calorie malnutrition.

Pests (insect pests, diseases, and storage pests) reduce productivity and quality across the pulse value chain. In general, declining of potential yield of pulse crops have significant instability, mainly due to its cultivation on marginal lands under poor management, adoption of inappropriate production technology and heavy infestation of biotic stress that is wilt, collar rot and pod flies and borers at different crop growth stages of most of the pulses. Chemical controls are the only strategy being currently adopted by the farmers and rely on synthetic organic insecticides to manage the most of the insect pests in pulses. This increases the risk of environmental contamination, loss of biodiversity and development of resistance in many insects towards synthetic insecticides. To overcome these problems the farmers paid more attention towards the integrated pest management. IPM integrates cultural, biological and chemical measures to maintain pest populations below economic injury levels while minimizing environmental and human health risks. Despite proven IPM modules for pulses developed by ICAR/NCIPM/ICRISAT and state KVKs, on-farm adoption remains fragmented and variable across regions and pulse types. This review examines the literature on adoption of IPM in pulses in India, synthesizes major findings, and suggests actionable recommendations aligned with UASB-style structure.

Concept and Components of IPM

IPM is based on ecological principles and involves combining multiple pest control methods. The major components of IPM include:

1. Cultural methods - crop rotation, timely sowing, resistant varieties.
2. Mechanical methods - hand picking, traps, destruction of infected plant parts.
3. Biological control - predators, parasitoids, entomopathogenic fungi, bacteria, and nematodes.
4. Botanical pesticides - neem-based formulations.
5. Monitoring and surveillance - pheromone traps and field scouting.
6. Need-based pesticide application - selective and judicious use of chemicals.

IPM aims to reduce dependence on synthetic pesticides and improve sustainability in agriculture.

Methods

A systematic literature search was conducted across academic journals, institutional reports, and extension bulletins (sources include ResearchGate, ICAR epubs, Indian Journal of Agricultural Sciences, NCIPM/ICRISAT publications and recent journal articles). Search terms included combinations of: 'IPM', 'integrated pest management', 'pulses', 'pigeonpea', 'chickpea', 'mungbean', 'black gram', 'lentil', and 'adoption' with geographic filter 'India' (coverage ~2010-2025). Key studies (n>30) reporting empirical adoption rates, determinants, demonstrations and impact assessments were selected for detailed synthesis.

Results and Synthesis

1. Adoption levels and variability: Studies report wide variability in adoption of IPM components across pulse crops and regions. Adoption of some cultural practices (timely sowing, summer ploughing, seed treatment) is higher than adoption of biological controls and monitoring-based decisions. Several district- and state-level surveys indicate majority of farmers fall into low-to-medium adoption categories for IPM modules in chickpea, pigeonpea and mungbean.

Status of IPM Adoption in India: The adoption of IPM technologies in India differs among crops and regions. Adoption levels are generally higher in commercial crops such as cotton, chilli, vegetables, and rice compared to food grains.

Studies from Andhra Pradesh showed that more than 80% of chilli farmers adopted border crops, trap crops, scouting techniques, and mechanical control methods, while only 46% adopted bio-agents. Research in Odisha reported adoption rates of 45% for brinjal IPM modules, 30% for cauliflower, 25% for paddy, and 20% for pigeon pea IPM modules.

A study in Jammu and Kashmir among paddy farmers found that adoption was mainly limited to cultural practices, while adoption of biological and mechanical practices remained low. In Karnataka, hybrid tomato growers with better education and extension contact showed significantly higher adoption of IPM technologies.

Government programs such as Farmer Field Schools (FFS), National Centre for Integrated Pest Management (NCIPM), and Integrated Pest Management Packages have improved awareness and adoption among farmers.

Statistical Data on Adoption of IPM Practices: Several studies conducted in India provide statistical evidence regarding adoption levels of IPM practices:

- Adoption of pheromone traps in chilli cultivation: above 80% in Andhra Pradesh.
- Adoption of bio-agents in chilli cultivation: approximately 46%.
- Adoption rate of brinjal IPM modules in Odisha: 45%.
- Adoption rate of cauliflower IPM modules: 30%.
- Adoption rate of paddy IPM modules: 25%.
- Adoption rate of pigeon pea IPM modules: 20%.
- Farmers receiving extension support had significantly higher adoption rates than farmers without training.
- Partial adoption of IPM practices is more common than complete adoption.

Research indicates that education level, extension contact, scientific orientation, and environmental awareness positively influence adoption behavior.

2. Drivers of adoption: Common positive drivers include farmer education, participation in Farmer Producer Organizations (FPOs) or community groups, extension contact (Krishi Vigyan Kendra demonstrations), farm size, and pest recognition ability. Economic incentives—reduced pesticide cost and yield gains—also encourage adoption.

Economic and Environmental Benefits of IPM: IPM provides several economic and environmental advantages:

- Reduction in pesticide costs.
- Increased net income due to reduced input expenditure.
- Improved soil and environmental health.
- Conservation of natural enemies.
- Reduced pesticide residues in food products.
- Improved biodiversity in agricultural ecosystems.

Studies in pigeon pea cultivation in Andhra Pradesh reported reduced insecticide use and increased net returns among IPM adopters. Farmers adopting IPM also experienced lower pest resistance problems and better ecological balance.

Factors Influencing Adoption of IPM: The following factors strongly influence IPM adoption in India:

- Educational status of farmers.
- Farm size and economic condition.
- Access to extension services.
- Availability of bio-control agents.
- Participation in farmer training programs.
- Knowledge regarding pest identification.
- Social participation and farmer organizations.
- Market demand for residue-free products.

Logistic regression studies revealed that education, scientific orientation, and extension contact are highly significant predictors of adoption.

Role of Extension Services and Government: Extension services play a critical role in improving IPM adoption. Krishi Vigyan Kendras (KVKs), agricultural universities, and government departments conduct demonstrations, training programs, and farmer field schools to improve farmer awareness.

The Government of India established the National Centre for Integrated Pest Management (NCIPM) to promote sustainable pest management practices. Farmer Field Schools have been particularly effective in improving farmers' knowledge regarding pest surveillance and biological control methods.

Future Strategies for Improving IPM Adoption: The following measures can improve adoption of IPM in India:

- a. Strengthening extension education.
- b. Increasing availability of bio-control agents.
- c. Providing subsidies for pheromone traps and bio-pesticides.
- d. Encouraging participatory research.
- e. Developing region-specific IPM packages.
- f. Promoting digital agriculture and mobile-based advisory services.
- g. Integrating traditional knowledge with scientific pest management.
- h. Conducting regular farmer training and demonstrations.

Awareness programs and practical demonstrations can significantly improve adoption behavior among small and marginal farmers.

3. Constraints: Reported constraints include limited availability of biopesticides and botanical formulations at local markets, lack of timely and credible extension advice, perceived complexity of IPM packages, risk-averse behaviour preferring quick knock-down insecticides, lack of monitoring tools (traps, pheromone lures), and weak supply chains for biological inputs.

4. Impact evidence: Field trials and demonstrations (NCIPM/ICAR/ICRISAT & KVK reports) show IPM can reduce chemical pesticide use, increase yields by 10-20% in several pulse crops, and improve profitability when farmers follow recommended modules. Area-wide IPM and SMS-based advisories have demonstrated strong local impacts in targeted regions.

5. Crop-specific highlights: Pigeonpea: Adoption studies highlight use of summer ploughing, NSKE (neem seed kernel extract), pheromone traps and conservation biological control; extension-led area-wide programs reported yield improvements. - Chickpea: Cultural measures and seed treatments are more commonly adopted than biocontrol agents; awareness gaps and market access limit uptake. - Mungbean and blackgram: Seed treatment (Trichoderma, botanicals) and storage pest management (cleaning, inert dust) show moderate adoption in demo studies, but farmer surveys report mixed uptake.

Discussion

The literature suggests that while IPM modules for pulses are technically sound, scaling adoption requires addressing institutional, logistical and perception barriers. Extension demonstrations increase awareness but sustained adoption needs reliable input supply (biopesticides, pheromone lures), locally adapted communication (mobile advisories, SMS), and incentive structures (market linkages for residue-safe produce).

Policy initiatives such as national IPM programs and state-level KVK demonstrations have been effective at pilot scales, yet adoption remains patchy. Strengthening public-private partnerships for biopesticide distribution, investing in community-based monitoring, and promoting farmer field schools can bridge the gap between demonstration and farmer uptake.

Conclusions and Recommendations

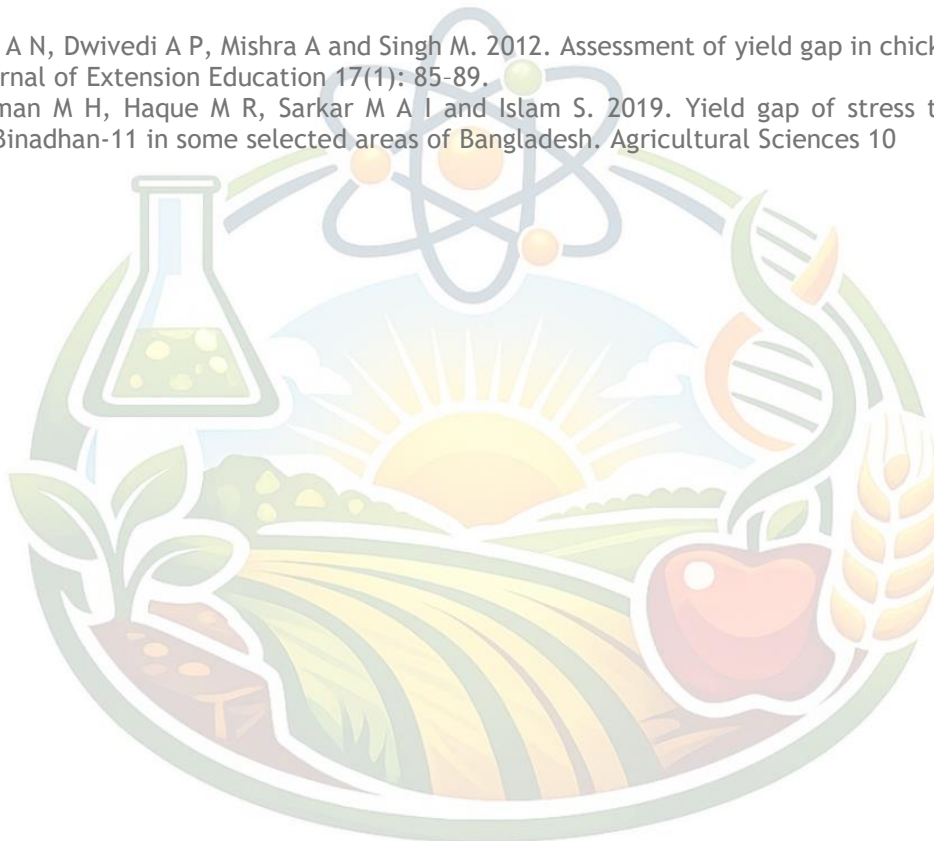
IPM offers clear benefits for sustainable pulse production in India, but adoption is uneven. To accelerate uptake the following are recommended:

1. Strengthen extension: scale up KVK/IPM demonstrations, use local lead farmers and FPOs.
2. Improve supply chains: ensure local availability of quality biopesticides, pheromone traps and diagnostics.
3. Digital advisory services: deploy SMS and app-based pest advisories and decision support tools.
4. Incentivize residue-safe production through market linkage and minor price premium for IPM-grown pulses.
5. Build farmer capacity via repeated trainings, participatory monitoring and farmer field schools.

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Quantification of Sudan Dye Residues in Chilli Powder: Analytical Methods, Occurrence, Health Risks, and Regulatory Perspectives

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Abstract

Sudan dyes (I-IV) are synthetic azo dyes of the aminoazo aromatic class that are illicitly incorporated into chilli and chili-based products to enhance their visual attractiveness and replicate an appealing red hue. These dyes are designated as potential human carcinogens (Group 2B) by the International Agency for Research on Cancer (IARC) and are explicitly banned in food products by regulatory bodies globally, including the European Union (EU), the United States Food and Drug Administration (USFDA), and the Pakistan Standards and Quality Control Authority (PSQCA). This paper thoroughly analyses the chemical characteristics of Sudan dyes I-IV, their adulteration pathways in chilli matrices, the related toxicological issues, and the primary analytical methods used for their identification and quantification. The reviewed methods encompass high-performance liquid chromatography with diode array detection (HPLC-DAD), liquid chromatography-tandem mass spectrometry (LC-MS/MS), thin-layer chromatography (TLC), enzyme-linked immunosorbent assay (ELISA), surface-enhanced Raman spectroscopy (SERS), and electrochemical sensor methodologies. Significant attention is given on sample preparation methodologies, including liquid-liquid extraction, solid-phase extraction (SPE), QuEChERS, and dispersive solid-phase extraction (DSPE). Documented limits of detection (LODs) vary from 0.001 to 0.5 mg/kg across diverse methodologies and matrices. Data from various nations reveal contamination rates in locally marketed chilli powder samples ranging from 5% to 60%. A comprehensive analysis of regulatory frameworks, maximum residue limits, and monitoring problems is presented, along with prospective advancements in quick, field-deployable detection technology.

Keywords: Sudan dyes; *Capsicum annum*; chilli adulteration; HPLC-DAD; LC-MS/MS; food safety; azo dyes; carcinogens; QuEChERS.

Introduction

Chilli (*Capsicum annum* L.) and its derivative spice products hold a pivotal role in global culinary traditions, especially in South Asia, Latin America, the Middle East, and East Africa. Chilli powder is esteemed for its distinctive spiciness, due to capsaicinoids, and its vibrant red colour, which comes from natural carotenoids such as capsanthin and capsorubin. These carotenoids significantly deteriorate with processing, storage, and light exposure, leading to a reduced red hue that diminishes the product's commercial value. To counteract this inherent colour degradation and to mislead consumers while commanding elevated prices, unethical vendors engage in the adulteration of chilli powder with synthetic colourants, such as coal-tar-derived azo compounds referred to as Sudan dyes (Tateo & Bononi, 2004; Calbiani et al., 2004).

Sudan dyes are a category of fat-soluble synthetic azo dyes, encompassing Sudan I (1-phenylazo-2-naphthol), Sudan II (1-[(2,4-dimethylphenyl)azo]-2-naphthol), Sudan III (1-[4-(phenylazo)phenylazo]-2-naphthol), and Sudan IV (1-[4-(o-tolylazo-o-tolylazo)]-2-naphthol), along with the closely associated Sudan Red B and Sudan Orange G. These compounds are employed industrially as colourants in petroleum products, shoe polish, floor wax, and plastics, although lack permission for food usage. Their lipophilic characteristics render them especially susceptible to buildup in fatty food matrices, such as oily spices, which raises significant concerns about chronic dietary exposure (Genualdi et al., 2012; Huang et al., 2005).

The initial significant food safety alert regarding Sudan dye contamination in chilli-based products was issued by the European Food Safety Authority (EFSA) in 2003, succeeded by a pivotal Rapid Alert System for Food and Feed (RASFF) notification in 2005, which involved the recall of more than 580 products from European supermarkets contaminated with Sudan I derived from imported chilli spices. Subsequently, surveillance studies have validated the pervasive use of Sudan dyes in chilli goods sold throughout South Asia, Southeast Asia, Africa, and the Middle East (European Commission, 2005; SCF, 2005).

This article offers a thorough, scientifically robust examination of: (i) the physicochemical and structural properties of Sudan dyes; (ii) the toxicological mechanisms that contribute to their carcinogenicity; (iii) the sample preparation techniques appropriate for chilli matrices; (iv) the validated analytical methods for quantifying Sudan dyes; (v) global prevalence data; and (vi) the existing regulatory framework, accompanied by a critical evaluation of limitations and future directions for enhanced food safety monitoring.

Chemical Properties and Classification of Sudan Dyes

1. Structural Characteristics: Sudan dyes belong to the aminoazo aromatic family and share the common structural motif of one or more azo linkages ($-N=N-$) bridging aromatic rings, with a naphthol moiety serving as the coupling component. The four primary Sudan dyes differ in the number of azo linkages and the substitution pattern on the aromatic rings. Sudan I and Sudan II are monoazo compounds, whereas Sudan III and Sudan IV are bisazo compounds. The presence of hydroxyl groups adjacent to the azo bridge confers a hydrazone tautomeric form that is stabilized by intramolecular hydrogen bonding (Marmion, 1991; Berzas Nevado et al., 2009).

All four dyes exhibit strong absorption in the visible spectrum (400-550 nm), which is exploited in spectrophotometric detection methods. Their log P (octanol-water partition coefficient) values range from 4.0 (Sudan I) to approximately 6.0 (Sudan IV), confirming pronounced lipophilicity and preferential partitioning into fatty food matrices. The molecular weight ranges from 248.28 g/mol (Sudan I) to 380.48 g/mol (Sudan IV). These physicochemical properties directly influence method development choices, particularly solvent selection for extraction (Cheung et al., 2013; Calbiani et al., 2004).

Table 1. Physicochemical Properties of Sudan Dyes I-IV:

Dye	CAS No.	MW (g/mol)	λ_{max} (nm)	log P	Molecular Formula
Sudan I	842-07-9	248.28	478	4.00	C ₁₆ H ₁₂ N ₂ O
Sudan II	3118-97-6	276.33	493	4.56	C ₁₈ H ₁₆ N ₂ O
Sudan III	85-86-9	352.41	508	5.46	C ₂₂ H ₁₆ N ₄ O
Sudan IV	85-83-6	380.46	520	6.06	C ₂₄ H ₂₀ N ₄ O

MW = molecular weight; λ_{max} = wavelength of maximum absorption; log P = partition coefficient (octanol/water).

2. Photostability and Thermal Stability: Sudan dyes demonstrate moderate to high thermal stability, with decomposition temperatures generally exceeding 200 °C, making them resistant to conventional food processing methods such as grinding, cooking, and spray-drying employed in chilli powder manufacture. Their photostability is lower compared to thermal stability; prolonged UV exposure causes partial photodegradation via azo bond cleavage, generating aromatic amine photoproducts that may be independently genotoxic. This characteristic is exploited in photocatalytic degradation research but complicates long-term storage of analytical standards (Berzas Nevado et al., 2009; Huang et al., 2005).

Toxicological Profile and Health Implications

1. Carcinogenicity and Genotoxicity: The IARC has classified Sudan I as a Group 2B carcinogen (possibly carcinogenic to humans) based on sufficient evidence of carcinogenicity in experimental animals and limited evidence in human epidemiological data. Sudan II, III, and IV are similarly classified or considered to exhibit analogous genotoxic potential, though formal IARC evaluations are ongoing. The primary mechanism of carcinogenicity involves metabolic activation of the azo group by hepatic and intestinal azo-reductases, yielding aromatic amines and reactive nitroso intermediates capable of forming DNA adducts, particularly at guanine N7 and C8 positions (IARC, 1975; Combes & Bhatt, 2003).

Studies employing the Ames test and in vitro micronucleus assays have consistently demonstrated the mutagenic activity of Sudan I and its primary metabolite 1-amino-2-naphthol, with *Salmonella typhimurium* strains TA98 and TA100 (with S9 activation) showing strong mutagenic responses. Sudan I has been shown to induce hepatocellular carcinoma in rodent models following chronic dietary exposure, and to promote urinary bladder papillomas in rats co-exposed with known initiating carcinogens (Stiborova et al., 2002; Cheung et al., 2013).

2. Immunotoxicity and Organ Toxicity: Beyond their carcinogenic potential, Sudan dyes exhibit immunotoxic effects characterized by suppression of lymphocyte proliferation, inhibition of natural killer (NK) cell activity, and altered cytokine production in in vitro and in vivo systems. Hepatotoxicity has been documented via elevation of serum alanine aminotransferase (ALT) and aspartate aminotransferase (AST) activities in rodent studies. Sudan IV, due to its greater lipophilicity, demonstrates preferential bioaccumulation in adipose tissue and the liver, with a longer biological half-life compared to Sudan I and II (El-Desouky et al., 2018; Combes & Bhatt, 2003).

3. Acceptable Daily Intake and Threshold of Concern: No Acceptable Daily Intake (ADI) has been established for any Sudan dye, as their genotoxic and potentially carcinogenic mechanisms do not admit a definitive no-observed-effect level (NOEL) suitable for risk characterization using the classical safety factor approach. The European Food Safety Authority (EFSA) has assessed the dietary exposure risk using the Margin of Exposure (MOE) approach, concluding that MOE values for realistic dietary exposure scenarios are of concern and warrant strict enforcement of the prohibition on Sudan dye use in food (EFSA, 2005).

Analytical Methods for Sudan Dye Detection and Quantification

1. High-Performance Liquid Chromatography with Diode Array Detection (HPLC-DAD): HPLC-DAD is the most widely employed reference method for Sudan dye quantification in chilli matrices and is the basis of the official European Commission method (2005/402/EC). Separation is typically performed on a reversed-phase C18 column (150 × 4.6 mm, 5 µm or 3.5 µm particle size) using gradient elution with acetonitrile and water or methanol/water as the mobile phase,

with UV-Vis detection at 478 nm (Sudan I) and 508 nm (Sudan III/IV). The simultaneous detection of multiple Sudan dyes is achieved through programmed wavelength switching or by using the DAD array for spectral confirmation (Calbiani et al., 2004; Genualdi et al., 2012).

Validated HPLC-DAD methods in chilli matrices report LODs of 0.05-0.5 mg/kg and limits of quantification (LOQs) of 0.1-1.0 mg/kg for Sudan I-IV, satisfying the EU performance criterion of $LOQ \leq 0.5$ mg/kg for Sudan I and $LOQ \leq 1.0$ mg/kg for Sudan II-IV in foods. Inter-laboratory validation studies conducted through the European Reference Laboratory for Food Contact Materials (EURL-FCM) have confirmed the robustness of HPLC-DAD methods with between-laboratory RSDs below 15% (European Commission, 2005; Tateo & Bononi, 2004).

2. Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS): LC-MS/MS combining electrospray ionization (ESI) or atmospheric pressure chemical ionization (APCI) with triple-quadrupole mass analyzers provides unambiguous molecular identification and superior selectivity compared to UV detection, enabling reliable quantification at sub-ppb levels in complex spice matrices. Multiple reaction monitoring (MRM) transitions are monitored for each Sudan dye: Sudan I (249.1 $\rightarrow$ 232.0 and 249.1 $\rightarrow$ 168.1), Sudan II (277.1 $\rightarrow$ 168.1 and 277.1 $\rightarrow$ 198.0), Sudan III (353.2 $\rightarrow$ 198.1 and 353.2 $\rightarrow$ 168.0), Sudan IV (381.2 $\rightarrow$ 226.1 and 381.2 $\rightarrow$ 168.0) (Cheung et al., 2013; Wang et al., 2016).

Reported LODs for LC-MS/MS in chilli matrices range from 0.001 to 0.01 mg/kg, providing a 10-100-fold improvement in sensitivity compared to HPLC-DAD. This enhanced sensitivity is critical for detecting trace contamination arising from cross-contamination during food processing rather than deliberate adulteration. The method is increasingly adopted as the confirmatory technique in official control laboratories across the EU and Asia (Deng et al., 2012; Berzas Nevado et al., 2009).

3. Thin-Layer Chromatography (TLC) and High-Performance TLC (HPTLC): TLC and HPTLC on silica gel G60 plates represent low-cost, high-throughput screening tools well suited for resource-limited laboratories in developing countries where sophisticated LC-MS/MS equipment is unavailable. The mobile phase system of benzene:cyclohexane:acetone (5:4:1, v/v/v) achieves satisfactory separation of Sudan I-IV with characteristic R_f values of 0.73, 0.68, 0.59, and 0.54 respectively under UV light at 366 nm. Densitometric quantification using reflectance scanning at 478 nm provides LODs of 0.1-1 mg/kg. The primary limitation is co-migration of naturally occurring chilli carotenoids, necessitating preliminary SPE cleanup (Tateo & Bononi, 2004; El-Desouky et al., 2018).

4. Enzyme-Linked Immunosorbent Assay (ELISA): Competitive indirect ELISA methods using polyclonal and monoclonal antibodies raised against Sudan I-BSA conjugate haptens have been developed for rapid screening of chilli samples. Commercial ELISA kits for Sudan I detection exhibit LODs of 0.005-0.05 mg/kg with a sample throughput of 90 samples per day, far exceeding the capacity of chromatographic methods. Cross-reactivity of Sudan I antibodies with Sudan II (typically 40-80%) and Sudan III (15-35%) can provide a broad-screen result but requires confirmatory LC analysis for definitive identification of the specific dye present (Wang et al., 2016; Zhao et al., 2004).

5. Surface-Enhanced Raman Spectroscopy (SERS): SERS platforms using gold or silver nanoparticles as SERS substrates have demonstrated remarkable sensitivity for Sudan dye detection, exploiting the electromagnetic enhancement of Raman scattering signals at molecule-nanoparticle junctions. Characteristic Raman bands for Sudan I at 1394 cm^{-1} (N=N stretching), 1138 cm^{-1} (C-N stretching), and 1456 cm^{-1} (phenyl ring deformation) serve as analytical fingerprints. SERS LODs in buffer systems reach as low as 10^{-9} mol/L, though matrix effects in chilli extracts typically reduce practical sensitivity to 0.01-0.1 mg/kg (Huang et al., 2014; Cheung et al., 2013).

6. Electrochemical Methods: Electrochemical sensors based on modified glassy carbon electrodes (GCE) or carbon paste electrodes functionalized with molecularly imprinted polymers (MIPs), graphene oxide, or carbon nanotubes have been developed for Sudan dye detection via differential pulse voltammetry (DPV) and square wave voltammetry (SWV). Oxidation peaks for Sudan I at approximately +0.56 V (vs. Ag/AgCl) and Sudan II at +0.62 V provide electrochemical selectivity. MIP-based sensors achieve LODs of 0.02-0.08 $\mu\text{mol/L}$ with linear dynamic ranges spanning two orders of magnitude, and offer the advantage of field-deployable, real-time monitoring without requirement for chromatographic separation (Deng et al., 2012; Wang et al., 2016).

Table 2. Comparison of Analytical Methods for Sudan Dye Quantification in Chilli:

Method	LOD (mg/kg)	LOQ (mg/kg)	Recovery (%)	Time/Sample	Key Reference
HPLC-DAD	0.05-0.5	0.1-1.0	85-105	20-30 min	Calbiani et al. (2004)
LC-MS/MS	0.001-0.01	0.003-0.05	88-108	15-25 min	Cheung et al. (2013)
HPTLC	0.1-1.0	0.5-2.0	75-95	30-45 min	Tateo & Bononi (2004)
ELISA	0.005-0.05	0.02-0.1	80-100	2-4 h (batch)	Wang et al. (2016)
SERS	0.01-0.1	0.05-0.3	78-98	5-10 min	Huang et al. (2014)
Electrochemical	0.01-0.2	0.05-0.5	80-102	5-15 min	Deng et al. (2012)

LOD = limit of detection; LOQ = limit of quantification.

Occurrence of Sudan Dyes in Chilli Products: Global Surveillance Data

Extensive surveillance surveys have documented the widespread occurrence of Sudan dye contamination in chilli products across multiple continents. The following section synthesizes key findings from representative studies.

1. Asian Studies: A comprehensive survey of chilli powder samples from retail markets in Pakistan conducted by Bhatti et al. (2019) identified Sudan I contamination in 38.5% of 130 samples at levels ranging from 0.28 to 482 mg/kg. Sudan II and Sudan IV were detected in 18.4% and 11.5% of samples respectively, with several samples exceeding 100 mg/kg—a level approximately 100-200-fold above the EU performance criterion. A similar survey in China reported by Deng et al. (2012) found Sudan I in 22.3% of chilli powder samples from Guangdong and Hunan provinces, with maximum concentrations of 18.7 mg/kg. Indian market surveillance data published by Arora & Bhatt (2016) documented Sudan I in 31% and Sudan III in 19% of analyzed chilli samples from major spice-producing states (Bhatti et al., 2019; Deng et al., 2012).

2. African Studies: In Egyptian markets, El-Desouky et al. (2018) surveyed 75 chilli and paprika samples and detected Sudan I in 60% and Sudan IV in 24% of samples, reflecting particularly high adulteration rates attributable to limited regulatory enforcement capacity. Moroccan surveillance identified Sudan I and II contamination in 45% of locally processed chilli powder samples with concentrations up to 790 mg/kg, among the highest reported globally. These levels in North African markets are of particular public health concern given the high per capita consumption of chilli-based products in these regions (El-Desouky et al., 2018).

3. European RASFF Notifications: European RASFF portal data document over 1,200 notifications involving Sudan dye contamination in spices, chilli, and chilli-containing products between 2003 and 2023, with chilli and paprika of Indian, Pakistani, and Bangladeshi origin accounting for the majority of alerts. The 2005 incident involving Worcester sauce contaminated with chilli paste containing Sudan I precipitated recalls of over 580 derivative food products and represented the most extensive single food safety recall in UK history at the time, highlighting the amplifying effect of chilli-derived ingredients in processed food supply chains (European Commission, 2005; RASFF, 2023).

Regulatory Frameworks and Maximum Residue Limits

1. European Union: EU Regulation EC No. 1333/2008 on food additives does not authorize any Sudan dye for use as a food color. Commission Decision 2005/402/EC mandates that all consignments of chilli, chilli products, turmeric, and palm oil originating from defined third countries must be accompanied by an official analytical certificate confirming the absence of Sudan I-IV before import clearance. The performance criterion established by the EU for official control methods is an LOQ of ≤ 0.5 mg/kg for Sudan I and ≤ 1.0 mg/kg for Sudan II-IV. Member States are required to report all positive findings to the RASFF within 24 hours of confirmation (European Commission, 2005; EC Regulation 1333/2008).

2. United States: The USDA prohibits the use of Sudan dyes in food under 21 CFR § 73 and § 74, which list only GRAS-approved color additives. Sudan dyes are not listed as permitted color additives. The FDA exercises import alert authority to detain shipments of spices and chilli products with historical non-compliance records. However, the US lacks a codified maximum residue limit specifically for Sudan dyes in food matrices, and enforcement is exercised under the general adulteration provisions of the Federal Food, Drug, and Cosmetic Act (FD&C Act) (USFDA, 2023).

3. Pakistan: In Pakistan, the Pure Food Ordinance (1960) and subsequent Provincial Food Authority Acts (Punjab, Sindh, KPK, and Balochistan, 2011-2016) prohibit the addition of any non-permitted color to food products. The PSQCA has established a zero-tolerance policy for Sudan dyes in spices under PS 3675:2020 (Spices—Requirements). However, implementation and enforcement remain inconsistent due to limited laboratory infrastructure, inadequate trained inspectors, and the dominance of informal small-scale spice processing operations outside formal regulatory oversight (PSQCA, 2020; Bhatti et al., 2019).

Challenges and Future Perspectives

1. Matrix Complexity: The chilli matrix poses unique analytical challenges arising from co-extractable compounds including carotenoids (particularly capsanthin and β -carotene), capsaicinoids, flavonoids, and chlorophylls that interfere with chromatographic separation and immunoassay cross-reactivity. The natural red-orange coloration of chilli extracts can mask spectrophotometric signals at wavelengths used for Sudan dye detection, necessitating comprehensive sample cleanup steps that add time and cost. Developing simplified, matrix-tolerant methods remains an active research priority (Genualdi et al., 2012; Berzas Nevado et al., 2009).

2. Emerging Sudan Dye Analogues: Regulatory surveillance has increasingly identified adulteration with Sudan dye analogues and derivatives not covered by existing reference methods, including Sudan Red B, Sudan Orange G, Sudan Red G, and more recently Sudan Red 7B and Sudan Black B. These compounds exhibit distinct chromatographic retention times and mass spectral fragmentation patterns, requiring regular expansion and revalidation of analytical methods. Multi-target methods capable of simultaneously detecting 10-20 azo dye analogues using LC-QTOF-MS are emerging as the gold standard for comprehensive screening (Wang et al., 2016; Huang et al., 2014).

3. Rapid Field Detection: The deployment of validated rapid screening methods at point-of-entry and point-of-sale locations represents the most significant unmet need in Sudan dye surveillance for developing countries. Portable near-infrared (NIR) spectrometers, lateral flow immunochromatographic strips (LFIA), and smartphone-coupled colorimetric sensors based on aptamer recognition offer promising avenues. LFIA strips for Sudan I detection with visual readout LODs of 5-10 mg/kg have been developed and demonstrate acceptable false-negative rates compared to HPLC reference methods in spiked chilli samples (Wang et al., 2016; Huang et al., 2014).

4. Blockchain and Traceability Technologies: Supply chain transparency represents a complementary approach to analytical surveillance. Blockchain-based food traceability systems piloted in spice supply chains from India and Pakistan to European importers have demonstrated the capability to record batch-level analytical certificates, reduce documentation fraud, and enable targeted rather than blanket surveillance programs. Integration of analytical data with geographic information systems (GIS) can identify geographic hotspots of adulteration for targeted enforcement action (RASFF, 2023; EFSA, 2005).

Conclusions

Sudan dyes I-IV represent a significant, persistent, and globally distributed food safety hazard in chilli and chilli-derived products. Their illegal use is primarily motivated by economic factors and is facilitated by the visual similarity of synthetic dyes to natural carotenoid pigments, incomplete supply chain oversight, and the limitations of conventional visual inspection at border controls. The analytical toolkit for Sudan dye detection has matured considerably, with LC-MS/MS providing the highest sensitivity and specificity while HPLC-DAD remains the practical standard for official control laboratories. Emerging platforms including SERS, electrochemical sensors, and LFIA strips offer compelling advantages for rapid screening, though further validation in authentic chilli matrices is required before widespread deployment.

Global surveillance data consistently indicate contamination rates between 5 and 60% across chilli-producing and chilli-consuming regions, with concentrations in individual samples occasionally exceeding 100 mg/kg—levels that represent a non-trivial carcinogenic risk under high chilli consumption scenarios. Strengthening regulatory capacity in producing countries through investment in laboratory infrastructure, inspector training, and industry awareness programs is essential to complement import controls at destination markets. The development and international harmonization of rapid screening methods deployable at farm gate and processing unit level represents the most impactful future direction for reducing consumer exposure to these prohibited carcinogenic colorants.

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Heteropteran Predators: Valuable Allies in Integrated Biological Control

Article ID: 74013

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Traditionally, biological control of insect pest by predator has been predominantly referred only in Coccinellidae and Chrysopidae for augmentation. Other hemipteran predatory groups of insects are highly ignored due to poor understanding on their life history strategy and ecology. In addition to that problems associated with measuring the biological control provided by the hemipteran predator is also partially responsible for limited research in this area. In the complex agroecosystem, where the main pest is obsolescent after suppression or characterized by migratory behavior in such a case hemipterans being a generalist predators have a survival advantage over host specific predator or parasitoids by being able to switch to secondary prey during the absence of main pest.

The Heteroptera or true bugs are a morphologically and ecologically diverse group of insects. The true bugs have piercing-and-sucking mouthparts. However, while other hemipterans are exclusively phytophagous, the true bugs have evolved to prey on arthropods and other animals and to become ectoparasites of vertebrates. The central concept of this evolution is their piercing and sucking mouthparts and sophisticated venom apparatus. The piercing-sucking mouthparts of the true bugs have allowed diversification from a plant-feeding ancestor into a wide range of trophic strategies that include predation and blood-feeding. Hemipteran predators are widely distributed in all ecosystem like terrestrial, aquatic and even the haematophagous bugs. Out of 89 families of predators only few families like Reduviidae, Pentatomidae, Anthracoridae, Miridae, Lygaeidae, Nabidae, Belastomidae predatory behaviours are well studied for use as predators in agriculture pest management.

Heteropteran predators are well adapted to various agroclimatic and agroecological regions. The life cycle comprises of an egg, variable nymphal instars, and adult stages. Eggs are laid on stems and petioles of plants with protective encrustation to the eggs. Nymph resemble the adults in all aspects except wings and reproductive capacity. Adult period is long unlike moths and butterflies. Most of them are generalist predators and feed on larvae of lepidopteran, planthoppers, aphids, mealybugs, thrips, psyllids etc. The specialized predatory behaviours and novel prey capturing strategies make them the potential and generalistic predators.

Predatory Behaviour

Predators commonly rely on cryptic morphology and behaviour to avoid detection by the prey they are stalking or preparing to ambush. However, predators belonging to a less-studied minority actively advertise their presence and use deceptive communication to lure their prey into range of attack. Hemipteran predators express a ray of predatory behaviour, which made them potential predators are:

1. Aggressive mimicry: Aggressive mimicry is a form of mimicry in which predators mimic the prey of its host, host itself etc. to avoid them being correctly identified by their prey or host. Aggressive mimicry is opposite in principle to defensive mimicry, where the mimic generally benefits from being treated as harmful. Such type of mimicry expressed by heteropteran predators for instance assassin bug *Stenolemus bituberus* thread-legged insect (Emesinae) preys on spiders, by entering their web and plucking its silk threads until the spider approaches within the strike. This vibrational aggressive mimicry matches a general pattern of vibrations which spiders treat as prey, having a similar temporal structure and amplitude to leg and body movements of typical prey caught in the web.

2. Venom association: The venom of predaceous species is not only used to digest prey, but for defense (by causing pain when injected into a potential predator) and to rapidly immobilise and kill prey.

3. Resin coating forelegs: Apiomerini (Reduviidae: Harpactorinae) collect plant resins with their forelegs and use these sticky substances for prey capture and maternal care. Females mix the plant resin with ventral abdominal secretions use this mixture to coat on the eggs. After hatching the young ones coat the resin on the egg coat to their forelegs which helps in capturing prey and defense as well. The specialized prey capturing strategies like the above explained ones along with normal prey capturing strategies helps the hemipteran predators to become the efficient predators. Some potential hemipteran predators are *Cyrtorhinus lividipennis*, *Orius tanctillus*, *Eocanthecona furcellata*, *Rhynocoris marginatus*, *Geocoris ochropterus*, etc., are in the agroecosystem naturally and maintain pest population in natural control.

Predator Family	Predator Species	Major Prey
Miridae	<i>Cyrtorhinus lividipennis</i>	Eggs and nymphs of brown planthopper (<i>Nilaparvata lugens</i>), white-backed planthopper (<i>Sogatella furcifera</i>), green leafhopper (<i>Nephotettix virescens</i>)

Anthocoridae	<i>Orius insidiosus</i>	Thrips, aphids, mites, whiteflies, insect eggs
	<i>Orius laevigatus</i>	Thrips, whiteflies, aphids, mites
Geocoridae	<i>Geocoris punctipes</i>	Aphids, whiteflies, leafhoppers, caterpillar eggs
Nabidae	<i>Nabis capsiformis</i>	Planthoppers, leafhoppers, aphids, caterpillars
	<i>Nabis americoferus</i>	Aphids, thrips, caterpillars, leafhoppers
Reduviidae	<i>Rhynocoris marginatus</i>	Lepidopteran larvae, beetles, grasshoppers
	<i>Rhynocoris fuscipes</i>	Caterpillars, beetles, other soft-bodied insects
Pentatomidae (Asopinae)	<i>Eocanthecona furcellata</i>	<i>Spodoptera</i> , <i>Helicoverpa</i> , other caterpillars
	<i>Andrallus spinidens</i>	Rice leaffolders, armyworms, stem borers
	<i>Podisus maculiventris</i>	Caterpillars, beetle larvae, sawfly larvae

Table.1: List of important Heteroptean predators.

Conclusions

In the complex agroecosystem, where the main pest is become obsolescent after suppression or characterized by migratory behavior in such a case hemipterans being a generalist predators have a survival advantage over host specific predator or parasitoids by being able to switch to secondary prey during the absence of main pest. Hemipteran predators are having high potential to use in agroecosystem. Morphologically and ecological adaptations along with novel prey capturing strategies make them efficient predator. For the successful utilization of any bioagent, it is important to develop protocols for its mass production. Efficient mass production techniques helps in Biointensive IPM in pest management.

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Sustainable Pest and Disease Management in Leafy Vegetables through IPDM

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Abstract

Leafy vegetables such as spinach, lettuce, coriander, and amaranthus are highly nutritious and widely consumed, but their production is often affected by various pests and diseases. Insect pests like aphids, whiteflies, thrips, and caterpillars, along with fungal and bacterial pathogens, can cause significant yield and quality losses. Integrated Pest and Disease Management (IPDM) offers an effective and eco-friendly approach to address these challenges. It combines cultural, biological, mechanical, and need-based chemical methods to manage pests in a sustainable manner. Practices such as crop rotation, use of resistant varieties, biological control agents, and proper field management help reduce dependency on chemical pesticides. However, challenges like limited farmer awareness, pest resistance, and lack of access to advanced technologies still exist. Strengthening research, farmer training, and adoption of modern tools can enhance IPDM effectiveness, ensuring safe, productive, and environmentally sustainable cultivation of leafy vegetables.

Introduction

Leafy vegetables are essential for global food security and human nutrition, yet their cultivation is often challenged by numerous pests and diseases. Common insect pests like aphids, whiteflies, thrips, and caterpillars, along with pathogens caused by fungi, bacteria, and viruses, can significantly reduce both yield and quality.

In the past, chemical pesticides have been widely used as the main method of controlling these problems. However, their overuse has resulted in several issues, including environmental pollution, contamination of soil and water, development of pest resistance, and harm to beneficial organisms and human health.

Integrated Pest and Disease Management (IPDM) offers a more sustainable and eco-friendly approach to managing these challenges. It involves the combined use of different control methods such as cultural practices, biological agents, mechanical measures, and need-based chemical applications. This approach emphasizes reducing reliance on chemicals while promoting environmentally safe techniques.

Practices like crop rotation, selection of resistant varieties, use of natural enemies, and precise application of pesticides help in effective and long-term pest control. In addition, modern developments in biotechnology, precision farming, and nanotechnology are enhancing the efficiency of IPDM strategies.

Principles of Integrated Pest and Disease Management

- 1. Monitoring and Surveillance:** Regular field observation helps detect pests and diseases at an early stage. Tools like traps and simple monitoring methods make it easier to decide the right time for control measures.
- 2. Economic Threshold Level (ETL):** Control actions are taken only when pest or disease levels reach a stage where they can cause economic loss. This avoids unnecessary pesticide use and reduces costs.
- 3. Use of Resistant Varieties:** Growing resistant crop varieties helps protect plants from major pests and diseases. This reduces the need for chemical control and supports sustainable farming.
- 4. Biological Control:** Natural enemies such as predators, parasitoids, and beneficial microbes help keep pest populations under control. This method is safe for the environment and maintains ecological balance.
- 5. Cultural Practices:** Practices like crop rotation, proper irrigation, field sanitation, and intercropping help prevent pest and disease buildup. These methods disrupt pest life cycles and improve crop health.
- 6. Chemical Control as a Last Resort:** Pesticides are used only when other methods are not enough and pest levels are high. Careful and limited use helps avoid resistance and reduces harm to the environment.

Major Pests and Diseases in Leafy Vegetables

- 1. Aphids (*Aphis* spp.):** Small sap-sucking insects that weaken plants by draining nutrients. They also spread viral diseases from one plant to another.
- 2. Whiteflies (*Bemisia tabaci*):** These insects suck plant sap and reduce plant vigour. They are also important carriers of several plant viruses.

3. Thrips (Thripidae): Tiny insects that damage leaves, causing curling, silvery patches, and distortion. They also transmit viral infections.

4. Caterpillars (Lepidoptera species): Larval stage of moths and butterflies that feed on leaves and fruits. They cause heavy defoliation and direct crop damage.

Major Diseases in Leafy Vegetables

1. Powdery Mildew (*Erysiphe*, *Podosphaera*): You'll notice a white, powder-like coating on the leaves of crops like spinach, lettuce, and coriander. As it spreads, it reduces the plant's ability to make food, which slows down growth.

2. Downy Mildew (*Peronospora*, *Plasmopara*): This disease shows up as yellow patches on the top of leaves, with a soft, fuzzy growth underneath. It commonly affects leafy vegetables like spinach, fenugreek, and lettuce, making plants weak.

3. Leaf Spot (*Pseudomonas*, *Xanthomonas*): Small brown or black spots appear on leaves of crops such as amaranthus, spinach, and mustard greens. Over time, these spots increase and reduce the overall health of the plant.

4. Bacterial Wilt (*Ralstonia solanacearum*): Plants like lettuce and spinach may suddenly wilt even when the soil has enough moisture. This happens because the bacteria block water movement inside the plant.

Cultural Control

1. Crop Rotation: Growing different leafy vegetables or rotating them with other crops helps break the life cycle of pests and soil-borne diseases, reducing their buildup in the field.

2. Use of Resistant and Tolerant Varieties: Choosing varieties of leafy vegetables like spinach, lettuce, and amaranthus that can resist pests and diseases reduces the need for chemical sprays.

3. Proper Irrigation and Drainage Management: Maintaining the right amount of moisture and avoiding waterlogging helps prevent problems like root rot and damping-off, keeping the plants healthy.

Mechanical and Physical Control

1. Handpicking and Destroying Infected Plants: Removing affected leaves, plants, eggs, and larvae by hand helps reduce pest spread. This is especially useful in small fields and kitchen gardens.

2. Use of Traps (Pheromone, Sticky, and Light Traps): Different traps are used to attract and catch pests, helping to monitor and lower their population in crops like spinach and lettuce.

3. Mulching and Netting: Mulching helps control weeds and soil pests, while netting acts as a physical barrier to protect leafy vegetables from insects like aphids and whiteflies.

Biological Control

1. Encouraging Beneficial Insects: Helpful insects like lady beetles, lacewings, and parasitic wasps feed on harmful pests such as aphids and caterpillars, naturally keeping their numbers under control.

2. Use of Microbial Agents: Biological products like *Bacillus thuringiensis* (Bt) and *Beauveria bassiana* infect and kill specific insect pests, while remaining safe for beneficial organisms and the environment.

Chemical Control

1. Application of Biopesticides: Products like neem-based formulations, microbial pesticides, and plant extracts help control pests in crops like spinach and coriander in an eco-friendly way.

2. Use of Botanical Extracts: Natural substances such as pyrethrins and essential oils act as effective alternatives to chemical pesticides, helping manage pests safely.

3. Rational Use of Synthetic Pesticides: Chemical pesticides are used only when pest levels cross the Economic Threshold Level (ETL). They are applied carefully by following resistance management practices to avoid overuse and maintain their effectiveness.

Challenges of IPDM in Leafy Vegetables

Limited Farmer Awareness: Many farmers are not fully aware of IPDM practices and mainly depend on chemical pesticides for quick pest control.

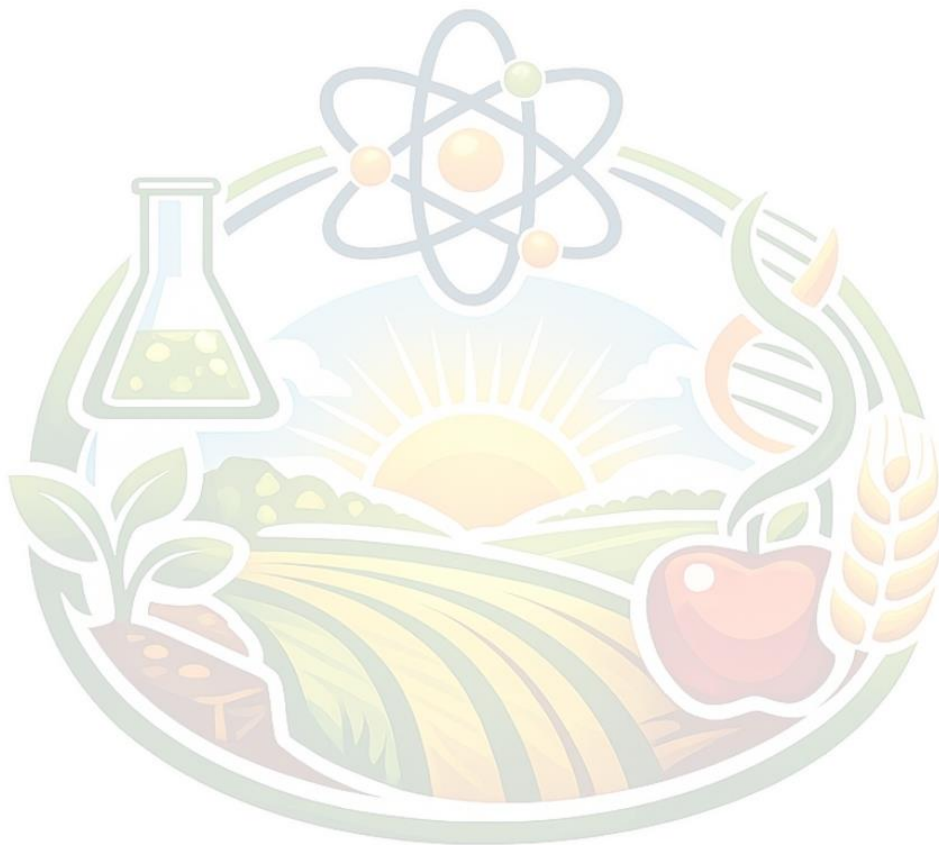
Pest Resistance: Excessive use of pesticides leads to pest resistance, making chemicals less effective over time.

Limited Bio-based Solutions: Biopesticides and beneficial microbes are eco-friendly, but their performance varies under different environmental conditions.

Poor Access to Modern Technology: High cost and lack of technical knowledge limit the use of advanced tools like IoT and AI for pest monitoring.

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Relevance of Community-Based Organizations in the Current Scenario

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Abstract

Community-Based Organizations (CBOs) play a significant role in addressing grassroots challenges and promoting sustainable development. In the present scenario, agriculture faces multiple challenges such as climate change, resource degradation and market inefficiencies. CBOs act as a bridge between farmers, institutions and government agencies, facilitating knowledge transfer, capacity building and resource mobilization. This article highlights the importance, roles, functions and challenges of CBOs in agricultural development, rural empowerment and socio-economic transformation.

Keywords: *Community-Based Organizations, rural development and sustainability.*

Introduction

Community-Based Organizations (CBOs) operate at the local level with a primary focus on addressing the unique needs and challenges of specific communities. They are typically formed and led by community members, following a grassroots approach to problem-solving and development. CBOs adopt a people-centric model that promotes access to microfinance, encourages active participation in development processes and contributes to improvements in community health, education and infrastructure over time. These organizations exist in diverse forms such as Self-Help Groups (SHGs), Farmer Producer Organizations (FPOs), cooperatives, youth groups, water user groups and women's groups, each addressing specific social, economic and developmental needs of the community (Augusty *et al.*, 2020).

Current Scenario of CBOs

In the Indian context, Community-Based Organizations (CBOs) play a crucial role in grassroots development and service delivery. India has over 3 million registered NGOs and CBOs, making it one of the largest voluntary sectors in the world. According to report of NITI Aayog 2021, a significant proportion of these organizations are involved in rural development, health, education and livelihood support. Under the National Rural Livelihoods Mission, more than 8 crores (80 million) rural women have been mobilized into Self-Help Groups (SHGs), which function as strong community-based institutions. In the health sector, community-level workers like ASHAs contribute significantly, with over 10 lakhs ASHA workers supporting public health services across the country. Additionally, community-driven watershed and natural resource management programs have covered over 50 million hectares of land, improving livelihoods and resilience. These figures highlight the immense contribution of CBOs in strengthening participatory development and inclusive growth in rural India.

Role and Significance of CBO's in Communities

CBOs also play a significant role in strengthening communities by fostering collective action and local leadership. They enhance access to essential services such as healthcare, education and livelihood opportunities, particularly in underserved areas. CBOs also contribute to improved implementation of government schemes and programs by ensuring better awareness, transparency and accountability. Their presence encourages community ownership, which leads to more effective and long-lasting outcomes. By focusing on local solutions and inclusive participation, CBOs play a key role in promoting equitable and sustainable development. The role of CBOs is presented in Figure 1.

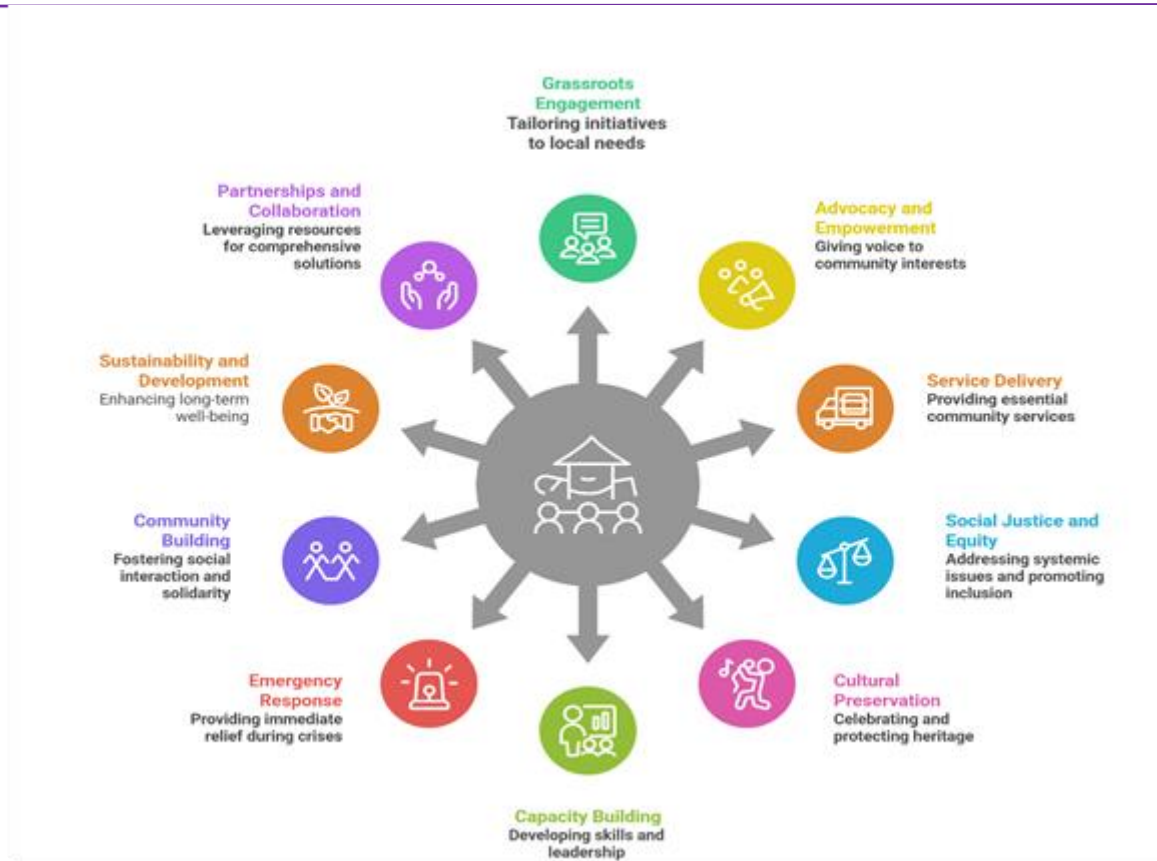


Figure 1. Role and Significance of CBO's in Communities

Key Characteristics of CBOs

CBOs play a vital role in grassroots initiatives by effectively addressing the diverse needs of local communities. They possess a deep understanding of local issues, enabling them to design relevant and need-based interventions. By promoting active community participation, CBOs ensure greater ownership and sustainability of development programs. They act as a bridge between communities and external agencies, facilitating access to resources, services and government schemes. Additionally, CBOs empower marginalized groups through capacity building, skill development and inclusive practices. Their localized approach makes development efforts more responsive, cost-effective and sustainable. The Key Characteristics of CBOs are represented in Figure 2. (Dodman *et al.*, 2013).

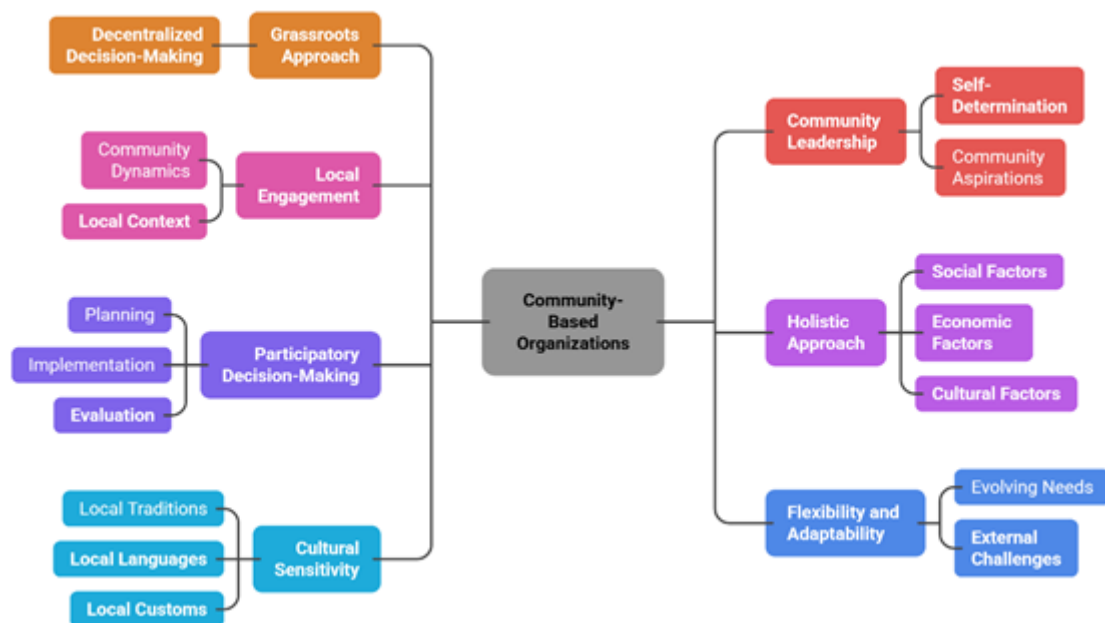


Figure 2. Characteristics of Community-Based Organizations

Importance of CBOs in Grassroots Initiatives in Addressing Community Needs

CBOs are essential for driving effective grassroots development by working closely with local people and their realities. They help identify genuine community problems and design solutions that are practical and culturally appropriate. By encouraging participation, CBOs strengthen people's confidence and promote collective decision-making. They also support skill development and enhance the capacity of individuals, especially women and marginalized groups. Their presence improves coordination between communities and government programs, ensuring better access to services and benefits. CBOs contribute to building unity and cooperation within the community, which is crucial for sustainable development. Here are key points highlighting the significance of CBOs in grassroots initiatives.

Importance of CBOs in Grassroots Initiatives

1. **Local Understanding:** Deep knowledge of local culture, needs and problems → ensures relevant solutions.
2. **Community Empowerment:** Active participation of people in decision-making → ownership and sustainability.
3. **Need-Based Interventions:** Flexible, context-specific programs → solve real community issues.
4. **Social Capital Building:** Builds trust, cooperation and collective responsibility.
5. **Inclusiveness:** Reaches marginalized and vulnerable groups → promotes equity.
6. **Quick Response:** Rapid action during crises due to strong local presence.
7. **Voice and Advocacy:** Represents community needs at higher levels → influences policies.

Key Roles of CBOs in Agricultural Extension

CBOs contribute significantly to rural and social development by strengthening local institutions and improving livelihoods. They facilitate resource access, promote innovation and ensure sustainable and inclusive growth at the community level. (Rafique *et al.*, 2018). Thereby fulfil the principles, roles and responsibilities of agricultural extension.

Facilitating Market Access for Smallholder Farmers

1. **Market Linkages and Networking:** Connect farmers with markets, cooperatives and agribusinesses → ensure fair prices and better bargaining power by providing require market information in relation to market price, demand and supply of products.
2. **Training on Market-Oriented Practices:** Provide skills on quality standards, post-harvest handling and packaging → improve marketability and access to market through better market intelligence.
3. **Policy Advocacy:** Advocate for better infrastructure, fair trade policies and financial support → ease market access.

Key roles of CBOs in Disease Prevention and Awareness Campaigns

CBOs serve as essential partners in strengthening public health systems, particularly in rural and underserved areas where access to formal healthcare services may be limited. Their close connection with local communities enables them to build trust, address misconceptions and promote behavior change effectively. By working in collaboration with government agencies and health institutions, CBOs contribute to early detection, timely intervention and improved health outcomes. They play a vital role in improving public health at the grassroots level. They actively engage with communities to promote awareness, prevention and preparedness against various health risks. Disease prevention and awareness campaigns is presented in Figure 3.

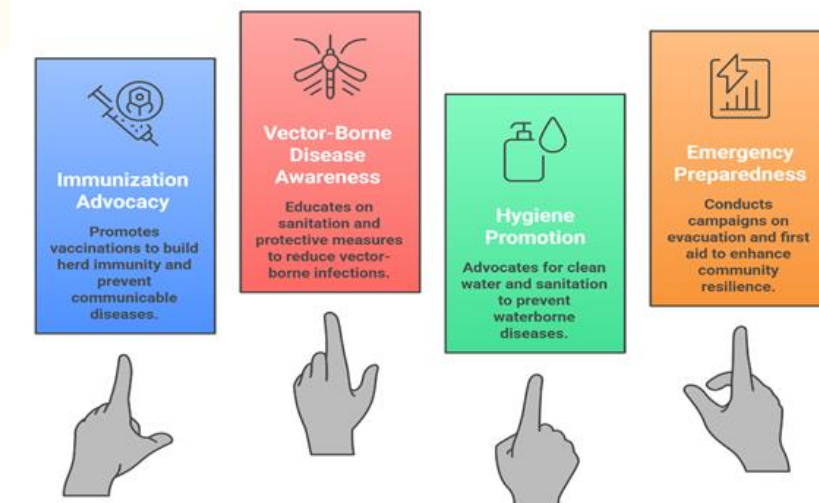


Figure 3: Disease prevention and awareness campaigns

Community-Based Organization Role in Education and Skill Development

CBOs play a crucial role in fostering education and skill development within local communities. This involvement is instrumental in empowering individuals enhancing employability and contributing to overall socio-economic development. They facilitate access to formal and non-formal education support school enrolment and retention and provide vocational training tailored to local livelihood opportunities. By focusing on women youth and marginalized groups CBOs help bridge skill gaps and promote inclusive growth. They also collaborate with government and training institutions to implement skill development programs such as entrepreneurship training and capacity-building initiatives.

1. Adult Education Programs by CBOs:

- a. **Functional Literacy:** Improves basic reading, writing and numeracy → supports daily life and participation.
- b. **Customized Curriculum:** Focus on practical skills (financial, health, civic) → real-life application.
- c. **Flexible Learning:** Evening classes, weekend sessions and distance learning → easy access for all.
- d. **Community Participation:** Local involvement in program design → relevance and effectiveness.
- e. **Building capacities among farmers, farm women and rural youth:** Vocational trainings for rural youths, farmers and farm women → improve efficiency and enhance the productivity.

B. Skill Development Initiatives by CBOs:

- a. **Identifying Local Skills:** Assess local job market needs → align training with employment opportunities.
- b. **Vocational Training:** Provide practical skills (carpentry, agriculture, tech, etc.) → improve employability.
- c. **Entrepreneurship Training:** Develop business and financial skills → promote self-employment.
- d. **Job Placement and Career Guidance:** Link with employers and guide career paths → better job access.
- e. **Digital Literacy:** Enhance technology skills → prepare for modern job market.

The Digital Transformation of CBOs

In recent years, CBOs have embraced digital tools as a means of enhancing communication and service delivery, ushering in a new era of connectivity and efficiency. The digital transformation of CBOs is pictorially represented in Figure 4.

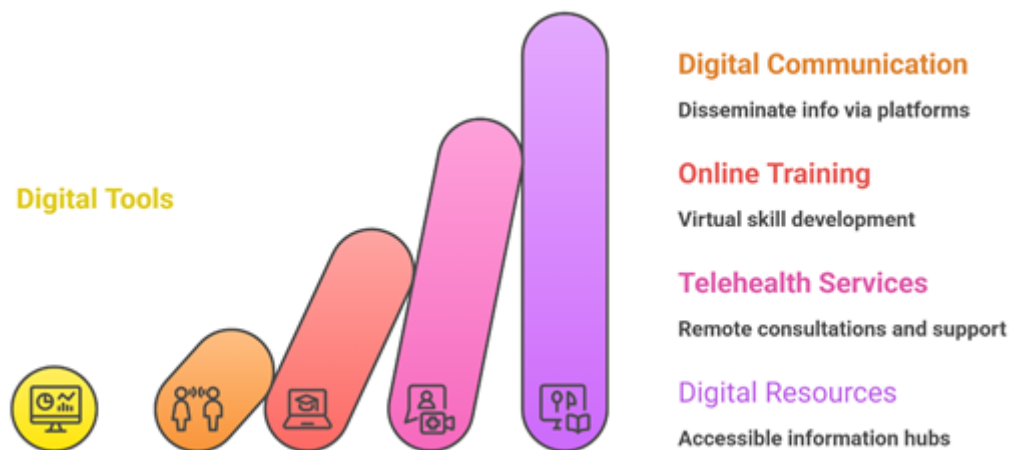


Figure 4: Digital Transformation of Community-Based Organizations

Figure 4: Digital Transformation of Community-Based Organizations

CBOs face several challenges that hinder their effectiveness and sustainability. These issues often arise due to financial, institutional and capacity-related constraints. Addressing these challenges is essential for strengthening their impact at the grassroots level. Limited access to consistent funding and technical support often restricts their ability to scale up activities. The challenges faced by CBOs are presented in Figure 5.

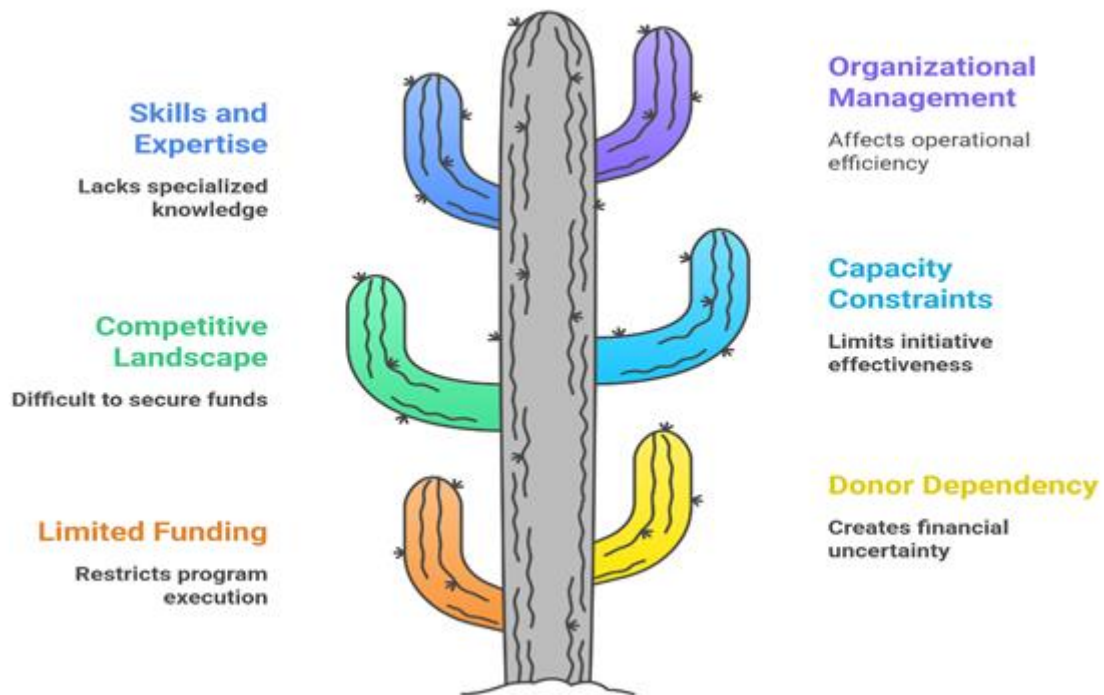


Figure 5: Challenges of community Based organizations

Conclusion

CBOs play a pivotal role in fostering inclusive and sustainable development at the grassroots level. Through their deep connection with local communities, they effectively address diverse needs related to health, education, livelihoods and social welfare. By promoting participatory approaches and strengthening local capacities, CBOs empower individuals and enhance community resilience. Despite facing challenges such as limited resources and institutional constraints, their contributions to improving service delivery, social inclusion and economic opportunities remain significant. Overall, CBOs serve as vital agents of change, driving community transformation and supporting long-term development outcomes.

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Carbon Sequestration: Capturing Carbon for a Better Future

Article ID: 74016

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Introduction

As the world faces rising temperatures and unpredictable climate patterns, reducing carbon emissions has become a global priority. Carbon dioxide (CO₂), one of the main greenhouse gases, is responsible for trapping heat in the atmosphere. Carbon sequestration offers a powerful way to tackle this issue by capturing and storing carbon before it can harm the environment.

Understanding Carbon Sequestration

Carbon sequestration is the process of capturing carbon dioxide and storing it safely for long periods. It can occur naturally through ecosystems or be enhanced using advanced technologies.

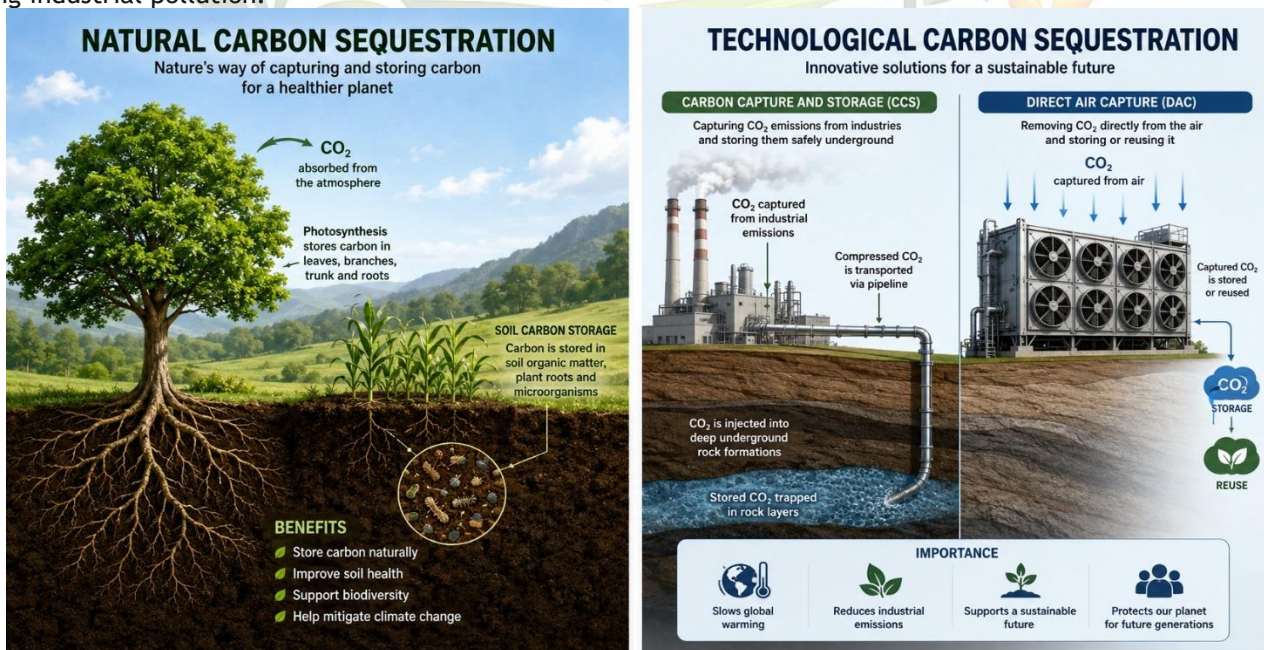
Natural Methods of Carbon Sequestration

Forests and Vegetation: Trees absorb CO₂ during photosynthesis and store it in leaves, stems, and roots. Forests are among the most effective carbon sinks.

Soil Carbon Storage: Soil stores carbon through organic matter such as plant roots and microorganisms. Sustainable farming practices improve this storage.

Artificial and Technological Methods

Carbon Capture and Storage (CCS): Industries capture CO₂ emissions and store them underground in rock formations, reducing industrial pollution.



Direct Air Capture (DAC)

Machines remove CO₂ directly from the air and store or reuse it. This method is still developing but promising.

Importance of Carbon Sequestration

1. Helps slow global warming
2. Supports ecosystems
3. Enhances agriculture

4. Reduces industrial emissions.

Challenges

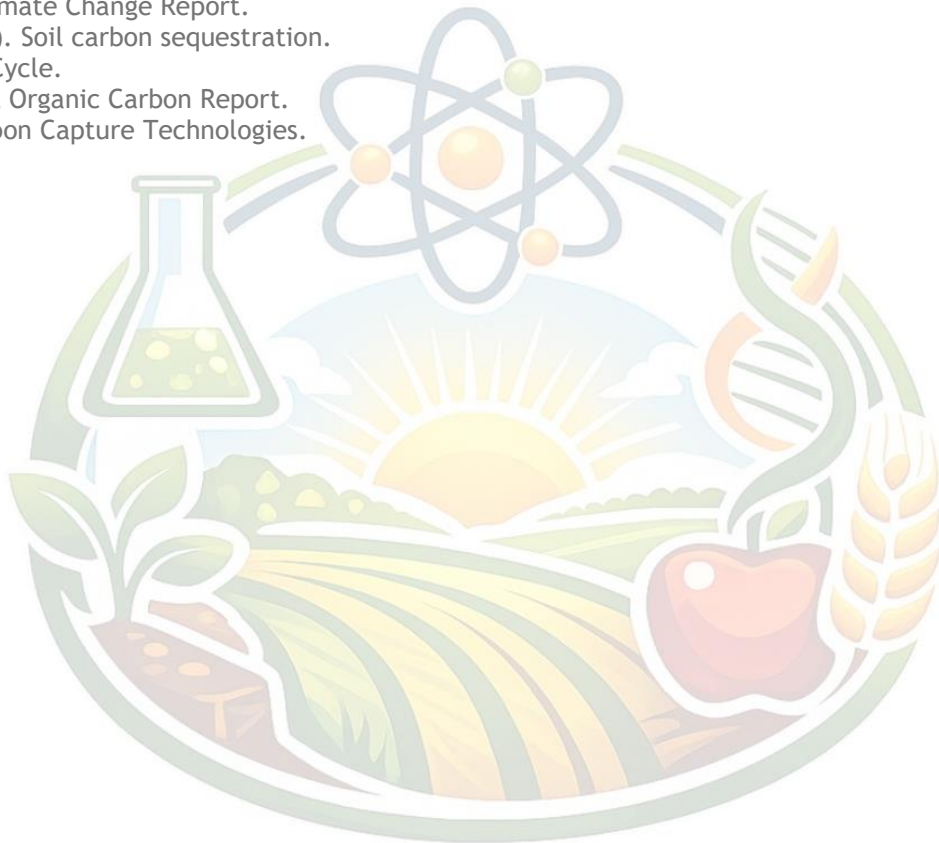
1. High costs
2. Advanced technology required
3. Risk of leakage
4. Policy support needed.

Conclusion

Carbon sequestration is essential in the fight against climate change. Combining natural and technological methods can help protect the planet.

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Role of Minimum Support Price (MSP) in Improving Farmers' Living Standards in India: Present Scenario of Kharif MSP 2026-27

Article ID: 74017

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Abstract

Agriculture continues to play a significant role in the Indian economy by providing employment, food security, and rural livelihood support. However, Indian farmers frequently face challenges such as unstable market prices, increasing input costs, climate variability, and low profitability. To protect farmers from price fluctuations and ensure remunerative returns, the Government of India implements the Minimum Support Price (MSP) policy. The present paper examines the role of MSP in improving the living standards of farmers in India with special reference to the MSP announced for the kharif marketing season 2026-27. The study highlights the increase in MSP for major kharif crops including paddy, pulses, oilseeds, and cotton, and analyzes its impact on farmers' income, production incentives, rural development, and food security. The paper also discusses the limitations and challenges associated with the MSP system and provides policy suggestions for improving its effectiveness. The study concludes that MSP remains an important agricultural price policy instrument for ensuring income stability and socio-economic development of farmers in India.

Keywords: Minimum Support Price, Farmers' Income, Kharif Crops, Agricultural Policy, Rural Development, Food Security, India.

Introduction

Agriculture is one of the most important sectors of the Indian economy and serves as the primary source of livelihood for a large proportion of the population. Despite rapid industrialization and expansion of the service sector, agriculture continues to support rural employment and national food security. Indian farmers, however, face numerous challenges including fluctuating market prices, rising cultivation costs, indebtedness, and climate-related risks. These challenges often reduce farm profitability and negatively affect the standard of living of farmers.

To safeguard farmers from distress sales and market uncertainties, the Government of India introduced the Minimum Support Price (MSP) mechanism. MSP is the pre-announced price at which the government procures agricultural produce from farmers. It aims to ensure fair remuneration and provide income security to cultivators.

For the kharif marketing season 2026-27, the Government of India announced revised MSPs for 14 major crops. The MSP for paddy, the principal kharif crop, was increased from Rs 2,369 to Rs 2,441 per quintal. Significant increases were also announced for sunflower seed, cotton, pulses, and oilseeds. The government stated that MSPs were fixed at least 50 percent above the estimated cost of production in accordance with the policy announced in the Union Budget 2018-19.

The present study examines the role of MSP in improving farmers' living standards in India and evaluates the present MSP scenario for the kharif season 2026-27.

Objectives of the Study

The major objectives of the study are:

1. To examine the concept and objectives of Minimum Support Price in India.
2. To analyze the MSP revisions announced for kharif crops during 2026-27.
3. To study the role of MSP in improving farmers' income and living standards.
4. To identify the major challenges associated with the MSP system.
5. To suggest policy measures for strengthening MSP implementation.

Research Methodology

The study is based on secondary data collected from government reports, agricultural policy documents, newspapers, research articles, and official announcements related to MSP for the kharif marketing season 2026-27. Descriptive and analytical methods have been used to evaluate the impact of MSP on farmers' socio-economic conditions.

Concept of Minimum Support Price (MSP)

Minimum Support Price refers to the guaranteed price announced by the Government of India for selected agricultural crops before the sowing season. MSP is recommended by the Commission for Agricultural Costs and Prices to ensure that farmers receive remunerative prices for their produce.

The main objectives of MSP are:

- To provide price assurance to farmers.
- To protect farmers from market fluctuations.
- To encourage agricultural production.
- To maintain national food security.
- To promote crop diversification.

The government procures crops mainly through agencies such as the Food Corporation of India and the National Agricultural Cooperative Marketing Federation of India

Reduction in Distress Sales: Small and marginal farmers often sell crops immediately after harvest due to urgent cash needs. MSP prevents exploitation by middlemen and ensures farmers receive fair prices through government procurement agencies like:

- Food Corporation of India
- National Agricultural Cooperative Marketing Federation of India

This strengthens farmers' confidence in agricultural production.

Encouragement for Crop Production: Higher MSPs motivate farmers to increase production of priority crops such as pulses and oilseeds. In 2026-27:

- Sunflower MSP increased by Rs 622
- Nigerseed increased by Rs 515
- Soybean increased by Rs 380

These incentives can reduce India's dependence on edible oil imports and improve domestic agricultural growth. .
Encouragement for Crop Production

Higher MSPs motivate farmers to increase production of priority crops such as pulses and oilseeds. In 2026-27:

- Sunflower MSP increased by Rs 622
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- Soybean increased by Rs 380

These incentives can reduce India's dependence on edible oil imports and improve domestic agricultural growth.

Improvement in Rural Economy: Higher farm income directly boosts rural demand for:

- Agricultural machinery
- Education
- Healthcare
- Housing
- Consumer goods

Thus, MSP contributes not only to farmer welfare but also to overall rural economic development.

Food Security and National Stability: MSP-supported procurement helps maintain buffer food stocks for the Public Distribution System (PDS). Procurement of rice and wheat ensures food availability for poor households under welfare schemes.

This strengthens national food security and price stability.

MSP Scenario for Kharif Crops 2026-27

The Government of India announced revised MSPs for 14 kharif crops for the marketing season 2026-27. The MSP increases were intended to provide farmers with better returns and encourage the cultivation of pulses and oilseeds.

Table 1: MSP for Major Kharif Crops (2026-27):

S.NO.	Crop	MSP 2025-26 (Rs/qlt)	MSP 2026-27 (Rs/qlt)	Increase (Rs/qlt)
1	Paddy (Common)	2369	2441	72
2	Paddy (Grade A)	2389	2461	72
3	Jowar (Hybrid)	3699	4023	324
4	Bajra	2775	2900	125
5	Maize	2400	2410	10
6	Tur (Arhar)	8000	8450	450
7	Moong	8768	8780	12
8	Urad	7800	8200	400

9	Groundnut	7263	7517	254
10	Soybean	5328	5708	380
11	Sunflower Seed	7721	8343	622
12	Sesame	9846	10346	500
13	Nigerseed	9537	10052	515
14	Cotton (Medium Staple)	7710	8267	557

Among all crops, sunflower seed recorded the highest increase of Rs 622 per quintal followed by cotton and nigerseed.

Gap between MSP and Market Access

Many farmers are unable to sell at MSP because: Procurement centres are far away, Lack of awareness, Delayed payments and Poor infrastructure Thus, the actual benefits of MSP remain uneven.

Role of MSP in Improving Farmers' Living Standards

1. Income Security and Stability: MSP provides guaranteed prices to farmers irrespective of fluctuations in market prices. This reduces income uncertainty and strengthens farmers' financial stability. The increase in MSP for paddy, pulses, and oilseeds during 2026-27 is expected to improve farmers' purchasing capacity and standard of living.

Present Scenario and Challenges of MSP: Despite its importance, the MSP system faces several challenges.

a. Limited Procurement Coverage: Although MSP is announced for 23 crops, effective procurement mainly occurs for rice and wheat in states like:

- i. Punjab.
- ii. Haryana.

Farmers growing pulses, oilseeds, and coarse cereals often do not benefit fully due to weak procurement systems.

b. Prevention of Distress Sales: Due to lack of storage and immediate financial needs, farmers often sell produce at lower prices after harvest. MSP acts as a protective mechanism against exploitation by middlemen and traders. Government procurement at MSP ensures that farmers receive fair prices for their produce.

2. Regional Imbalance: MSP benefits are concentrated in a few states, while farmers in eastern and central India receive limited procurement support.

3. Rising Fiscal Burden: Large-scale procurement, storage, and subsidies increase government expenditure. Maintaining buffer stocks also creates storage and wastage problems

4. Promotion of Agricultural Production: Higher MSP encourages farmers to cultivate crops that are strategically important for national food security. Significant MSP increases for pulses and oilseeds are likely to motivate farmers to increase production and reduce India's dependence on imports

5. Rural Economic Development: Increased farm income contributes to higher expenditure on education, healthcare, agricultural inputs, machinery, and rural infrastructure. MSP therefore plays a significant role in stimulating rural economic growth and employment generation

6. Contribution to Food Security.

The MSP System Supports Public Procurement and Maintenance of Buffer Stocks Under the Public Distribution System (PDS)

Procurement of rice and other crops ensures food availability for economically weaker sections of society.

Challenges Associated with MSP: Despite its importance, the MSP system faces several limitations.

1. Limited Procurement: Although MSP is announced for 23 crops, effective procurement is largely concentrated in rice and wheat. Farmers cultivating pulses and oilseeds often do not benefit fully due to weak procurement mechanisms.

2. Rising Fiscal Burden: Government procurement, storage, and food subsidy operations require large financial expenditure, increasing fiscal pressure on the government.

3. Environmental Concerns: Continuous procurement of rice and wheat encourages monocropping, excessive groundwater use, and soil degradation, especially in northwestern India.

4. Lack of Awareness and Infrastructure: Many small and marginal farmers are unable to access procurement centers due to poor infrastructure, transportation constraints, and lack of awareness regarding MSP operations.

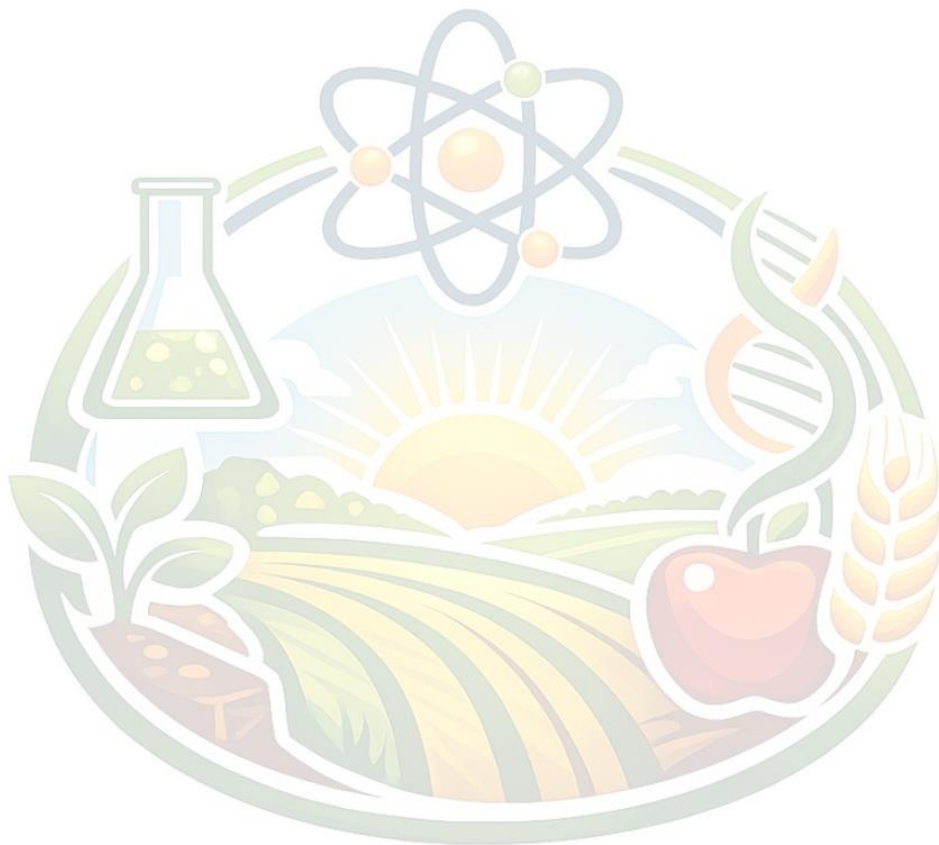
Conclusion

Minimum Support Price remains one of the most important agricultural policy instruments in India for ensuring income security and improving the socio-economic conditions of farmers. The MSP revisions for the kharif marketing season 2026-27 indicate the government's commitment to providing remunerative prices to farmers by ensuring returns of at least 50 percent above production costs.

The increased MSPs for pulses, oilseeds, sunflower, and cotton are expected to improve farm profitability, encourage diversified cropping patterns, and strengthen rural livelihoods. However, the effectiveness of MSP depends upon efficient procurement systems, wider regional coverage, and timely implementation. Therefore, reforms aimed at expanding.

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Nutritional and Functional Evaluation of *Moringa oleifera* as a Sustainable Protein Source in Aquaculture

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Abstract

Aquaculture has become the fastest-growing food production sector worldwide and plays a crucial role in ensuring global food and nutritional security. The rapid expansion of aquaculture has increased the demand for high-quality feed ingredients, particularly fishmeal which remains the most preferred protein source in aquafeeds because of its balanced amino acid profile, high digestibility and palatability. However, increasing fishmeal prices, limited availability and sustainability concerns associated with the exploitation of wild fish stocks have intensified the search for alternative protein sources. Among various plant-based feed ingredients *Moringa oleifera* has emerged as a promising sustainable feed resource due to its high protein content, favorable amino acid composition, abundance of vitamins and minerals and diverse bioactive compounds. The leaves of *M. oleifera* contain approximately 25-32% crude protein along with substantial quantities of calcium, iron, potassium and antioxidant compounds such as flavonoids and phenolics. These nutritional characteristics make it a potential partial substitute for fishmeal in aquaculture diets. Numerous feeding trials have demonstrated that appropriate inclusion levels of *Moringa oleifera* leaf meal (MOLM) can enhance growth performance, feed utilization efficiency, hematological status, antioxidant capacity and immune responses in various cultured fish species. However, the presence of anti-nutritional factors such as phytates, tannins, saponins and fiber may limit its utilization at higher inclusion levels. Processing methods including soaking, boiling, fermentation and enzymatic treatment have been reported to improve the nutritional quality of MOLM by reducing these anti-nutritional compounds. Hence, *M. oleifera* represents a promising sustainable protein source capable of reducing dependence on fishmeal while contributing to environmentally friendly aquaculture production systems.

Keywords: *Moringa oleifera*, aquaculture nutrition, fishmeal replacement, sustainable aquafeeds, plant protein, growth performance, immunostimulant.

Introduction

Aquaculture has become one of the most rapidly expanding sectors of global food production and is increasingly recognized as a major contributor to food security, nutrition and economic development. The increasing global population and rising demand for fish protein have accelerated the growth of aquaculture, which currently supplies more than half of all aquatic foods consumed by humans (FAO, 2024).

Feed constitutes the largest operational expenditure in aquaculture production systems, accounting for approximately 50-70% of total production costs depending on the culture species and production intensity (FAO, 2018). Among feed ingredients, fishmeal is considered excellent protein source because of its high digestibility, balanced essential amino acid profile, high palatability and abundance of long-chain omega-3 fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (FAO, 2022). Consequently, fishmeal has traditionally been the primary protein ingredient in commercial aquafeeds.

Despite its nutritional superiority, fishmeal faces several challenges that threaten its long-term sustainability. Global fishmeal production relies heavily on capture fisheries, which are under increasing pressure due to overfishing, climate change and environmental degradation. Moreover, the growing demand for aquafeeds has resulted in increased fishmeal prices and market volatility, thereby reducing profitability for fish farmers (OECD & FAO, 2023).

Plant-derived protein ingredients have gained considerable attention as sustainable alternatives because of their availability, lower cost and reduced environmental footprint. Among these, *Moringa oleifera* Lam., commonly known as drumstick tree, horseradish tree, or miracle tree, has emerged as a particularly promising candidate. Native to the Indian subcontinent and widely cultivated throughout tropical and subtropical regions, *M. oleifera* is valued for its exceptional nutritional profile and medicinal properties (Mukhtiar et al., 2025).

The leaves of *M. oleifera* contain substantial levels of crude protein, essential amino acids, vitamins, minerals and various bioactive compounds including flavonoids, phenolics, carotenoids and isothiocyanates (El-Fakharany et al., 2024). These compounds not only support growth and nutrient utilization but also exhibit antioxidant, antimicrobial, anti-inflammatory and immunostimulatory properties that can improve fish health and disease resistance (Saleh et al., 2025).

Therefore, a comprehensive assessment of the nutritional and functional attributes of *M. oleifera* is essential to determine its suitability as a sustainable protein source in modern aquaculture systems.

Moringa oleifera

Moringa oleifera, a fast-growing tree native to the Indian subcontinent, distributed in tropical and subtropical regions. It is commonly known as drumstick or horseradish tree (Mukhtiar et al., 2025). Moringaceae family constituted by 13 well known species of which *Moringa oleifera* is the most commonly available drought resistant variety. The leaves are rich in beta carotene, vitamin C, protein, iron, and potassium (Mbah et al., 2012).



(Saleh et al., 2025) Fig.1 Nutritional value of *Moringa oleifera*

M. oleifera exhibits properties such as antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and anticancer activities. Because presence of bioactive compounds like flavonoids, phenolics, and isothiocyanates (El-Fakharany et al., 2024).

Table 1: List of *Moringa* species diversity throughout the world:

S.No.	Species	Country/region	Common name	References
1	<i>M. oleifera</i>	India	Horseradish, Ben-oil, Drumstick, Kelor	Rani et al., 2018
2	<i>M. arborea</i>	Kenya, Somalia	—	www.theplantlist.org; www.bihrmann.com
3	<i>M. borziana</i>	Kenya, Somalia	—	www.theplantlist.org
4	<i>M. concanensis</i>	India	—	www.bihrmann.com
5	<i>M. drouhardii</i>	Southern Madagascar	—	www.theplantlist.org
6	<i>M. hildebrandtii</i>	Southwest Madagascar	Hildebrandt's Moringa	www.bihrmann.com
7	<i>M. longituba</i>	Kenya, Southeast Ethiopia, Somalia	—	www.theplantlist.org
8	<i>M. ovalifolia</i>	Namibia, Southwest Angola	Phantom tree, Ghost tree, African Moringo	Rani et al., 2018
9	<i>M. peregrina</i>	Red Sea, Arabia, Northeast Africa	Ben tree, Yasar tree, Wild drumstick tree	www.theplantlist.org
10	<i>M. pygmaea</i>	North Somalia	—	www.theplantlist.org
11	<i>M. rivaie</i>	Kenya, Ethiopia	Swaniehro	—
12	<i>M. ruspoliana</i>	Kenya, Ethiopia, Somalia	—	Rani et al., 2018
13	<i>M. stenopetala</i>	Kenya, Southwest Ethiopia, Somalia	Cabbage tree, Haleko, Shelagda, Shiferaw	www.worldfloraonline.org

Nutritional Composition of *Moringa oleifera* Leaf Meal (MOLM)

The nutritional value of *Moringa oleifera* leaf meal (MOLM) has attracted considerable attention in aquaculture nutrition due to its high protein content, balanced amino acid profile, rich mineral composition and abundance of bioactive compounds. These characteristics make MOLM a promising alternative protein source capable of partially replacing fishmeal in aquafeeds. However, nutrient composition may vary depending on geographical location, plant age, cultivation practices, harvesting season and processing methods (Mukhtiar et al., 2025).

Proximate Composition

The leaves of *M. oleifera* are recognized as one of the most nutrient-dense plant materials available for animal feeding as shown in table 2&3. Several studies have reported crude protein levels ranging from 22% to 39%, which is substantially higher than many conventional plant feed ingredients used in aquaculture (Mbah et al., 2012; Reda et al., 2023; Faisal et al., 2024).

The protein concentration of MOLM is comparable to certain oilseed meals and provides an important source of essential amino acids necessary for fish growth and tissue development. In addition to protein, moringa leaves contain moderate quantities of lipids (2-10%), crude fiber (4-20%) and ash (5-12%), indicating their potential contribution to both energy and mineral nutrition (Shahzad et al., 2020; Tabassum et al., 2023).

Table 2. Representative Proximate Composition of *Moringa oleifera* Leaf Meal Reported by Different Studies:

Study	Crude Protein (%)	Lipid (%)	Fibre (%)	Ash (%)
Mbah et al. (2012)	26.7	-	1.4	2.6
Shahzad et al. (2020)	28.95	2.83	19.95	10.87
Ajithkumar et al. (2021)	27.22	8.65	10.84	9.97
Reda et al. (2023)	38.90	10.79	-	5.84
Faisal et al. (2024)	27.59	6.48	8.54	9.36

The consistently high protein content observed across studies supports the utilization of MOLM as a sustainable plant protein ingredient in aquaculture feed formulations.

Mineral Composition

Apart from its protein value, *M. oleifera* leaves serve as an excellent source of macro and micro minerals essential for fish growth, metabolism, skeletal development and immune competence. Minerals play critical roles in osmoregulation, enzymatic activity, oxygen transport and maintenance of physiological homeostasis (NRC, 2011).

Calcium is among the most abundant minerals present in moringa leaves. High calcium concentrations support bone mineralization, scale formation and muscle contraction. Potassium and magnesium contribute to nerve transmission and metabolic regulation, while phosphorus participates in energy metabolism through ATP synthesis (Anwar et al., 2007).

Furthermore, moringa leaves contain appreciable quantities of iron, zinc, copper and manganese. Iron is essential for hemoglobin synthesis and oxygen transport, whereas zinc functions as a cofactor for numerous enzymes involved in protein synthesis and immune function (Gopalakrishnan et al., 2016).

Table 3. Composition of dried moringa leaves

Amino Acids		Vitamins (Mg)	
Tryptophan	0.14	Vit-C	15.8 mg
Threonine	0.41	Thiamine	2.02
Isoleucine	0.45	Riboflavin	21.3
Leucine	0.79	Niacin	7.6
Lysine	0.54	Pantothenic acid	0.13
Methionine	0.12	Vit-B6	1.20
Cystein	0.14	Folate	40.00
Phenylalanine	0.49	Vit-A	7564.00 IU
Tyrosine	0.35	Vit-E	10.8
Valine	0.61	Vit-D	0.00 IU
Arginine	0.53	Minerals (Mg)	
Histidine	0.20	Calcium	185 mg
Alanine	0.71	Iron	25.6
Aspartic acid	0.92	Magnesium	448
Glutamic acid	1.04	Phosphorus	112.00
Glycine	0.52	Potassium	337.00
Proline	0.45	Sodium	9.00
Serine	0.41	Zinc	0.60
Proximate Composition (%)		Copper	0.11

Water	78.66	Manganese	1.06
Ash	2.26	Selenium	0.90
Fibre	12.5	Isolhamnetin	0.40
Proteins	29.4	Kaempferol	6.00
Fats	5.2	Myricetin	0.00
Carbohydrate	41.2	Quercetin	16.60
Calories	329 cal		

Source- US Department of Agriculture, Agricultural research service. Food data central. 2022. Nature Claim team. National Institute of health, Office of dietary supplements. <https://ods.od.nih.gov/factsheets/list-VitaminsMinerals>.

Functional and Bioactive Properties of *Moringa oleifera*

Beyond its nutritional value, *M. oleifera* possesses numerous functional properties attributable to its rich array of phytochemicals. These bioactive compounds provide antioxidant, antimicrobial, anti-inflammatory and immunomodulatory effects that can improve fish health and enhance resistance to environmental stressors (Saleh et al., 2025). The leaves contain substantial concentrations of phenolic compounds and flavonoids, including quercetin, kaempferol, rutin and chlorogenic acid. These compounds neutralize reactive oxygen species (ROS), thereby reducing oxidative stress and protecting cellular structures from damage (El-Fakharany et al., 2024). Additionally, isothiocyanates and glucosinolates present in moringa exhibit antimicrobial activity against several pathogenic bacteria and fungi. Such properties are particularly relevant in aquaculture, where disease outbreaks can cause substantial economic losses (Mohai Ud Din et al., 2025).

Anti-Nutritional Factors in *Moringa oleifera* Leaf Meal

Anti-nutritional compounds are naturally occurring substances that interfere with nutrient digestion, absorption and metabolism, thereby reducing the nutritional value of feed ingredients (Francis et al., 2001). The concentration of these compounds in moringa leaves is generally lower than that observed in many other plant protein sources; however, their presence can still influence feed utilization and fish performance, particularly at high dietary inclusion levels (Makkar & Becker, 1996). Among the major anti-nutritional compounds reported in moringa leaves are phytates, tannins, saponins, alkaloids, oxalates and excessive fiber fractions.

Phytates: Phytic acid is considered one of the most important anti-nutritional compounds in plant-derived feed ingredients. It binds phosphorus and forms insoluble complexes with minerals such as calcium, iron, zinc and magnesium, thereby reducing their bioavailability to fish (NRC, 2011). Most fish species lack sufficient endogenous phytase activity to effectively hydrolyze phytate-bound phosphorus. Consequently, phosphorus utilization decreases, which may impair skeletal development, growth performance and mineral metabolism (Cao et al., 2007). Furthermore, undigested phytate phosphorus is excreted into aquatic environments, contributing to eutrophication and water quality deterioration.

Tannins: Tannins are polyphenolic compounds capable of forming complexes with proteins and digestive enzymes. High tannin concentrations may reduce protein digestibility and impair nutrient absorption in fish (Makkar & Becker, 1996). Moderate concentrations may exhibit beneficial antioxidant properties, highlighting the importance of optimizing inclusion levels (Francis et al., 2001).

Saponins: Saponins are glycosidic compounds known for their detergent-like properties. At elevated concentrations, saponins can damage intestinal epithelial cells, alter membrane permeability and reduce nutrient absorption efficiency (Francis et al., 2001). Studies indicate that low concentrations of dietary saponins may exert beneficial immunostimulatory effects and enhance disease resistance in fish. Therefore, complete elimination may not be desirable and controlled reduction through processing is generally preferred (Saleh et al., 2025).

Alkaloids and Oxalates: Alkaloids may interfere with normal metabolic activities when consumed in large quantities, while oxalates can bind calcium and reduce mineral availability. Although the concentrations of these compounds in moringa leaves are generally below toxic thresholds, their cumulative effects should be considered during diet formulation (Anwar et al., 2007).

Crude Fiber: Fiber represents another important limitation of MOLM utilization. Elevated fiber levels may reduce digestible energy availability and nutrient digestibility, particularly in carnivorous fish species with limited capacity to digest complex carbohydrates (NRC, 2011). Studies indicate that inclusion levels exceeding the optimal range often result in reduced growth performance due to increased dietary fiber and associated reductions in nutrient utilization efficiency (Patel et al., 2018).

Processing Methods

These techniques can significantly increase the suitability of moringa leaves for aquaculture feed formulations.

Water Soaking: Water soaking is one of the simplest and most economical processing techniques. During soaking, water-soluble anti-nutritional compounds diffuse from plant tissues into the surrounding medium. Research has shown that

soaking moringa leaves for 12-24 hours can significantly reduce phytates, tannins, saponins and alkaloids while maintaining most of the nutritional components (Gopalakrishnan et al., 2016).

Boiling: Boiling is widely used to reduce heat-sensitive anti-nutritional compounds. Thermal processing disrupts cellular structures and facilitates the removal or degradation of undesirable metabolites. Boiling moringa leaves for short durations (5-10 minutes) has been reported to significantly decrease phytates, saponins, tannins and alkaloids while retaining acceptable protein quality (Anwar et al., 2007).

Fermentation: Fermentation has emerged as a promising biological treatment for improving plant feed ingredients. During fermentation, beneficial microorganisms produce enzymes capable of degrading phytates, fiber and complex carbohydrates. Fermented moringa leaf meal often exhibits improved digestibility, enhanced amino acid availability and reduced anti-nutritional factor concentrations (El-Sayed, 2020). Additionally, fermentation may enrich probiotic populations and generate beneficial metabolites that support gut health.

Enzymatic Treatments: The supplementation of exogenous enzymes such as phytase, cellulase, xylanase and protease can further enhance nutrient digestibility and nutrient release from plant cell walls. Phytase supplementation is particularly important because it hydrolyzes phytate complexes and increases phosphorus availability, thereby improving mineral utilization and reducing phosphorus discharge into aquatic ecosystems (Cao et al., 2007).

Collectively, these processing methods significantly improve the nutritional quality of MOLM and facilitate its incorporation into aquafeeds at higher inclusion levels.

Effects of *Moringa oleifera* Leaf Meal on Growth Performance of Fish

Growth performance is one of the most important indicators used to evaluate the suitability of alternative feed ingredients in aquaculture. Numerous feeding trials conducted across different fish species have demonstrated that dietary supplementation with *Moringa oleifera* leaf meal (MOLM) can improve growth performance when included at optimal levels as shown in table 4. The positive effects are primarily attributed to its high protein content, favorable amino acid composition, vitamin and mineral richness and bioactive compounds that enhance nutrient utilization (Saleh et al., 2025).

In Indian major carps, particularly *Labeo rohita* and *Cirrhinus mrigala*, moderate inclusion levels of MOLM have shown promising results. Sharma et al. (2017) reported enhanced weight gain and specific growth rate in *L. rohita* fed diets containing approximately 10-15% MOLM. Similarly, Faisal et al. (2024) observed significantly greater final body weight and growth performance in *C. mrigala* fingerlings receiving a diet containing 10% MOLM compared with the control diet.

Table 4. Growth performance & hematological Improvements Associated with MOLM Supplementation:

Dosage	Duration (days)	Experimental Fish	Results	Reference
10%	90	<i>Heteropneustes fossilis</i>	Increased final weight, SGR, condition factor, and survivability	Hridoy et al. (2025)
10%	180	<i>Cirrhinus mrigala</i>	Increase growth performance (final weight: 422.32 g, weight gain: 406.97 g).	Faisal et al. (2024)
30% MOLM	56	<i>Labeo rohita</i>	High inclusion reduced growth performance	Patel et al. (2018)
30%	90	<i>Labeo rohita</i>	Enhanced weight gain, SGR, and FCR	Sharma et al. (2017)
10% MOLM	28	<i>Sparus aurata</i>	Improved growth and immune status	Yilmaz et al. (2013)
0.5% extract	60	<i>Macrobrachium rosenbergii</i>	Improved physiology and immune function	Rahman et al. (2019)
19.3-25 g/kg	56	<i>Oncorhynchus mykiss</i>	Boosted growth rate	Ahmad et al. (2018)
5-10% MOLM	42	<i>O. niloticus</i>	Enhanced growth performance	Ibrahim et al. (2015)
2.5 g/kg	60	<i>O. niloticus</i>	Increased growth and feed intake	Soltan et al. (2015)
20 mg/g feed	28	<i>Puntius altus</i>	Significantly increased body weight	Sultana et al. (2017)
15%	150	<i>Heterobranchus longifilis</i>	Enhanced growth performance	Fasakin et al. (2008)
15%	150	<i>H. longifilis</i>	Improved weight gain and feed intake	Adewolu et al. (2008)
30%	84	<i>Cyprinus carpio</i>	Growth parameters substantially enhanced	Abbas et al. (2014)
15%	56	<i>Clarias gariepinus</i>	Improved weight, FCR, and SGR	Olaniyi et al. (2010)
20%	56		Best performance in FCR and growth	Nsofor et al. (2013)
8.2 g	84		Improved FCR, AWG, and SGR	Dada et al. (2012)
10%	56		Better mean weight gain and FCR	Aderolu et al. (2011)
20%	90		Highest growth rate observed	Gopalakrishnan et al. (2016)
		<i>Oncorhynchus mykiss</i>		

Hematological and Physiological Responses

Hematological parameters are widely used as indicators of physiological health, nutritional status and immune competence in fish. Numerous investigations have shown that dietary supplementation with MOLM positively influences hematological characteristics. Increases in red blood cell (RBC) count, hemoglobin concentration (Hb), packed cell volume (PCV) and white blood cell (WBC) count have been reported in fish receiving moringa-supplemented diets (Aderolu et al., 2011; Faisal et al., 2024). The improvement in RBC and hemoglobin levels may be attributed to the high iron content of moringa leaves, which supports erythropoiesis and oxygen transport. Elevated WBC counts indicate enhanced immune responsiveness and disease resistance.

In *Cirrhinus mrigala*, dietary inclusion of 10% MOLM significantly improved RBC count, hemoglobin concentration and overall hematological profile compared with control fish. Similar observations have been reported in Nile tilapia and African catfish (Rahman et al., 2019; Saleh et al., 2025).

These findings suggest that MOLM functions not only as a nutrient source but also as a physiological enhancer capable of improving fish health status.

Immunomodulatory and Antioxidant Effects

One of the most attractive characteristics of *M. oleifera* is its abundance of biologically active compounds with antioxidant and immunomodulatory properties. Phenolic compounds, flavonoids, carotenoids and isothiocyanates act as potent antioxidants that scavenge reactive oxygen species and reduce oxidative stress (El-Fakharany et al., 2024). Dietary supplementation with MOLM has been associated with enhanced antioxidant enzyme activities, including superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx). These enzymes protect cellular structures from oxidative damage and improve physiological resilience under stressful conditions (Saleh et al., 2025). Furthermore, several studies have demonstrated improved innate immune responses in fish fed MOLM-containing diets. Increased lysozyme activity, enhanced phagocytic activity, elevated respiratory burst responses and improved pathogen resistance have been reported in various aquaculture species (Mohai Ud Din et al., 2025).

Economic and Environmental Sustainability

Moringa oleifera offers several advantages from both economic and environmental perspectives. The plant grows rapidly under diverse climatic conditions, requires relatively low agricultural inputs and can be cultivated on marginal lands unsuitable for conventional crops (Mukhtiar et al., 2025). Lower feed costs associated with locally available moringa leaves may improve profitability, particularly for small-scale fish farmers in developing countries. From an environmental perspective, replacing a portion of fishmeal with MOLM reduces pressure on marine fisheries and contributes to the conservation of aquatic biodiversity. Furthermore, the use of plant-based ingredients aligns with the principles of circular bioeconomy and sustainable resource utilization.

Conclusion

Moringa oleifera possess high crude protein content, favorable amino acid composition, abundant minerals and numerous bioactive compounds with antioxidant, antimicrobial and immune-stimulatory properties. These nutritional and functional characteristics enable MOLM to support fish growth, improve feed utilization efficiency, enhance hematological health and strengthen immune responses.

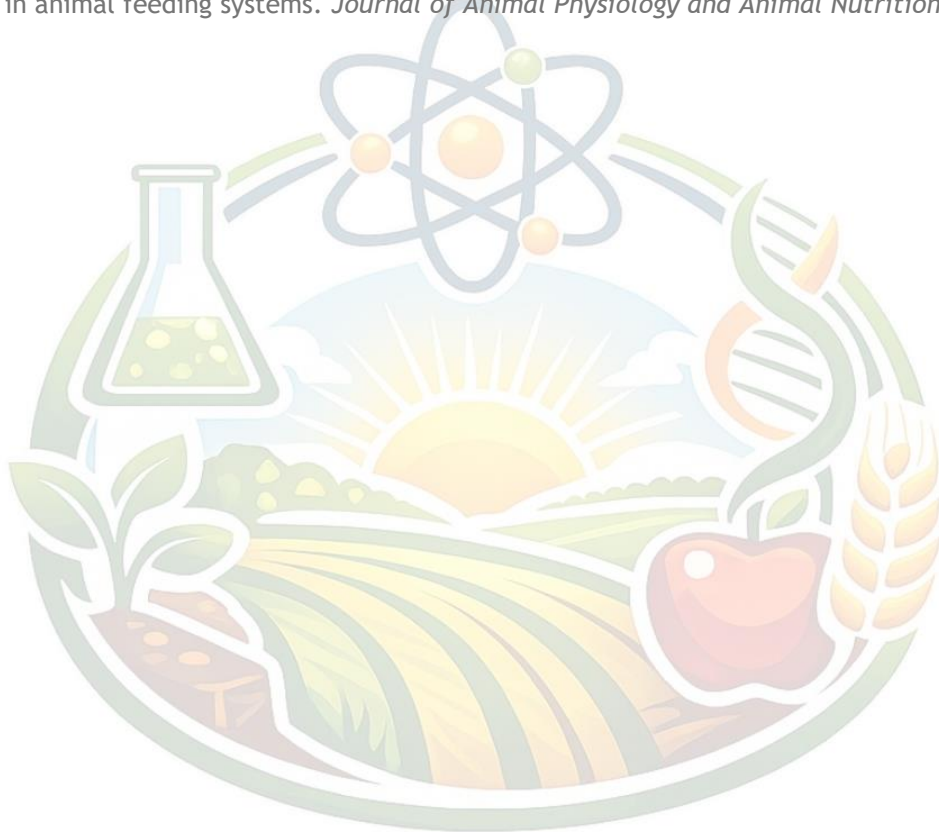
Although the presence of anti-nutritional factors limits unrestricted dietary inclusion, processing methods such as soaking, boiling, fermentation and enzymatic treatment substantially improve nutritional quality and nutrient availability. Evidence from numerous feeding trials indicates that dietary inclusion levels of approximately 5-15% can successfully replace a portion of fishmeal without compromising fish performance. The integration of MOLM into aquafeeds offers significant economic and environmental benefits by reducing feed costs, lowering dependence on marine-derived ingredients and supporting sustainable aquaculture development. Overall, *M. oleifera* possesses considerable potential to contribute to the future sustainability and resilience of global aquaculture production systems.

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Processing Strategies and Waste Utilization Approaches in Jamun-Based Products

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Introduction

India is blessed with a wide diversity of indigenous fruits, many of which remain underutilized despite their immense nutritional and economic value. Among these, *jamun* (*Syzygium cumini*), also known as Indian blackberry, stands out as a powerhouse of health-promoting compounds. Traditionally consumed fresh during its short seasonal window, jamun has often been neglected in terms of processing and value addition. Even more concerning is the large-scale wastage of its seeds and pulp residues.



With increasing awareness about sustainability, functional foods, and waste minimization, jamun offers a remarkable opportunity to transform from a seasonal fruit into a year-round functional ingredient. This article explores the potential of jamun value addition and innovative waste utilization strategies that can benefit farmers, processors, and consumers alike.

Nutritional and Functional Significance of Jamun

Jamun is rich in anthocyanins, flavonoids, phenolic compounds, vitamins (especially vitamin C), and essential minerals such as iron and calcium. Its deep purple color is attributed to anthocyanins, which possess strong antioxidant properties. One of the most significant attributes of jamun is its antidiabetic potential. The seeds contain bioactive compounds like jamboline and ellagic acid, which help regulate blood sugar levels. This makes jamun particularly valuable in developing functional foods targeted toward diabetic and health-conscious populations.

Value Addition: Expanding the Product Portfolio

The perishable nature and astringent taste of fresh jamun limit its direct consumption and marketability. However, through strategic value addition, jamun can be transformed into a wide range of commercially viable and consumer-friendly products. This not only extends shelf life but also enhances its economic value and accessibility.

1. Beverage Sector: Functional and Refreshing Products: Jamun has immense potential in the beverage industry due to its vibrant color, unique flavor, and health benefits. It can be processed into:

- Juice and Ready-to-Serve (RTS) beverages, which retain much of the fruit's antioxidant properties.
- Squash and syrups, offering extended shelf life and easy dilution for consumption.
- Fermented products such as jamun wine, cider, and vinegar, which enhance flavor complexity while introducing probiotic and functional benefits.
- Functional beverages, where jamun extract is blended with other fruit juices or herbal ingredients to develop health drinks targeting diabetes and immunity.

2. Processed and Convenience Foods: Jamun pulp can be incorporated into a variety of processed foods to improve both nutritional quality and sensory appeal:

- Jam, jelly, and preserves, which reduce astringency while maintaining flavor.
- Chutneys and sauces, suitable for culinary applications.
- Dairy-based products like yogurt, ice cream, and flavored milk, where jamun adds both color and antioxidant value.

d. Bakery and confectionery items, including cakes, biscuits, chocolates, and candies enriched with jamun pulp or powder.

3. Development of Functional Ingredients: One of the most promising areas is the conversion of jamun into functional powders and extracts:

- a. Jamun pulp powder can be used in instant mixes, beverages, and nutritional supplements.
- b. Jamun seed powder, rich in antidiabetic compounds, can be incorporated into flours, extruded snacks, and gluten-free formulations.
- c. Encapsulated jamun extracts, using techniques such as spray drying or freeze drying, improve stability and allow controlled release of bioactives.

These ingredients are particularly valuable in the development of low glycemic index foods, which are in high demand among diabetic and fitness-conscious populations.

4. Natural Colorant and Clean Label Ingredient: With increasing consumer demand for clean-label products, jamun anthocyanins can be utilized as a natural food colorant in beverages, desserts, and confectionery. Unlike synthetic dyes, these pigments offer both aesthetic appeal and health benefits.

5. Innovative and Emerging Applications: Advanced food processing technologies are opening new avenues for jamun utilization:

- a. **Extruded products:** snacks and breakfast cereals fortified with jamun powder
- b. **Functional pasta and gluten-free products:** aligning with current dietary trends
- c. **Smart packaging systems:** where jamun-derived pigments act as pH indicators for freshness monitoring
- d. **Nutraceutical formulations:** including capsules, tablets, and herbal blends

6. Small-Scale and Rural Entrepreneurship Opportunities: Jamun processing can be easily adapted to small-scale and cottage industries, requiring minimal investment. Products like squash, seed powder, and jam can be manufactured locally, providing income generation opportunities for rural communities and reducing post-harvest losses.

Waste Utilization: Turning By-Products into Wealth

A significant portion of jamun processing generates waste, particularly seeds and peel residues. However, these by-products are treasure troves of valuable compounds.

1. Jamun Seed Powder: Seeds, often discarded, can be dried and ground into powder. This powder is rich in alkaloids, glycosides, and tannins and is widely used for managing diabetes. It can be incorporated into functional foods like biscuits, chapati flour, and herbal formulations.

2. Extraction of Bioactive Compounds: Jamun seeds and peels can be used for extracting antioxidants, phenolics, and natural pigments. These extracts find applications in pharmaceuticals, cosmetics, and food preservation.

3. Dietary Fiber Source: Jamun residues are high in dietary fiber and can be utilized in developing high-fiber food products, improving gut health and digestion.

4. Animal Feed and Compost: Remaining biomass can be used as livestock feed or converted into organic compost, contributing to a circular economy.

5. Encapsulation and Functional Delivery Systems: Modern food engineering approaches, such as microencapsulation, can be applied to jamun bioactives to enhance stability and controlled release in functional foods.

Conclusion

Jamun is no longer just a seasonal fruit - it is a potential superfood with immense industrial and therapeutic value. Through strategic value addition and efficient waste utilization, this underutilized fruit can be transformed into a sustainable and profitable resource. Bridging traditional knowledge with modern food processing technologies will be key to unlocking the full potential of jamun in the years to come.

Application of Fuzzy Time Series for Modeling Mango Size and Weight

Article ID: 74020

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Objective

To apply the Fuzzy Time Series (FTS) technique for analyzing and forecasting mango size and weight, thereby demonstrating the usefulness of fuzzy mathematics in agricultural studies.

Introduction

Mango is an important tropical fruit crop whose size and weight determine its quality and market value. Accurate prediction of fruit growth helps farmers in harvesting, grading, packaging, and marketing. Since agricultural data often contain uncertainty due to environmental and biological factors, Fuzzy Time Series (FTS) can be used to model and forecast such data effectively. FTS converts numerical observations into fuzzy sets and establishes logical relationships among them to predict future values.

Mango Growth and Measurement

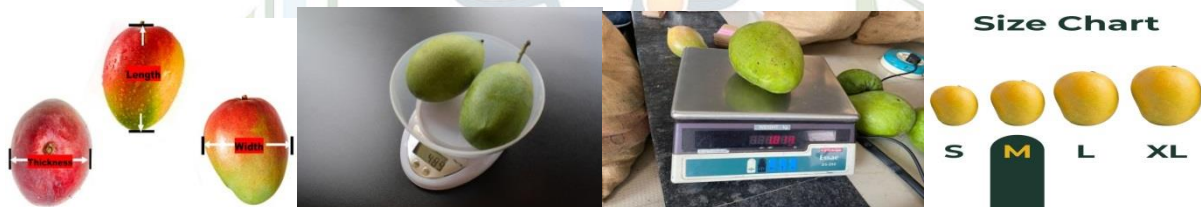


Figure 1. Measurement of mango size and weight used for FTS analysis

Mathematical Model

The Fuzzy Time Series model consists of the following steps:

1. **Universe of Discourse:** For mango weight data, $U=[200,380]$ where U represents the range of observed mango weights in grams.

2. **Fuzzy Sets:** The universe is divided into five fuzzy intervals:

Fuzzy sets	Weight Range
A1	200-240
A2	240-280
A3	280-320
A4	320-360
A5	360-400

3. **Fuzzy Logical Relationship:** If A_i and A_j are fuzzy states then $A_i \rightarrow A_j$ represents the transition from one state to another.

4. **Forecasting Formula:** For Chen's FTS model, the forecast value is obtained using the midpoint of the consequent fuzzy intervals:

$$\hat{Y}(t+1) = \sum_k m_j \text{ where:}$$

- m_j = midpoint of consequent fuzzy intervals
- k = number of consequent states

Methodology

1. Collect mango size and weight data.
2. Define the universe of discourse.
3. Divide the universe into fuzzy intervals.
4. Convert observations into fuzzy sets (fuzzification).
5. Construct fuzzy logical relationships.
6. Generate forecasts using defuzzification.

FTS FLOWCHART FOR MANGO WEIGHT PREDICTION

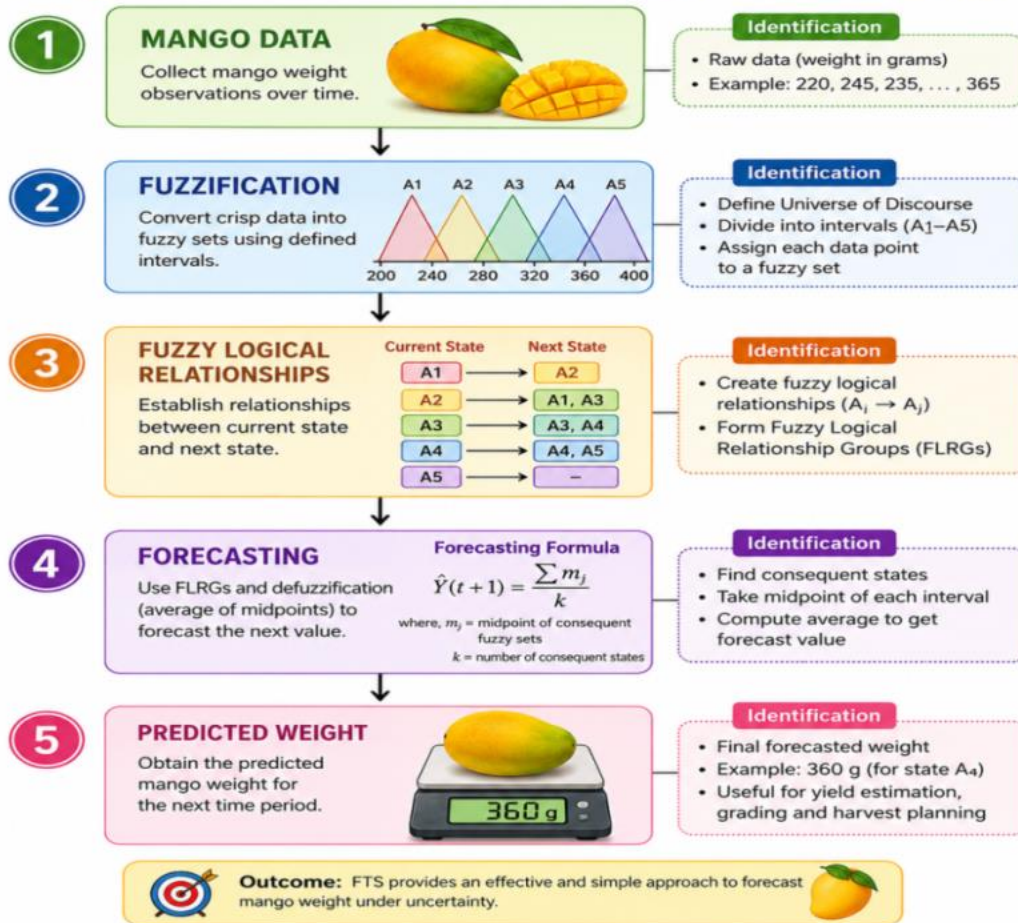


Figure 2. Flowchart of the Fuzzy Time Series forecasting procedure

Result and Discussion

The mango weight observations were transformed into fuzzy states A₁-A₅. The fuzzy logical relationships showed a gradual transition from lower-weight states to higher-weight states, indicating normal fruit growth. Using the midpoint values of the fuzzy intervals, the forecasted mango weight for state A₄ was calculated as approximately **360 g**. The results demonstrate that FTS effectively captures growth trends and provides a simple forecasting tool for agricultural applications.



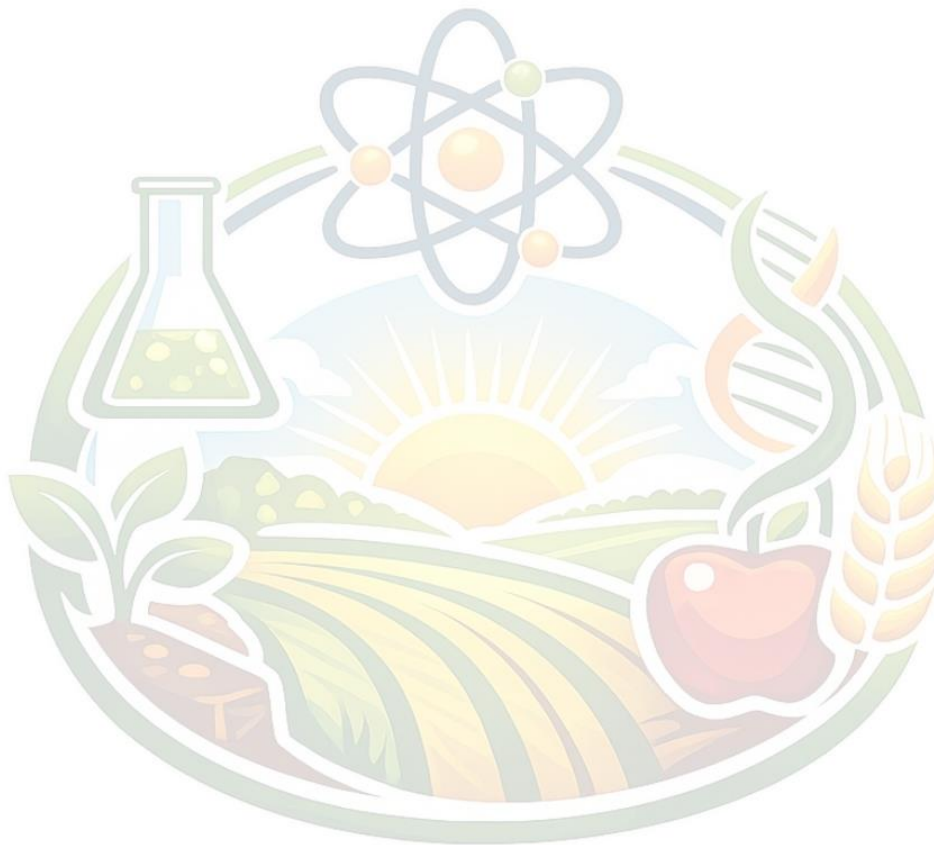
Figure 3. Mangoes classified according to size and weight categories.

Conclusion

Fuzzy Time Series is a simple and effective mathematical technique for modeling and forecasting mango size and weight. The method handles uncertainty in agricultural data and provides meaningful predictions without complex calculations. The approach can assist in fruit grading, yield estimation, harvest planning, and smart agriculture applications.

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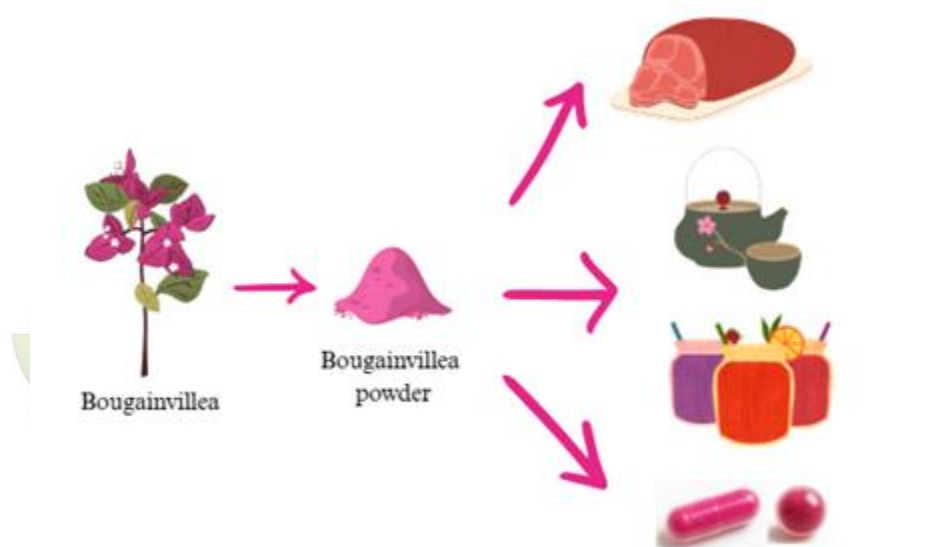
Bougainvillea as a Sustainable Source for Health, Hue and Harmony

Article ID: 74021

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Abstract

Bougainvillea commonly known as paper flower due to the soft and papery bracts is an evergreen plant seen in different colors. It is a precious medicinal shrub with remarkable properties. The Nyctaginacea family comprises about eighteen species but only four species are commercially grown and utilized as functional foods, due to their great potential in exhibiting antibacterial, anti-inflammatory, anti-diabetic and antioxidant properties. Bougainvillea bracts are used to develop anthocyanin rich natural colorants. These health advantages stem from plenty of bioactive compounds present in them. The bracts powders are also used to enhance the hue of meat, improve functionality of fruit beverages. Moreover the bougainvillea bracts can be used to make herbal tisanes and cool drinks that support sustainable nutrition and food security. This article shows light on the application of bougainvillea flower in food sector and reveals promising prospects for developing novel foods and nutraceuticals.



Introduction

Bougainvillea flower commonly known as paper flower is a flowering plant with health beneficial effects, seen in purple, magenta, white, orange and yellow colors and the plant can also have two colored flowers in the same plant. This ancient therapeutic plant exhibits various health beneficial effects such as anti-inflammatory, anti-diabetic, antioxidant, antibacterial, anti-cancerous due to the presence of bioactive compounds. The plant is used as an anti-inflammatory agent in traditional medicine in kolli hills, Tamilnadu due to the presence of biochemical components including dihydrophenols, anthocyanin, lignin, and proline. The eight peltogynoids, including Bougainvinoes, present in the plant have shown cytotoxic effects against five cancer cell lines (Kaushik et al., 2023). The Nyctaginaceae family plant *Bougainvillea spectabilis* Wild. resides in tropical and subtropical areas where humans utilize it for medicinal purposes (Patel et al. 2022). Traditional phytochemicals in the plant consist of alkaloids, saponins, tannins, phenols, flavonoids and glycosides and quinones and terpenoids (Mahey et al., 2025). The botanical substance possesses antibacterial, antihyperlipidemic, antidiabetic, antiobesity, antioxidant, anti-inflammatory, and neuroprotective pharmacological properties (Kumar et al., 2022). Bougainvillea leaf extracts are also used to treat skin diseases (Kalpna et al. 2021). Kaushik et al. provide details on how *Bougainvillea spectabilis* can be used in food products. Since the prehistoric period, natural colorants have been used to dye different materials such as leather, silk, food and cotton among others across diverse societies. Natural dyes have gained significance in decreasing the dependence on synthetic dyes which are hazardous and non-eco-friendly because of their nonallergic, non-toxic and environmentally friendly characteristics.

The food industry has started using Bougainvillea spectra as a coloring agent in their manufacturing processes for noodles, pasta, juice, macaroni and frozen desserts as well as beverages, milk products, tablets and syrup (Ferreria et al., 2024). Exploring bougainvillea as a natural and sustainable source of health-boosting compounds and vibrant pigments offers a simple yet promising way to combine nutrition, natural hue, and eco-friendly food innovation in current food systems.

Bougainvillea Powder Incorporated Ham Formulations

The value of meat and meat products extends beyond human sustenance because they deliver nutrients which people can easily utilize including vitamins and minerals as well as proteins and iron. Meat manufacturers often include the additives nitrites and nitrates to improve multiple aspects of meat including quality, color, flavor, antioxidant benefits and antimicrobial properties. A report from the International Agency for Research on Cancer shows that eating red or processed meat might raise the chances of developing cancer. Product development for clean labels uses vegetables along with herbs, spices, fruits and flowers as sources of antioxidant ingredients. Natural coloring pigments exist with the colorful bracts of the Bougainvillea plant. The plant contains antioxidants such as flavonoids and alkaloids together with phenols and tannins that demonstrate anti-inflammatory actions. The Mexican folk medical practitioners use Bougainvillea to treat respiratory diseases while manufacturers employ this plant in food products for color addition. Ferreira et al. (2024) examines how *Bougainvillea spectabilis* addition to cooked ham affects its physicochemical and sensory attributes through different drying procedures. Bougainvillea powder demonstrates value as a natural color ingredient in ham products which retains cooking yields while preserving antioxidant properties during drying procedures.

Bougainvillea Powder Incorporated Fruit Juice

Fruit juices gained popularity as functional beverages because consumers focus on health-promoting ingredients but they deliver vitamins and minerals along with beneficial bioactive compounds. The tropical fruit pineapple produces a well-known beverage that serves as a non-liquid alcohol drink and contains antioxidant properties. The study conducted by Mahey et al. (2025) aims to produce a functional pineapple drink through addition of dried *Bougainvillea spectabilis* flower powder. The beverage acquired more health-benefiting components along with enhanced flavor and nutritional values by adding the powder.

Bougainvillea Encapsulated Alginate Beds

The food industry currently requires natural foods to substitute artificial ingredients due to increasing market demands. Orozco-Villafuerte and colleagues (2019) examined how *Bougainvillea spectabilis* compounds could be extracted through either aqueous or ethanolic solutions to prepare encapsulated alginate beads. The extraction of pigments yielded superior results when ethanol was used which led to higher measurements for total phenols alongside all betaxanthines/betacyanins and inhibition capacities. The FTIR analysis confirmed that extract-alginate chain interactions existed during development while the encapsulation method successfully safeguarded bioactive components of extracts until they were released.

Bougainvillea Anthocyanin Extract

The medicinal plants *Bougainvillea spectabilis* and *B. glabra* exhibit antidiabetic, antiviral, anti-inflammatory and antifertility properties together with antioxidant effects. *Bougainvillea spectabilis* along with *B. glabra* are incorporated in Mexican traditional medical practices for treating minor respiratory tract diseases. *B. spectabilis* possesses important nutrition such as phenolic compounds, flavonoids, alkaloids, tannins, saponins, terpenoids and mineral ions that form a defense system against multiple diseases. Research indicates that anthocyanin fractions diminish the probability of intestinal cancer development and prevent human intestinal carcinoma HCT-15 and HCT-116 colon cancer cells from multiplying. Anthocyanins with carotenoids and chlorophylls serve as key natural colorants attracting industry attention because they deliver antimicrobial and antioxidant properties alongside anti-inflammatory and anticancer advantages. Bougainvillea bracts offer promising potential for anthocyanin rich extract production because they can create high-quality nutritious foods that protect against cancer and aging and microbial diseases as they exhibit antibacterial antioxidant and anticancer activities (Abdelrahman et al., 2024).

Bougainvillea Encapsulated Food Colorant

Bougainvillea glabra bracts that remain underutilized for their betalains and phenolic compounds can be produced into encapsulated functional food coloring agents through spray-drying and freeze-drying processes while using polydextrose, inulin, and egg albumin as protective agents. Inulin functions as a carrier material for bioactive compounds because it is a non-digestible polysaccharide which displays prebiotic effects in dietary systems. Acidic conditions and digestive enzymes do not affect this compound because it shows resistance to both triggers which makes it appropriate for substance delivery in the colon. The food industry uses polydextrose both as dietary fiber and sugar replacer for food products. The functional proteins in egg albumin allow it to serve as a suitable encapsulating material. The researchers at Kuhn et al. (2020) conducted work to encapsulate *B. glabra* bracts extract through carrier material use with polydextrose and inulin and egg albumin. The research showed that food companies can use encapsulated *B. glabra* bracts extract bioactive compounds as functional food ingredients and colorants.

Future Direction

Bougainvillea is very promising in the future research and industry. The isolation and standardization of its bioactive compounds are subjects of future research that would result in effective functional foods, nutraceuticals, and herbal

therapeutics. The anthocyanin-rich bracts of it have a potential to be used as sources of natural, clean-label food colors, and the pigment stability of the anthocyanin could be enhanced by encapsulation technologies to be further used in food and beverage industries. New value-added products in terms of herbal teas, fortified foods and ready to drink beverages can be created and commercialized. It is a drought-resistant crop agriculturally and a low-input which makes it a sustainable crop to be used in farming and livelihoods in villages. The future studies are to consider standardization of extraction and stabilization process of the pigments found in bougainvillea coupled with a thorough phytochemical profiling and clinical validation of the therapeutic value of bougainvillea. Extensive toxicity and safety data is required to make sure that it is safe to consume, and that it is acceptable in regulations. The development of the product including further investigation of bioavailability and large scale cultivation can make it more effective as a functional, environmentally friendly, food ingredient.

Conclusion

Bougainvillea spectabilis is a common plant that shows medicinal capabilities which extend from anticancer through antidiabetic into anti-inflammatory with additional benefits of antihyperlipidemic antimicrobial antioxidant and antiulcer properties. Multiple compounds found in *Bougainvillea spectabilis* consist of alkaloids while its composition also contains flavonoids along with glycosides and phenolics with phlobotannins and quinones as well as saponins, tannins, and terpenoids. Bougainvillea can be utilized in the development of various food products and as a natural coloring agent, making it a valuable and sustainable option for promoting health. Rich in antioxidants and bioactive compounds, it offers potential benefits for enhancing food aesthetics and nutritional value. Moreover, its vibrant pigments can serve as an eco-friendly alternative to synthetic dyes, contributing to cleaner and more natural food formulations.

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Millets: Small Grains with Big Solutions for Water Scarcity and Nutritional Security

Article ID: 74022

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Water shortage, climate change and malnutrition are some of the biggest problems confronting the food and agricultural sectors globally. As a country supporting almost 18 percent of the world's population with just 4 percent of its total water availability, India needs to find ways of sustaining agriculture without depleting its natural resources. In this regard, millets have come forward as climate-resistant nutritious food that can cater to water scarcity as well as malnutrition. Millets are grown in arid and semi-arid regions, consuming much less water compared to common cereals like rice and wheat. This is because their deep rooting system, shorter crop period and their ability to grow in low rainfall and poor soil conditions make them better adapted to adverse climatic conditions. Besides their environmental suitability, millets are considered to be "nutri-cereals" owing to their nutritional value. They contain adequate quantities of protein, fiber, iron, calcium, zinc, magnesium, antioxidants, and vitamins, thus helping in eliminating hidden hunger, malnutrition, anemia, osteoporosis, diabetes, obesity and other health complications. Millet farming provides various advantages such as cost-effectiveness, reduction in the reliance on irrigation and chemicals, ability to yield well despite harsh weather conditions and potential for value addition and earnings. Besides these advantages, millet farming plays a role in fostering environmental sustainability through its contribution to healthy soils, increase in agro-biodiversity, lowering greenhouse gas emissions and practicing low input agriculture practices.

Millets are Smart Choice to Combat Drought and Water Scarcity

The agricultural sector around the world is facing serious threats from climate change, including warming temperatures, changing rain patterns, late monsoon periods and droughts. Such issues have raised fears over the problems of production of food and water, along with agricultural sustainability. The traditional crops such as rice and wheat, which serve as the basic diet for millions of people worldwide, use huge amounts of water, making them sensitive to climatic changes. Therefore, there is an increasing need to support such plants which can survive and grow well in conditions of scarcity of natural resources, providing food security. Among such crops, there are millets. They include bajra, jowar, ragi and others (Fig. 1). Being naturally adaptive to harsh environmental conditions, millets do not require large amounts of rainfall, good soils and other inputs needed for traditional crops to succeed. Understanding their great potential, the UN named 2023 the year of millets as a part of solving global issues related to sustainable agriculture and nutrition (FAO, 2023). The first advantage of millets lies in their excellent water usage efficiency.

Rice crop requires roughly 3,000-5,000 liters of water for production of one kilogram of rice, most types of millet can be cultivated using just 300-500 millimeters of rainfall without any additional water requirements (Davis et al. 2018). Research shows that pearl millet, sorghum, and finger millet consume almost 70% lesser amounts of water compared to rice, which makes them excellent crops to grow in drought-prone and water-scarce areas. This type of cultivation could help decrease reliance on groundwater sources and promote effective management of available water resources. There are various aspects of drought tolerance associated with growing millets, the millets have strong root systems capable of drawing water from deeper soil layers and enabling them to survive periods of drought. Besides, the majority of millet varieties take up to 60-100 days to mature, which is much shorter than in the case of most common cereals. Moreover, they do not require much water to grow and do not experience terminal drought stress. Finally, most varieties of millets can be cultivated on infertile soils, thus being quite applicable in resource-scarce agricultural settings. Drought and lack of water resources have become significant issues in India. Around 55 percent of the farmlands in India depend on rain for irrigation purposes, which is adversely affected by drought. Being home to almost 18 percent of the world's population but having access to only 4 percent of its fresh water, it becomes essential to save water in all agricultural activities (NITI Aayog, 2021).

The capability of millets to produce stable harvests despite being grown in areas with limited access to water ensures reduced risk to farmers and increases resilience against climate changes. There are multiple advantages of cultivating millets beyond their role in saving water. With the growing effects of climate change and ever-increasing water shortages, increasing the use of millets in farming is an effective way to ensure sustainable agriculture and nutrition. Eventually, rather than mere traditional crops, millets can be considered future-proof crops that will allow us to utilize every single drop of water while feeding more people.

Role of Millets in Nutritional Security and Combating Malnutrition

Malnutrition still remains one of the key problems that the world faces. In particular, malnutrition remains highly prevalent in developing nations like India. Despite the substantial progress in food production over the last several

decades, many individuals continue to experience deficits in iron, calcium, zinc, vitamins and protein. This problem is commonly called "hidden hunger," which describes the situation where people get enough calories while lacking important nutrients needed for normal growth, development and overall health. The groups most exposed to hidden hunger include children, pregnant and breastfeeding women and economically disadvantaged communities who face such issues as anemia, underdevelopment, weak immune system and higher risks of contracting various diseases. Millets can serve as a solution to this problem.

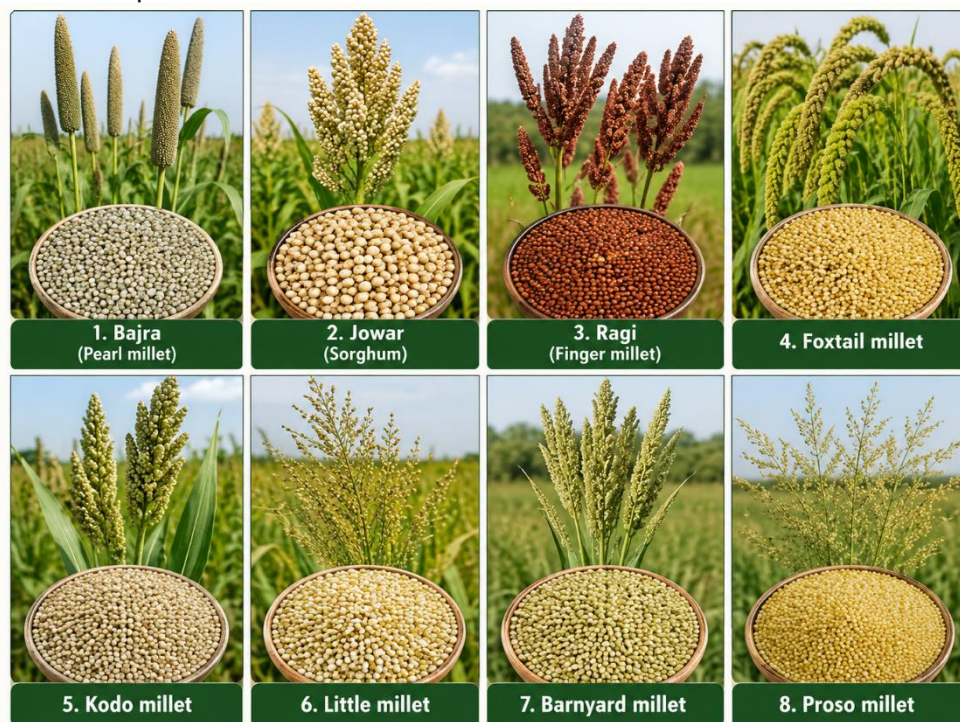


Fig. 1. Major Millet crops cultivated in India for their drought tolerance, nutritional richness and contribution to sustainable agriculture.

Popularly called "nutri-cereals," millets are very nutritious compared to other common cereals like rice and wheat. While processed rice lacks most of its nutritional content, millets contain high amounts of proteins, fiber, vitamins, minerals and phytonutrients. Several studies have indicated that millets contain about 30-300 percent more nutrient content than rice for various nutrients and thus make up for important food constituents in balanced diets (Anitha et al. 2022). The millet variety called ragi is exceptionally high in calcium content and contains about 344 mg per 100g grains. Ragi aids bone growth and reduces osteoporosis. Bajra, on the other hand, is a rich source of iron, zinc and magnesium and plays an important role in dealing with iron deficiency anemia. Foxtail millet, little millet and barnyard millet are rich in fiber, antioxidants and minerals that aid digestion and improve immunity (IIMR, 2017).

Moreover, millets have 7-12% proteins and much more dietary fiber than polished cereals. The presence of such high levels of dietary fiber is beneficial for proper digestion, intestinal health, satiation, weight loss and management of obesity. In addition, the glycaemic index of millets is rather low, which leads to slow glucose release into the blood stream. Thus, eating such products is recommended for people with diabetes and a higher risk of getting other related illnesses. As well, since they are gluten-free products, millets are recommended for patients with celiac disease. At present, India experiences issues regarding food and nutritional security at once. On one hand, caloric intake has increased substantially over the years. On the other hand, micronutrient deficiency remains common among large population groups. For this reason, eating more millets could prove extremely beneficial. This way, one could improve his or her health since millets are high in iron, calcium, zinc, magnesium, B complex vitamins, dietary fibers and antioxidants (Muthamilarasan et al. 2019). Burning issues, where climate changes and resource limitations are increasingly becoming a challenge in food systems, millets present a way forward to help achieve nutritional security. Not only do these crops withstand unfavorable weather, but they also provide high-quality nutrients, making them an ideal choice for addressing problems of malnutrition and hunger. Cultivation of these grains is thus an important strategy for ensuring healthy and nutritionally rich lives and securing our future generation. This clearly shows that millets are not just substitute grains but also important nutritional sources.

Millet Cultivation Benefits

Millets are emerging as crops that are beneficial to farmers due to their ability to adapt, reduced inputs and resistance to harsh environmental conditions. Millet cultivation needs less water compared to other cereals, along with reduced use of fertilizers and pesticides. This helps reduce the cost of cultivation, thus making millet cultivation feasible for

small-scale farmers who usually lack sufficient resources. As millets have the ability to grow in conditions of low rainfall and nutrient-poor soil, farmers can continue production at lower costs.

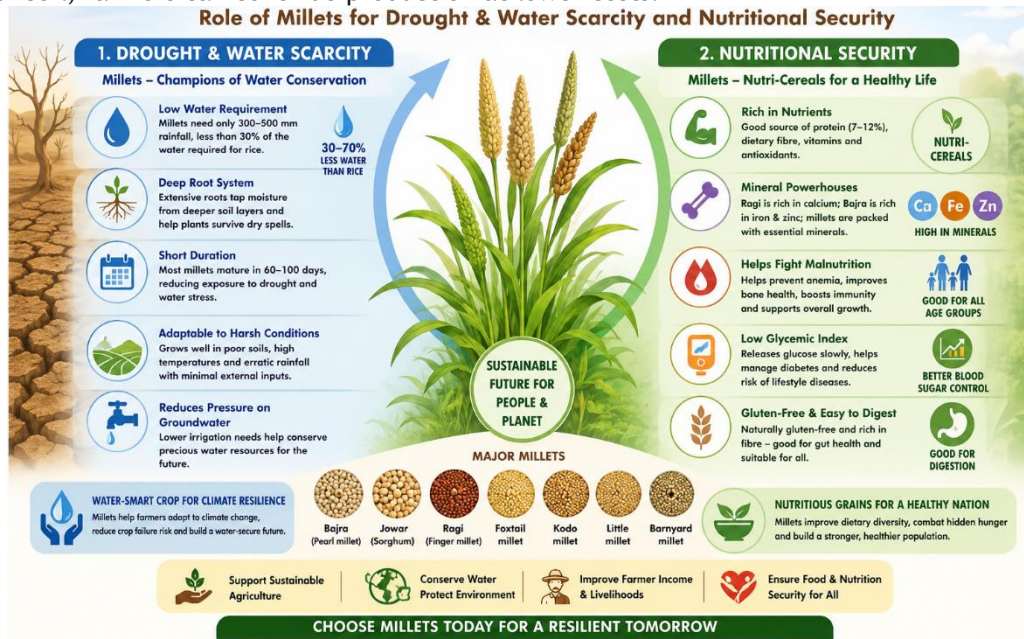


Fig. 2. Advancing water and nutritional security through millet cultivation

Another benefit that comes from the cultivation of millets is the consistent yield levels despite adverse weather conditions. With climate change affecting agriculture significantly, there have been several changes in the weather conditions, which make growing crops like maize and wheat very risky and difficult. For example, due to global warming, the incidence of drought and unpredictable rains in different regions has increased significantly. In such cases, normal crops will experience severe yield losses or even fail completely. However, the millets will produce reasonable yields because of their tolerance to drought and high temperatures. This way, millet farming offers more livelihood security to farmers (Fig. 2).

Besides, there has been an increase in the interest in healthy and nutritious foods. Due to this, millets can be processed into various food products like flour, biscuits, cookies, breakfast cereals, snacks, noodles, bakery items, among others. As people become aware of the various nutritional values of the grains, they create more market opportunities for the products at both national and international levels. In this regard, value chains of the grains can contribute to job creation and increase incomes for farmers and entrepreneurs.

In addition to their economic benefits, millets are highly environmentally friendly. Millet cultivation aids in soil conservation through erosion prevention and enhancement of soil composition. The root system formed by the crops is very strong and hence soil is better bound to reduce erosion, increase organic matter content and promote soil moisture absorption. Such qualities of millets make them valuable in cases where soil degradation is likely to occur. In addition, the crops do not require a lot of chemicals during cultivation and thus they reduce soil and water contamination.

Millets also help to conserve agricultural biodiversity. The last few decades have seen agriculture increasingly depend on few crops, especially rice and wheat. This practice has increased the risks posed by pests, diseases and climatic changes because there is little variation in crop type. Growing diverse varieties of millets ensures higher agro-biodiversity and helps in making ecosystems more resilient. Increased crop diversity makes the environment more stable while at the same time providing alternative crops for farmers in the face of adverse climatic change. Yet another significant ecological benefit of millets is the relatively small amount of greenhouse gas emissions they create. Due to less irrigation requirements and reduced use of fertilizers and machinery, millets are able to contribute less greenhouse gas emissions compared to water-intensive crops such as rice. Less need for irrigation would also mean lesser amounts of energy consumed in extracting groundwater. Thus, growing millets could lead to climate change mitigation as well as sustainable agriculture.

As a result of the numerous advantages that millets have over other crops, the Indian government has launched several campaigns to encourage their growth and consumption. Millets were officially designated as "Nutri-Cereals" by the government and they were also included in the National Food Security Mission in order to promote production and productivity improvements. In addition, the year of 2018 was declared as the National Year of Millets in order to raise awareness among growers, consumers, scientists and officials. Millets are actively being used in various nutrition programs, such as school feeding schemes, ICDS and public distribution programs.

The leadership of India in supporting millets received international recognition when it proposed to the UN, resulting in the proclamation of 2023 as the International Year of Millets. Despite their various benefits, some challenges still hinder

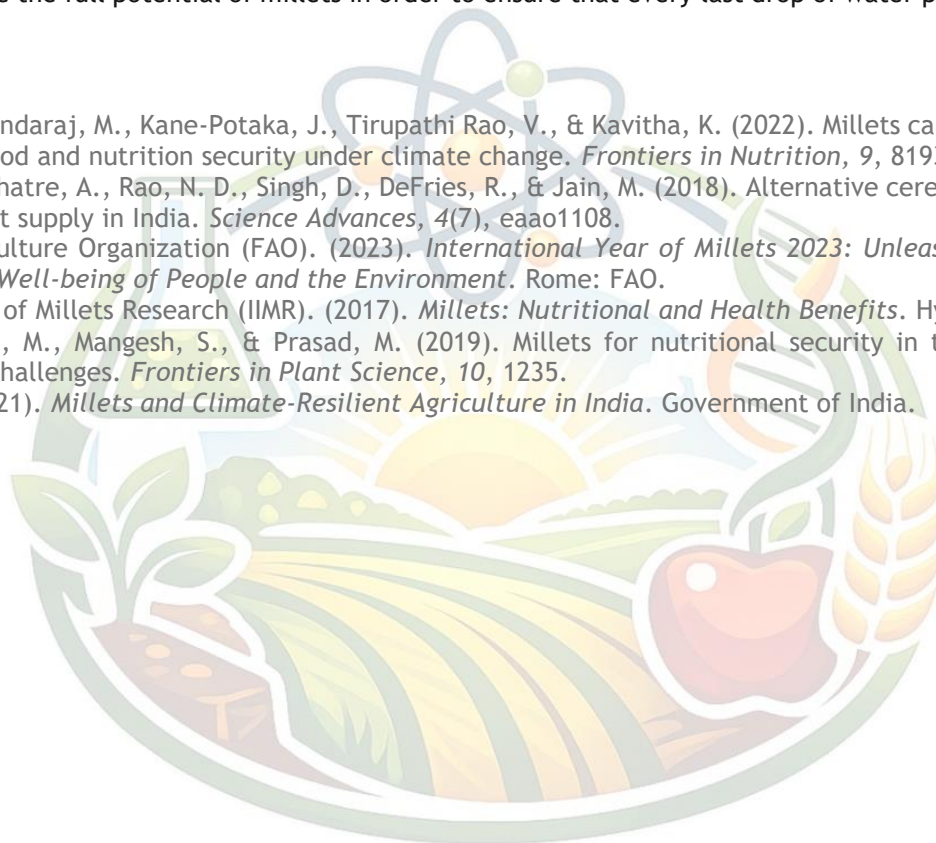
the adoption of millets by many nations. Consumer preference for rice and wheat is one of these challenges since most consumers prefer to consume rice and wheat. Low consumer awareness about the nutritional and environmental importance of millets is another issue that reduces consumer interest in millets. Farmers have faced various difficulties in adopting millets due to poor procurement, poor market infrastructure, poor processing systems and poor value chain structures for the crops. The accessibility of millets in retail shops is relatively low than traditional cereals like rice and wheat.

Conclusion

In summary, it becomes clear that millets are not merely conventional grains, but rather strategically important crops for the future. The capability of these crops to grow under conditions of low water availability, adaptability to unfavorable environmental conditions, nutritional quality, and their compatibility with sustainable agricultural practices makes them perfect candidates for solving today's pressing issues, such as food and nutritional security and the effects of global warming. Given the ever-present water shortages and increasing demand for nutritionally rich foods, it is imperative to utilize the full potential of millets in order to ensure that every last drop of water provides us with a good meal.

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Acoustic Measurement of Food Texture: Product Analysis

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Abstract

Acoustic measurement has become a rapid, non-destructive, and cost-effective method for assessing food texture and quality. Sound emissions during fracture or deformation can be analysed to quantify qualities such as crispness, crunchiness, firmness, and ripeness with great precision. Passive and active acoustic techniques, frequently combined with mechanical assessments, yield insights into sensory perception and customer acceptance. Applications encompass fruit ripening, sorting, grading, dairy product evaluation, and moisture testing. Improvements in sensors, signal processing, and modelling have increased reliability, rendering acoustic analysis a valuable instrument for quality assurance and process management in the agro-food sector.

Introduction

Nowadays, acoustic analysis is a well-known technique as it's fascinating to assess food and fruit quality. It is a fast, reliable, economical and nondestructive process. So that, instrumental acoustic methods very much popular for quality assessment of food and dairy products. This process can be summarized as scattering and reflecting of sound waves similar like to light waves. Here, Acoustic pulses are generated in a transducer and send to a particular object where it scattered, transmitted or reflected from the object. Quality assurance plays the crucial role for quality evaluation of final food products to ensure safety and to ensure that they meet consumer expectations with regard to organoleptic attributes and consistent quality.

Acoustic emission (AE) is recognized as key tool to measure quality of food texture. Acoustic properties of snack-type food are considered as important as fresh products. Crunchiness and crispness, which are considered as signs of freshness, are other aspects of acoustic properties. Assessment of crunchiness and crispness by the sound perception to human ear is main physical index which directly influenced the consumer's satisfaction on the quality of particular food product. Acoustic properties arise from elastic waves produced by the disintegration of food.

Alteration of food texture can be measured by analysis of the emitted sound. Measuring the sound produced by manipulating a food product can be done using destructive and nondestructive tests (passive and active methods). Acoustic methods are divided into methods for measuring sound emission and absorption, and methods for determining phase oscillations. All parameter changes are caused by the medium through which the wave is passing.

Acoustic Measurement

Acoustic measurement has an important role in understanding the internal quality of food texture. Microphones are used as sensors for acoustic emission signals in acoustic measurements of food; however, the contact method was preferred, i.e., using a sensor that remained in mechanical contact with the product sample (passive method). In the passive method, an internal sudden crack is the source of acoustic emission, and elastic waves then propagate through the material, whereas texture evaluation is based more on the number of cracks than on propagation properties. In active methods, also known as nondestructive methods, the acoustic emission source is an external transducer or pendulum. A preamplifier, acoustic emission sensor, specimen, main amplifiers, band-pass filter, and analog-to-digital converter are favored by many food professionals, as they can easily serve as a converter to carry out acoustic emission signal acquisition during the crushing of food products. These instruments consist of a texturometer equipped with a microphone probe, an acoustic signal amplifier, an A/D converter, a personal computer, interference software, and a few other devices to control the loading process and record the experimental results. It is observed that acoustic waves generally travel across the body under test, then through the air, and finally excite the thin membrane placed in the microphone probe. The microphone generally acts as a converter which converts vibrations into electric waveforms that is ready for further computer processing.

Acoustic and Food Texture Properties

In food products, Product texture is considered one of the important properties for assessing quality. So, it is important for technologists to have an understanding of the sensory perception of textural characteristics such as crispness in order to ensure the product's quality and exhibit characteristics of satisfaction to consumers. Texture properties are a combination of visual inspection, tactile and auditory sensations. Cell arrangement, chemical bonds and turgidity are the main factors of auditory sensations which directly depend on cells that are affected by the produced sound during rupture of cells in crisp products. Crispness is considered the most important food textural property. The force required to bite and the corresponding sound emitted are responsible for crispness. For example, an apple, which is a wet cellular

product, contains fluid within its cells and is composed of turgid cells, with liquid present within them and a combination of elastic cell walls. A sound pressure wave is produced when the cells are broken. Dry-texture products like potato chips contain air within their cells, with brittle walls surrounding them. When the force is applied, they bend and then break. This movement generates vibration and a sound pressure wave. Although wet and dry texture products differ in composition, both emit similar sounds. The majority of acoustic measurements of noisy food texture have been combined with force-deformation measurements or low-mass impact measurements to predict crispness sensations. Therefore, instrumental methods have been developed to evaluate and compare texture attributes used a texture analyzer coupled with an acoustic device to make a novel approach based on the mechanical and acoustic response of the flesh tissue. Researchers developed a new contact acoustic emission detector and calibrated models to predict apple sensory texture. The contact acoustic emission detector was particularly useful for evaluating sensory crispness, crunchiness, and hardness. Some researchers suggested using the mastication or fracture sound measurement method to assess the food texture.

Some researchers have developed a device using a piezoelectric sensor to directly measure and quantify food and fruit texture. It directly inserts a probe into a food sample, such as apples, persimmons, pears, and grapes, and detects the vibration caused by the sample's fracture. Factors such as the type of probe used and the crosshead speed during a penetration test are very important and should be carefully controlled, as they simulate the conditions of chewing in the mouth. Research has shown that puncture and compression tests are equivalent to the biting and molar action during mastication. The acoustic method can also be used to determine the elastic parameters of a bulk of cereal grains and rape seeds. These Tests were performed in a cylinder equipped with piezo elements for generating and recording of acoustic shear waves. Results showed that wave velocity increased with increasing hydrostatic pressure for all tested materials.

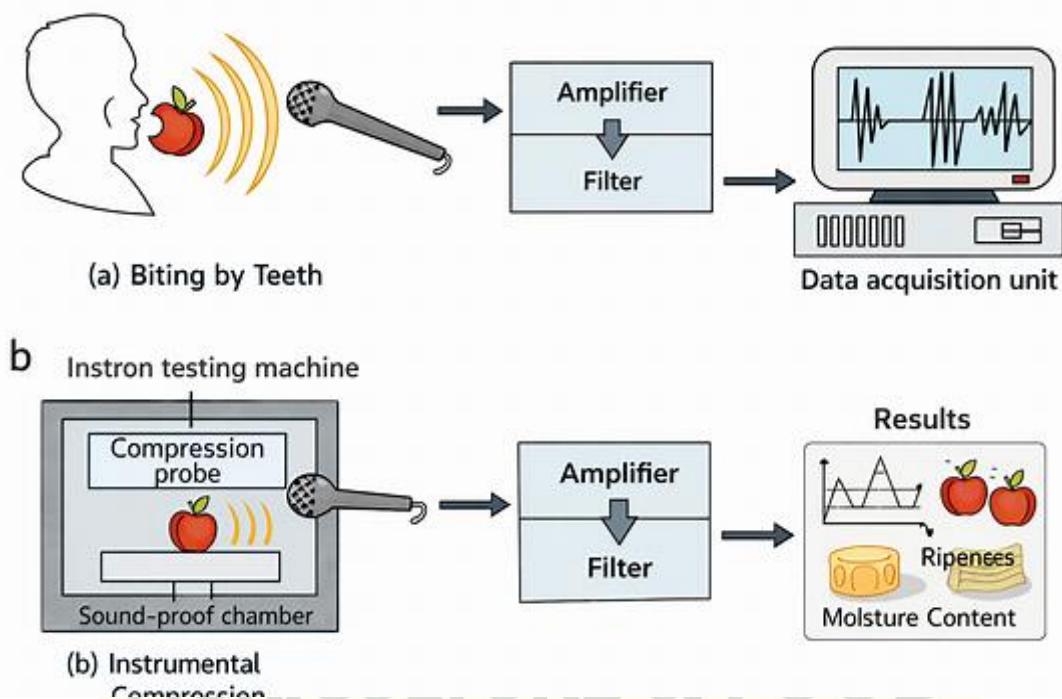


Figure 1. Sound measurement technique: (A) Biting with teeth and (B) Instrumental compression

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Acoustic and Crispiness

Crispy texture is an important parameter for assessing and improving the quality of foods. Crispness may be defined as the textural attribute which is associated with the freshness and firmness of fruit and manufactured foods. It showed an important quality to the brittle materials that rapidly fracture under stress at small strains. The sound emitted during the fracture of crispy food can be used as an indicator of instrumental crispness. It is also noted that hydration from mechanical and acoustic evaluation causes a loss of crispiness. Auditory sensations and its measurements showed an important result for evaluating crispness. Crispness and crunchiness are correlated parameters, but the main distinction between them lies in the required mechanical force to compress food until it fractures into small pieces, and in audible aspects such as acoustic output and mechanical strength. Molar chewing and crispness is used to determine crunchiness. However, crispness is recognized as a major auditory sensation, and the expected sound level is useful for determining the judge's product acceptability. Some researchers have combined mechanical sound measurements with sensory evaluation. Research work also showed that the sensory perception of crispness, pitch, and crumbliness of the corn-based extrudates are directly correlated to the fractal analysis dimensions of amplitude-time data. Consequently, crispness is a textural attribute associated with moistness, firmness and other aspects of agro-products and manufactured

foods that influence taste perception. Understanding the cracking process in fruit tissue is very important for measuring fruit freshness quality. For fruit that has been stored too long, the cracking process shows a mealy character, whereas for fresh fruit, cracking through the fruit tissue reveals juicy and crispy properties. Results showed that a combination of mechanical and acoustic evaluations of crispiness provides more information than either method alone. To accurately study the sound frequency of crispy products using fast Fourier transform (FFT), the sampling rate should be at least 50 kHz, which covers the entire audible range up to 20 kHz. The FFT technique has been used to determine the frequencies most evident during cell rupture in crisp products.

Water Activity and Acoustic Impulse

Water activity, crispness, and crunchiness are related to water activity. The relationship between water content and crispness is contrary. So, by increasing water content, the products' crispness decreases. The quality attributes of food products are largely associated with water content and its migration. The effect of water content on the acoustic properties of products such as cereal-based products, potato chips, and biscuits was studied. It was found that the intensity of emitted sound was strongly related to the moisture content of the materials. The acoustic emission of low-moisture food is highly related to its water content. Dry, crisp products contain cavities or cells filled with air rather than water. If a crispy product gains moisture, it loses crispness and maybe considered unacceptable and poor quality. Hydration causes the loss of sound during softening and plasticization of crispy food. Increasing the moisture content of food decreases the ability of macromolecules to interact, as well as the stiffness and viscosity of food. It examined the effect of water, as a plasticizer, on the mechanical and acoustic behavior of toasted sliced bread. Researchers found that the products became practically silent in the acoustic measurement at water contents over 10% because of the transition from a glass- and rigid-structure to a rubber one. The most salient feature of cereal food is the sound emitted during mastication. The moisture content of the specimen food is responsible for the production of mechanical failure. Sound is emitted in fried snacks and cereal foods when the cell walls snap during fracture and energy is released. These characteristics of crisp texture weaken as the moisture content increases. Further research has shown that when the water activity was increased to 0.65, the required force to break the food sample increased significantly due to moisture toughening. Crispiness in low-moisture foods such as biscuits is strongly related to their water content and/or water activity.

Acoustic for Fruit Firmness and Stiffness Evaluation

The firmness index and the modulus of elasticity have a synergistic relationship with the acoustic signal response. It plays a key factor in consumer acceptance, and many researchers have calculated the firmness of fruits and vegetables using impact techniques. Determining the effect of storage time on the firmness index is a valuable objective for producers, distributors, and consumers, who need reliable measuring sensors for commercial purposes. However, recently, the acoustic impulse response method has been used to measure firmness as related to the elastic properties and quality assessment of fruits and vegetables. In this method, the fruit is excited by a ball pendulum at an equatorial location; the response signal is captured using a microphone or film sensors and analyses for resonant frequencies.

Some evaluation systems for nondestructive firmness assessment have been developed, based on piezoelectric sensors, a microphone, and an accelerometer. These systems have been used to test several food products, such as apples, melons, pears, and peaches. Researcher used an acoustic impulse-response technique to monitor firmness of tomato fruit. This technique provides stiffness factors based on the first resonance frequency and the mass of the intact fruit.

Eggshell stiffness is measured by analyzing frequency response of eggshell excited with a light mechanical system. Mango fruit firmness was estimated by combining acoustic technique and optical method (Vis/NIR absorbance spectroscopy). Fruit firmness can be measured nondestructively by hand squeezing, a durometer, acoustic resonance, and low-mass elastic impact methods, and destructively by the penetrometer. The results indicated that the durometer and the penetrometer were better methods for assessing firmness than hand squeezing, acoustic resonance, or impact methods. Some researchers developed a low-cost, light-mass and flexible piezoelectric film sensors for dynamic testing of agricultural and food products. They concluded that the sensor could detect a decrease in resonance frequency or in the firmness index. Also, the firmness measurement technique for fruit using piezoelectric film sensors was found to be simple, fast, and repeatable. Classification models based on nondestructive parameters and sorting the fruits into two classes of firmness showed that scores of well-classified are higher than 90%. Results showed that nondestructive acoustic response can replace the conventional compression test to determine fruit firmness and expected shelf life. Accuracy and repeatability of subjective scores from the acoustic impulse-response technique by market experts were equally high.

Application of Acoustics in Food Processing

1. Fruit Ripening Measurement: Firmness index play key role in detecting the ripening acceptance of fruit. It is affected by temperature, maturity stage, atmosphere, storage time and genetic background. These have been identified as the main factors affecting the shelf life of whole fruits. The acoustic response method is a promising nondestructive technique for predicting the textural quality and ripening rate of agricultural products. Researchers evaluated the

capacity of acoustic signal responses to monitor changes in the firmness of mandarin fruit during storage. They established a good correlation between the acoustic parameters (firmness index and modulus of elasticity) and fruit compression force, with correlation coefficients of 0.88 and 0.91, respectively. These data are applied to the fusion concept for nondestructive testing data to classify fresh tomatoes by ripening stage. The Bayesian classifier was tested on all data of tomatoes taken by colorimeter and acoustic impact tests. The Bayesian classifier results were in agreement with numerical estimations, showing an 11% classification error in the multivariate case (multisensor) compared with a 48% obtained by the single sensor. The nondestructive acoustic vibration method was also used to determine the ripening rate of the melon cultivar “Miyabi-Haruaki” by monitoring its elasticity index. Nondestructive determination of the period of optimum ripeness in terms of the elasticity index is useful for estimating the shelf-life of melons. The time required for a melon to reach optimum ripeness can be predicted by determining the ripening speed. It can be stated that nondestructive acoustic tests can replace conventional compression tests to determine fruit firmness, ripening speed, and expected shelf life. The dominant frequency, firmness index, and elasticity coefficient could be expressed as functions of time for fruit ripening prediction.

2. Fruit Sorting, Grading and Separating: Recently, nondestructive acoustic experiments for sorting, grading and separating of food products have been used increasingly. It is part of the core research in the field of postharvest engineering. The rapid development of microprocessors, signal analysis methods, and sensors has opened new possibilities for employing acoustic techniques for this purpose. Commercial interest in sorting food products that are more homogeneous in quality and consumer preferences has led to a lot of effort for developing this technique. An acoustic-based intelligent system was developed for high-speed discrimination between potato tubers and soil clods. The developed system capacity is about 20 tons per hour with an accuracy of about 97%. Separation of open- and closed-shell Kerman variety pistachio nuts was performed using discriminant analysis of time-domain sound signals. The classification accuracy of this method was approximately 97%. A voice recognition technique was also used to separate open- and closed-shell pistachio nuts based on their impact acoustics. The classification accuracy for closed shell nuts exceeded 99%.

3. Determination of Physical Properties (Size, Shape, Volume and Moisture): There is growing interest in extracting physical properties such as size, shape, and moisture content of agricultural products from acoustic responses. Acoustic response has been utilized for density and volume measurement for quality assessment such as citrus granulation test. A near-field acoustic method was applied to characterize viscoelastic properties of mango pulp tissue. The developed acoustic method appears to be a promising tool for monitoring changes in mango texture during fruit ripening. A close relationship was found between acoustic parameter like velocity and the physical properties of fruit measured using a mechanical test. The effect of pears' shape on their resonant frequencies using finite element modal analysis was investigated. The length maximum diameter ratio and the Fourier descriptors were used as shape descriptors. Impact acoustic method was used for detecting and density separating of dry beans. FFT used data analysis consisting of real-time function and the integral against frequency 0-20 kHz was called signal level. A low-frequency acoustic technique was used to characterize the kinetics of the bread dough fermentation phenomenon. Their measuring device was designed to monitor the influence of various technological parameters such as temperature and other various ingredients. An online volume measurement system was developed to determine the relationship between an object's volume in a Helmholtz resonator and its acoustic resonant frequency. The researchers tested their developed system using wooden blocks, metal blocks, and boiled rice. The system delivered a high correlation with the actual volume, although the operating speed was rather slow. A prototype of an acoustic online grain moisture meter was developed and it can measure wheat moisture content over a typical range of harvest moistures. The acoustic resonance technique was used to measure light transmission through egg to estimate the eggshell conductance. A combination of acoustic and nondestructive light techniques can be used to differentiate different classes of eggs based on their shell conductance.

4. Acoustic Applications in Dairy field: The dairy industry is one of the most important parts of the global food system, and some researchers have used acoustic methods to assess the composition of dairy products. Some parameters, such as velocity and acoustic impedance, are linked to properties such as milk density. Consequently, the changes or differences in milk-like density should be detected using acoustic methods, and then sound velocity could be used to assess the attributed internal quality. Speeds of sound and densities of milk + NaHCO₃ and milk + H₂O₂ were measured at different temperatures. Speeds of sound, densities, specific acoustic impedance and Rao's molar sound function are fitted to a linear function of mass concentration and temperature. The acoustic technique was also used to control cheese quality. A tap-test acoustic technique has been developed and employed for cheese classification. Some researchers studied fouling detection on stainless steel based on acoustic parameters. Multiple optimized nonintrusive sensors were used to develop a real-time acoustic technique to monitor fouling inside plate heat exchangers during online trials. A good relationship exists between the textural parameters, the impact force-deformation and the acoustic impulse-response.

5. Acoustic Applications in other aspects: Guided wave ultrasonics and acoustic impact-these two acoustic methods were used for pipe fouling detection potential. For the acoustic impact method, they used a mechanical impacting hammer tap or a coin tap to generate sonic and ultrasonic waves in the specimen. Concentrations in sucrose, glycerol and online sodium chloride solutions using acoustic reflectance have also been addressed. Sound velocity and acoustic

impedance is the main parameters used for this purpose. Online product mass testing and process control greatly widen the applications of acoustics in food control.

Conclusion

The implementation of acoustic technique in food technology can be considered as a viable technology in quantity assessment and food safety. Commercial applications of these techniques will benefit consumers, growers, and traders. The risk of buying poor-quality products will decrease significantly, fruit growers' income will increase with product quality, and merchants will be able to sell products. The results discussed in this article clearly demonstrate that the availability and low cost of the acoustic method can be a significant advantage in the agro-food industry. In parallel with the promotion of computers and electronics, the application and accuracy of acoustic techniques will increase, as will data processing speed, enabling online decisions to be made on a quality assessment system. The acoustic method, among other contemporary methods, provides information on the nature of the destruction processes and enables detection of the onset of these phenomena that precede the occurrence of the maximum material stress. The advantages of nondestructive acoustic techniques ensure their widespread use in the food industry in the near future.

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Effect of Composition, Structure and Processing on Yak Milk Fat

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Abstract

Yak milk, primarily sourced from the Qinghai-Tibetan plateau, possesses distinctive chemical and structural characteristics that set it apart from other bovine milks. Yak milk is distinguished by its elevated fat (5.5-7.2%) and protein (4.9-5.3%) contents, larger casein micelles, and fat globules averaging 4.39-6 µm, which facilitate survival in harsh conditions and enhance its suitability for butter and cheese manufacturing. The fatty acid composition shows increased levels of palmitic and stearic acids, conjugated linoleic acid, and key polyunsaturated fatty acids, along with higher levels of fat-soluble vitamins and carotenoids. The benefits of processing include rapid cream separation and efficient butter production; however, cheese-making is more challenging due to globule disruption.

Introduction

Yaks (*Bos grunniens*) are members of subfamily Bovinae. Yaks are generally found in the high reaches of the Himalayan region (the Nepalese Himalayas, Indian Kashmir, and Mongolia) as well as on the Qinghai-Tibetan Plateau (China). It is estimated that the total world population of yaks is around 14.2 million. Among them, around 93.7% of which are found in China. Yaks are able to survive extreme conditions, and they are recognized as the only bovine species that are able to survive on the Qinghai-Tibetan plateau (heights of 2,500 to 6,000 m above sea level). Yak milk is the major supply of fat to the herders, where it accounts 15 to 32% of a herder's daily intake of fat. About 1.6 million tons of yak milk are produced per year in the southwest region of China, which includes the Qinghai, Gansu, Sichuan, and Tibet areas. So, yak milk has a major role in vital functions and provides important nutrients to the health of the Qinghai-Tibetan plateau people. The main compound produced from yak milk is high-quality yak butter. Butter quality can be determined by analyzing composition and fatty acid (FA) content. Yak milk contains some unique characteristics of fatty acids compared to other milk because of the differential grazing environment.

Composition

Milk composition is considered as a decisive factor for the quality of dairy products. Yak milk has a higher fat content (5.6 to 8.8%) and dry content (16.3 to 19.0%) than that of other species, providing support for their calves in harsh cold and anoxic conditions. Yak milk has about 16.9% - 17.7% solids, 4.9% - 5.3% protein, 5.5% - 7.2% fat, 4.5% - 5.0% lactose, and 0.8% - 0.9% minerals. Milk contains a high level of fat and dry matter, making it suitable for cheesemaking. It is observed that larger casein micelles are contained in yak milk than in Holstein casein micelles. So it is obvious that the aggregation of yak milk casein is slower than that of Holstein casein micelles. Furthermore, yak milk contained a higher average diameter size of fat globules (4.39 µm), which is twice that of Holstein milk fat globule average size.

The saturated and unsaturated fatty acids constitute 65.2% and 34.8%, respectively, of the total fatty acids in the yak milk, and they include 22 kinds of fatty acids. The total percentage of low molecular weight fatty acids, capryne, caprice and caprylic acids, which are responsible for the smell and taste of fat, is 7.2%. Among the saturated acids, palmitin (29.2%) and stearin (14.9%) are dominant. Olein occurs mostly among the unsaturated fatty acids, and there are 5.5 to 6.0% multiple bond unsaturated acids or vitamin F. This is found in very little amounts in the milk of cattle.

According to analyses of amino acids in yak milk by the Animal Product Processing Laboratory of Southwest National College in Chengdu, China, the total content of 17 amino acids in yak milk was found at 2,341 mg/100 g protein, and the levels of leucine and lysine were higher than in cow milk and goat milk.

The presence of linoleic, linolenic, and arachidonic acids in the yak milk indicates the biological activity of yak milk. There are some seasonal differences in the butter of yak milk. In winter, the number of volatile acids is higher, while the unsaturated acids are lower compared to summer. As a consequence, the expansion coefficient, melting temperature, and hardening of butter differ during winter compared to summer. Because of the higher fat content in the yak milk, the concentrations of fat-soluble vitamins are also higher. Research work has already shown that there is a significant difference between the gross composition of cow, camel, yak, and breast milk.

Table 1. Average Fatty acid (g/100g of total FA) content in yak milk

Fatty acids(g/100g of total FA)	Average Composition
C6:0	0.96
C8:0	0.66
C10:0	1.52
C12:0	1.57

C13:0	0.10
Iso-C14:0	0.21
C14:0	7.97
C14:1	0.65
Iso-C15:0	0.72
C15:0	1.42
Iso-C16:0	0.50
Anteiso-C16:0	0.43
C16:0	26.58
c9- C16:1	1.78
t9- C16:1	0.21
Iso-C17:0	0.70
C17:0	1.03
c9-C17:1	0.59
C18:0	18.93
t9- C18:1	0.42
t11- C18:1	4.78
c11- C18:1	0.13
c9-C18:1	21.78
c12- C18:1	0.57
c-9,c-12-C18:2	1.12
c-9,t-11-C18:2(CLA)	0.92
C18:3n-3	1.62
C19:0	0.22
C19:1	0.29
C20:0	0.58
C20:1	0.28
C20:4	0.12
C20:5N-3(EPA)	0.06
C21:0	0.31
C22:0	0.21
C22:6N-3(DHA)	0.06
SFAs	39.12
MFAs	22.48
PUFAs	3.90

Structure of Fat in Yak Milk

Yak milk fat globules have a heterogeneous structure that varies in diameter, triglyceride content, and membrane and fatty acid composition. The diameter of the milk fat globule varies between 0.2 and 15 μm (average is 5-6 μm) and its composition is observed to vary by size, adding more complexity to the study of their structure and function. The core of the milk fat globule is composed primarily of TAGs, which represent 98% of total yak milk fat and provide approximately half of the energy intake in addition to essential fatty acids required for growth and development. The triglyceride (TG) molecule consists of a glycerol backbone esterified with three fatty acids. The principal pigment in yak milk fat is β -carotene, accounting for about 95% of the total carotenoids present. In yak milk, β -carotene is found in the core of the milk fat globules and is higher than in other milk species. Small amounts of other sterols, namely campesterol, stigmasterol and β -sitosterol, have also been identified in yak milk fat.

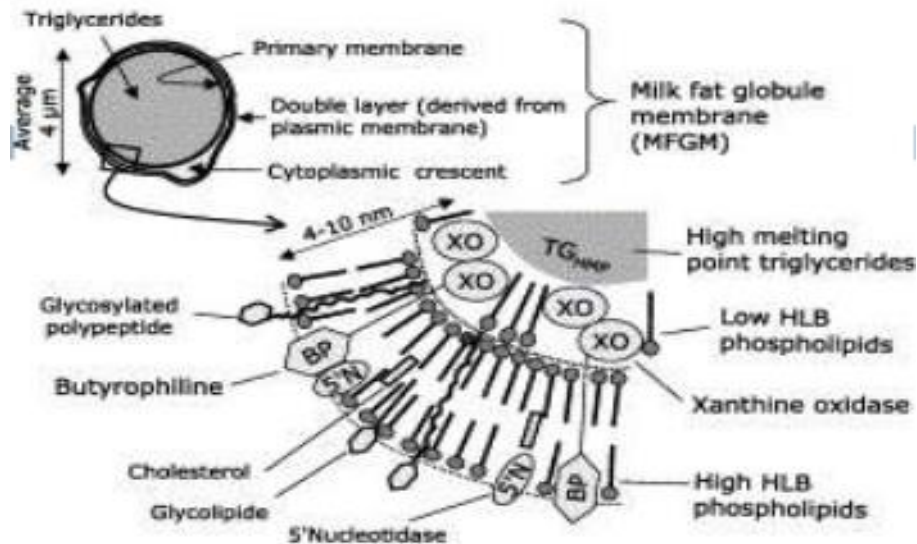


Figure 1: Structure of yak milk fat

Effect of Processing on Milk

- 1. Fast cream generation:** Yak milk contained a higher average diameter size of fat globules (4.39 μm), which is twice Holstein milk fat globule average size. This reduces cream separation in yak milk, making it suitable for making milk cream. Here, fat separation is easier than in other milks.
- 2. Difficulty during cheese making:** Yak milk contained a larger diameter of fat globule (5 to 6 μm). This might affect the cheese yield and moisture content because fat globules of large size are prone to disruption during curd stirring, which decreases the rate of curd syneresis, resulting in more moisture retention after the curd pressing. In support of this, elevated fat levels in the rennet coagulum added more than its own weight to the yield of cheese.
- 3. Fat loss problem during butter making:** Because of the large diameter of fat globules in the yak milk (5 to 6 μm), the fat globule is built up for 44 minutes on average (60 minutes in cattle). Due to the large size of fat globules, the loss of butter during separation is lower, and 97% of butter is extracted.

Conclusion

Yak milk, characterized by its elevated fat and protein content and distinctive fatty acid profile, serves a crucial nutritional role for Himalayan populations. The substantial fat globules improve butter production and cream separation, although they complicate cheese-making. The unique composition and processing characteristics of yak milk underscore its functional and nutritional importance.

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Oxidative Rancidity in Milk Fat and its Methods of Estimation

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Abstract

Oxidative rancidity in milk fat is a significant quality issue, primarily caused by the autooxidation of unsaturated fatty acids, which produces hydroperoxides and secondary compounds, such as aldehydes and ketones, that contribute to off-flavours and nutritional degradation. Various analytical techniques are utilized to evaluate lipid oxidation, including peroxide value, conjugated dienes/trienes, thiobarbituric acid (TBA) value, p-anisidine value, carbonyl content, Totox value, and free radical assessment. Each approach offers supplementary insights into primary and secondary oxidation phases. These methods collectively provide the proper monitoring of oxidative stability and inform preventive efforts to maintain milk product quality.

Introduction

Milk fat oxidation is a major threat to the dairy industry. It is mainly concerned with the unsaturated fatty acids as they oxidize and develop rancidity. Here, oxygen reacts directly with unsaturated fatty acids, generating primary oxidation products such as hydroperoxides and free radicals. These primary oxidation products further react to produce hydrocarbons, aldehydes, and ketones, which have a strong off-flavour and lead to nutritional loss in milk. The balance between anti- and pro-oxidative processes provides stability to milk and milk products. Factors such as exposure to light, degree of fatty acid unsaturation, content of transition metal ions, elevated temperature, and the content of antioxidants such as tocopherols and carotenoids play a significant role in milk fat oxidation.

Initiation: $RH \rightleftharpoons R^{\cdot}$ (RH is unsaturated fatty acid)

Propagation: $R^{\cdot} + O_2 \rightleftharpoons RO_2^{\cdot}$

$RO_2^{\cdot} + RH \rightleftharpoons ROOH + R^{\cdot}$

Termination: $2 RO_2^{\cdot} + O_2 \rightleftharpoons RO_2R$

$RO_2^{\cdot} + R^{\cdot} \rightleftharpoons RO_2R$

$2R^{\cdot} \rightleftharpoons R-R$

Figure 1. Lipid Autooxidation reaction

Methods: Several methods are widely used to measure the oxidative rancidity of milk fat. The major methods used to monitor lipid oxidation in milk are listed below:

1. Peroxide Value
2. Conjugated Dienes and Trienes
3. TBA value
4. p-Anisidine Value
5. Carbonyls content
6. Totox Value
7. Measurement of free radicals

Several methods like milk packaging material headspace oxygen measurement, sensory analysis, Iodine value etc. can also be performed for the assessment of milk fat autooxidation.

Peroxide Value

Rancidity is the most common cause for milk fat deterioration, which directly affects the flavour and quality of milk. Hydroperoxide is generally considered as the first product formed by the oxidation process of an oil or fat, while it further decomposes into secondary oxidation products, i.e. aldehydes and ketones, which play a key role in off-flavour generation. Peroxide value (PV) is considered the usual method for assessing rancidity in fat or oil, expressed in milliequivalents of peroxide oxygen per kg of fat or ml of 0.002 N sodium thiosulfate per g of sample. Iodometric titration is the most widely used method, which measures the production of iodine from potassium iodide due to the presence of peroxides in a fat. Ferric ion complex estimation and Fourier Transform Infrared Spectroscopy (FTIR) are also used to determine the PV value. PV is recognized as an indicator of primary oxidation and is known for its accuracy in the measurement of rancidity or the degree of oxidation.

1. Iodometric method: Oxidation results in the production of hydroperoxides, which are noted as the first detectable products of the auto-oxidation reaction. Hydroperoxides are classified as oxidizing agent and they release iodine from Potassium iodide (KI). This iodine estimation is performed by titration with standard sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3$), with starch added as an indicator. It is assumed that the PV value is directly proportional to the liberated iodine, which is directly proportional to the PV of the oil. The major advantages of this method are that it is inexpensive, simple and conventional laboratory glassware is required. The drawback of this method is that the flavour deterioration developed below the PV value limit was not measured by this method.

Reaction:

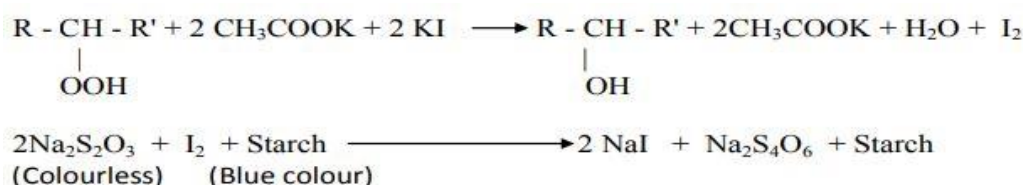


Figure 2. Possible reaction between hydroperoxides and KI

Reagents:

- Acetic acid - Chloroform solution - It is made by mixing 3 volumes of acetic acid with 2 volumes of chloroform.
- Saturated Potassium iodide solution-excess KI is dissolved in freshly boiled water. A solid portion should remain. It is now stored in dark conditions. Daily testing requires adding 0.5 mL to 30 mL of $\text{CH}_3\text{COOH}-\text{CHCl}_3$ (solution 1). After that, add 2 drops of 1% starch solution into it. The colour of the solution is observed. If it turns the solution blue but requires more than 1 drop of 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$ reagent and changes colour, then a fresh solution is needed.
- Sodium Thiosulphate standard solution - strengths are 0.1 N and 0.01N. Preparation of 0.01 N requires dilution of 0.1 N.

Procedure: A sample weighing 5 ± 0.5 g is to be placed in a 250 ml glass stoppered Erlenmeyer flask. Then, 30 mL of acetic acid was added to the chloroform solution, and the mixture was swirled until dissolved. The addition of 0.5 ml of saturated KI solution is to be made from the Mohr pipette; it should be shaken for at least 1 minute, and then 30 ml of water is added. Now, the titration process is to be done with 0.1 N of sodium thiosulfate solution with continuous shaking until the yellow colour is almost gone. Now, add 0.5 mL of starch solution, then continue the titration with continuous shaking until all iodine has been removed from the chloroform layer, just until the blue disappears. If less than 0.5 mL of 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$ is used, then repeating of the determination process is required with 0.01 N of $\text{Na}_2\text{S}_2\text{O}_3$. A Conductivity of blank determination (must be less than 0.1 mL 0.1N $\text{Na}_2\text{S}_2\text{O}_3$) is also to be carried out.

Peroxide Value (millieqvt oxygen / kg oil) = $S \times N \times 1000$

Weight of Sample

Where,

S = mL $\text{Na}_2\text{S}_2\text{O}_3$ (blank corrected) and

N = Normality of $\text{Na}_2\text{S}_2\text{O}_3$

2. Ferric ion complex estimation method: Oxidation of ferrous ion (Fe^{2+}) to ferric ion (Fe^{3+}) in an acidic medium and the formation of iron complexes are used to determine lipid oxidation. Here, spectrophotometric measurement of the ability of hydroperoxidases to oxidize ferrous ions to ferric ions is performed, leading to the formation of a complex with thiocyanate or xylenol orange. Ferric thiocyanate is observed as a red-violet complex which shows strong absorption at 500-510 nm. This PV measurement method using colorimetric detection is simple and more sensitive than the iodometric method. It has been used for lipid oxidation measurement of milk products, fats and oils.

The oxidation of xylenol orange (FOX) assay used xylenol orange dye, which forms a blue-purple complex with strong absorption at 550-600 nm. This method is observed as a rapid, inexpensive, and non-sensitive method to the atmospheric temperature or light. It is also reported that this method consistently quantifies the lower hydroperoxide level. This method has been successfully adapted to various fields.

3. Fourier Transform Infrared Spectroscopy (FTIR): Infrared spectroscopy is also used to determine hydroperoxides by measuring the characteristic O-H stretching absorption band. The absorption band at $2.93 \mu\text{m}$ indicates hydroperoxide generation. While the replacement on

a double bond or polymerization accounts for the disappearance of the band at $3.20 \mu\text{m}$. The formation of aldehydes, Ketones, or acids gives an extra rise in the band of $5.72 \mu\text{m}$. Also, cis-, trans-isomerization as well as conjugated dienes formation can be observed by the change in absorption band range of 10-11 μm .

FTIR spectroscopy is considered a simple, rapid, and highly precise method which shows an excellent correlation with the iodometric method. It avoids the disposal issue of the solvent and reagent.

Conjugated Dienes and Trienes

It is found that the formation of conjugated dienes in fats increases the absorption peak at 230-235 nm in the ultraviolet (UV) region. It is also noted that an important method for the measurement of lipid oxidation. During the degradation of unsaturated fatty acids into hydroperoxides, conjugated dienes are generated by the rearrangement of double bonds. These conjugated dienes showed an intense absorption at a wavelength of 234 nm, whereas conjugated trienes showed an absorption at 268 nm. The increase in UV absorption gives a clear idea of the formation of primary oxidation products in fats. This process is fast, simple, and no chemical reagents are required. Only a small number of samples are needed in this method. Whilst this method has lesser specificity and sensitivity than PV measurement. In addition, here a chance of result error may also be occurred as some compounds are also absorbed in the same region like carotenoids. To prevent these interferences, an alternative spectroscopic method has been proposed which measured conjugable oxidation products (COPs). Here, conjugated chromophores are produced by conversion of hydroperoxides and some decomposition products through reduction and subsequent dehydration process. These conjugated chromophores are spectroscopically measured in the wavelength of 268 and 301 nm and expressed as COP values.

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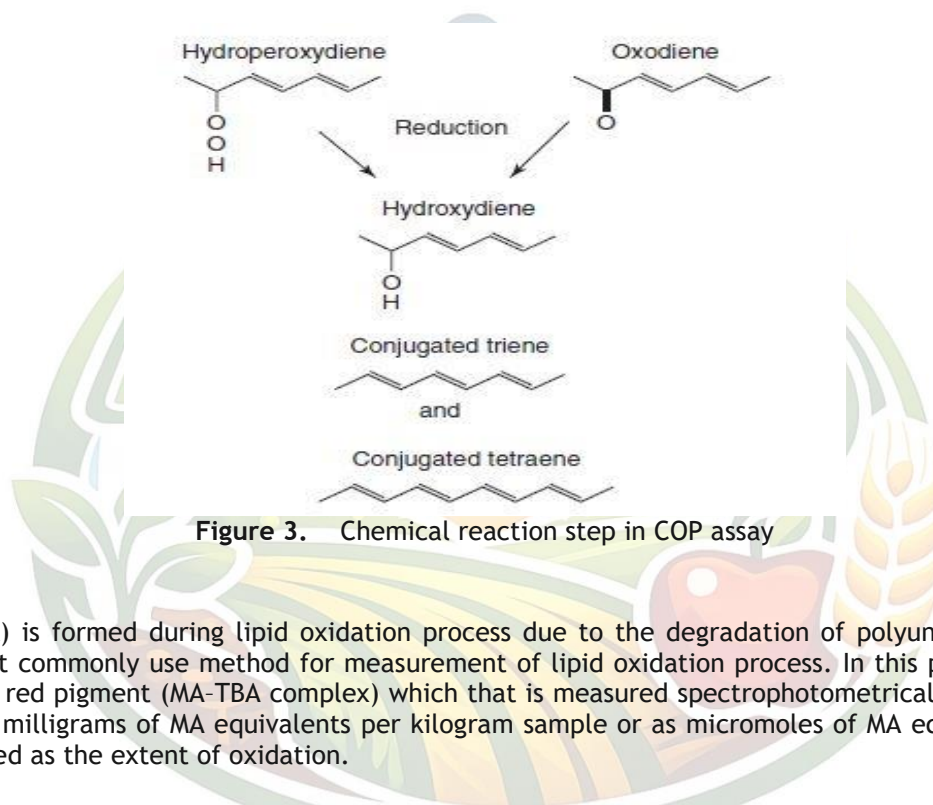


Figure 3. Chemical reaction step in COP assay

TBA Value

Malonaldehyde (MA) is formed during lipid oxidation process due to the degradation of polyunsaturated fatty acids. Nowadays It is most commonly use method for measurement of lipid oxidation process. In this process, MA is reacted with TBA to form a red pigment (MA-TBA complex) which that is measured spectrophotometrically at 530-535 nm. TBA value expressed as milligrams of MA equivalents per kilogram sample or as micromoles of MA equivalents per gram of sample, is mentioned as the extent of oxidation.

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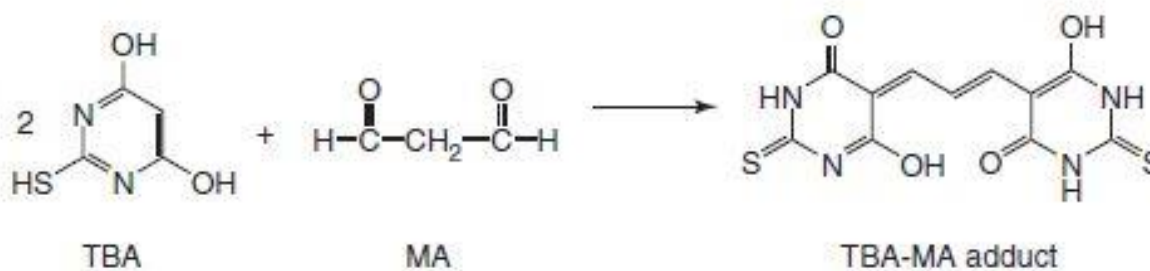


Figure 4. Reaction of 2-thiobarbituric acid (TBA) and malonaldehyde (MA)

Reagents: TBA Solution: Dissolve 0.67gms of TBA in 100 ml of boiled distilled water. Filter. Mix the content with acetic acid in the ration of 1:1

Carbontetrachloride- hexane mixture

Procedure: Here 3 gms of melted fat is to be taken in a glass stopper test tube. Then an addition of 10 ml of carbon tetrachloride-hexane mixture is done, and shaking is done. Now 10 ml of TBA solution is added into it and shake it in horizontal direction for 4min. Then allow it to settle down for 15min. Then removal of the aqueous layer with the help of pipette is to be done. 6ml of aqueous layer is Pipette out into a dry test tube and transfer it to a boiling water bath for 30min. Measurements are to be carried out in a spectrophotometer at 530 nm wavelength with blank sample.

p-Anidine Value (*p*-AnV)

The *p*-AnV method is a well-known method for measuring aldehyde content (principally 2-alkenals and 2,4-alkadienals), which is generally generated during hydroperoxide decomposition. This process based on the reaction between *p*-methoxyaniline (anisidine) and aldehydic compounds and their colour production under acidic condition. The reaction product with yellowish colour absorbed at 350 nm. The colour can be quantified, which is also converted into *p*-AnV. The *p*-AnV can be elucidated as the absorbance of a solution resulting from the reaction of 1 g of fat in an iso-octane solution (100 ml) with *p*-anisidine (0.25% in glacial acetic acid). This procedure is most accurate in unsaturated aldehydes rather than saturated aldehydes as the colored product produced from unsaturated aldehydes are strongly absorbed. Though this process directly measures presence of volatile substances. This process is widely adopted for the measurement of oxidative rancidity in fat.

Reaction:

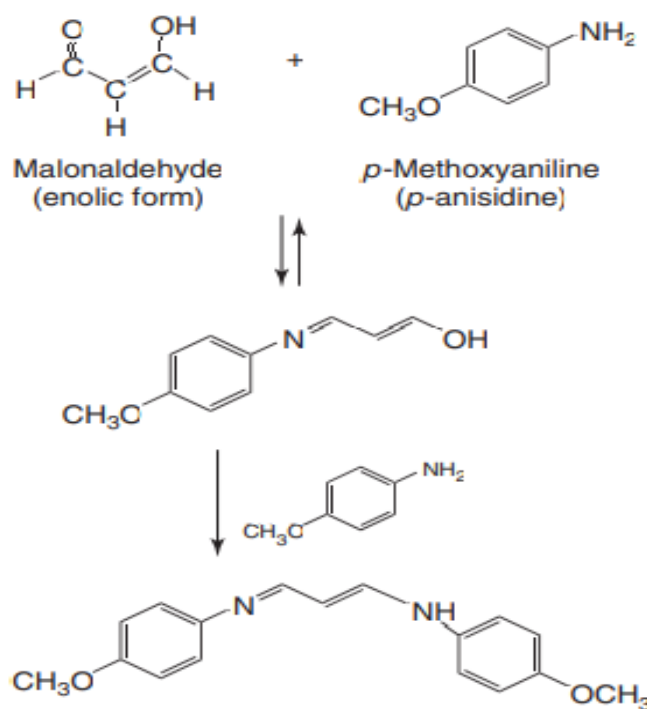


Figure 5. Possible reactions between *p*-anisidine reagent and MA

Procedure: Sample weight with 0.3 grams to be taken into a 10 ml flask. Then the sample was dissolved in iso-octane in the 10 ml flask. The absorbance (A_1) is to be recorded, which was produced from 2.5 ml of the sample, measured into glass cuvettes against a purely prepared iso-octane blank at the wavelength of 350 nm. Then 0.5 ml of *p*-anisidine reagent is to be added into cuvettes and kept 10 minutes before another spectrophotometric measurement (A_2). Measurements are required to be performed on a batch basis, with three samples with one blank at a time, to prevent oxidation.

***p*-AnV was calculated by the following formula:**

$$p\text{-AnV} = 10\text{ml} \times (1.2 \times (A_{S2} - A_{B2}) - (A_{S1} - A_{B1})) / W_{\text{smp}}$$

where,

10 ml = volume of iso-octane used to dissolve the sample

1.2 = correction factor for dilution of sample solution with 1 ml of anisidine reagent dissolved in acetic acid

A_{S1} and A_{S2} = first and second spectrophotometric measurement of samples

A_{B1} and A_{B2} = first and second spectrophotometric measurement of blanks

W_{smp} = weight of sample

Totox Value

It is used to measure the extent of lipid oxidation, including products of primary and secondary oxidation processes. It is recognized as a combination of PV and *p*-AnV.

$$\text{Totox value} = 2\text{PV} + p\text{-AnV}$$

It is often observed that PV value first rises then it falls down due to the decomposition of hydroperoxides. PV and *p*-AnV both measure oxidation at early and late stages, respectively. Whilst the Totox value provides a complete measure of both hydroperoxides and their fat breakdown products.

Carbonyls Content

During the secondary oxidation, carbonyl compounds (both of aldehydes and ketones) are produced due to the degradation of hydroperoxides. These compounds performed the leading role in off-flavours in combination with rancidity in milk product. Lipid oxidation can be measured by analysing the total carbonyl content by a colorimetric 2,4-dinitrophenylhydrazine procedure. Here carbonyl compounds reacted with the 2,4-dinitrophenylhydrazine (DNPH). Hydrazine products in alkaline condition which are recognised as chromogen. Analysis is made of this compound with the help of spectrophotometrically at a particular wavelength. This process is used in different oxidative stability studies. But this process gives false results. Carbonyls which are produced from protein oxidation may also give higher values than lipid oxidation.

Reaction:

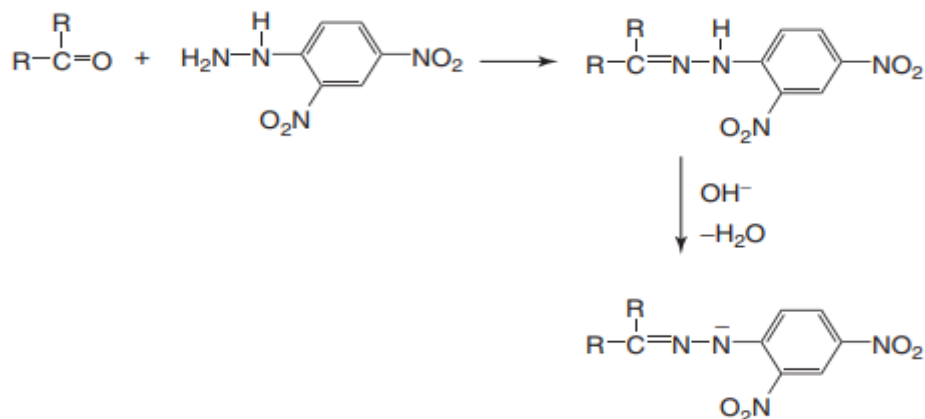


Figure 6. Reactions between carbonyls and 2,4-dinitrophenylhydrazine

Measurement of Free Radicals

During lipid oxidation, free radicals are produced in the initial stage and observed as short-lived intermediates. So, it is used to detect fat oxidation, as it relies on detecting radicals, which provide a good indication of lipid oxidation. Assessment of free radicals during lipid oxidation can be easily performed using ESR (electron paramagnetic resonance) spectroscopy. Here, the assay measures the microwave energy absorption of the given sample under varying magnetic fields. However, it is difficult to estimate the free radicals at a concentration of 10^{-9} M that are produced during the initial oxidation process due to their short life and highly reactive nature. Various approaches, including pulse radiolysis, UV photolysis, continuous-flow systems, and spin trapping, are used to overcome this issue. Among them, Spin trapping technique is employed to accumulate radicals with the addition of spin trapping agent. Common spin trap products are nitroso compounds and nitrones.

Conclusion

The mechanism of autooxidation and its influencing factors are well understood, and extensive research has been carried out on it. Methods such as peroxide value, conjugated dienes and trienes, TBA value, p-anisidine value, carbonyl content, totox value, and measurement of free radicals provide effective results for estimating milk fat oxidation. By applying these methods, preventive steps can be easily taken to stop milk fat or lipid oxidation.

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Principle of Fourier Infrared Spectroscopy & Applications in Dairy Industry

Article ID: 74026

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Abstract

Fourier Transform Infrared (FTIR) spectroscopy is a rapid, non-destructive analytical method widely used in dairy science for verification and quality evaluation. Using molecular vibrational absorption, FTIR provides structural signatures that facilitate the identification of adulterants, quantification of constituents, and assessment of milk composition. In conjunction with chemometric techniques like PLS, PCR, and PCA, FTIR has effectively identified species adulteration, cholesterol levels, melamine contamination, and solids-not-fat content in milk. The introduction of ATR-FTIR has streamlined sample preparation, improving accuracy and consistency. Despite the cost of equipment, FTIR provides reliable, real-time biochemical fingerprinting for the safety and quality assurance of dairy products.

Introduction

Fourier Transform Infrared (FTIR) has been a widely used spectroscopic method over the past few years for at-line, on-line, and even in-line analysis. This is due to the numerous developments of the design of FTIR instruments and equipment in their interface to chemical processes. It is used because of its functionality towards real-time monitoring of chemistry for different processes and also the ability to provide a wealth of information about the chemical structure. IR spectroscopy has the unique ability to determine the structure and identification of different compounds. One of the great things about this process is that it can be applied to any sample. IR analytical technique is used in a broad range because of its unique simplicity as well as non-destructive nature. Though IR Spectrometers have been commercially available since the 1940s, they have been used effectively in recent years, following the introduction of the FTIR spectrometer and advances in computer technology, which have greatly improved spectral quality and data turnaround time. So that these aspects of IR spectroscopy are considered important techniques for studying and identifying biological molecules with less sample preparation and time. This technique is already successfully applied in several biological systems, including proteins, fats and carbohydrates, food, dairy and pharmaceutical products. However, in recent years, advances in FTIR spectroscopy have made it a powerful tool for the authentication of food products. Moreover, a continual requirement is to develop rapid, instrument-based methods that exceed the detection limits and certainty of currently available analytical methods for the authentication of milk and milk products. It is very important to know about IR spectroscopy to better understand FTIR.

The Information FTIR Provides are

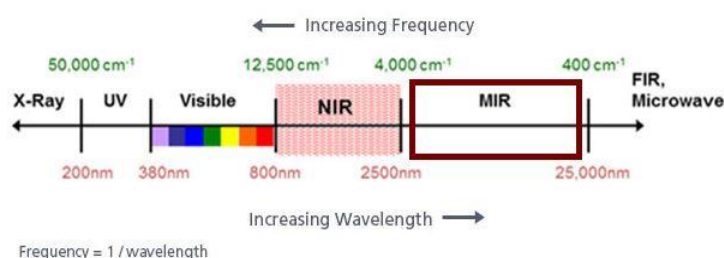
1. Identifies unknown materials
2. Determine the quality or consistency of the given sample
3. Determine the number of components in the given mixture

IR light is nothing but an electromagnetic radiation with higher wavelengths than visible light, extending from the nominal red edge of the visible spectrum at 14000 to 10 cm⁻¹. The corresponding frequency range is approximately 300 GHz to 400 THz, which is generally included with most of the thermal radiation emitted by the objects near ambient temperature. Molecules emit or absorb Infrared light by changing their rotational-vibrational movements. The general range of the electromagnetic spectrum of Infrared light covers the range of 14000 to 10 cm⁻¹. It is divided into three parts:

Near-Infrared (NIR) range: Ranges in between of 14000 to 4000 cm⁻¹

Mid-Infrared (MIR) range: Ranges in between of 4000 to 400 cm⁻¹

Far-Infrared (FIR) range: Ranges in between of 400 to 10 cm⁻¹.



Principle of IR Spectroscopy

The main principle of IR spectroscopy relies on irradiating a molecule with IR radiation and detecting the absorbed frequencies, which are highly specific to that molecule. Depending on its shape, each molecule can exhibit a variety of fundamental vibrations that absorb energy at specific frequencies, supported by the number of atoms it contains and its three-dimensional translational freedom. Molecular vibration might also involve changes in the length of a bond or its angle. The change within the length of a bond occurs during stretching vibration, and bonds may stretch symmetrically (in phase), or asymmetrically (out of phase). A molecular moment change has got to occur so as to soak up infrared light. Additionally, the intensity of the optical phenomenon increases in proportion to the change in the moment. As each molecule only absorbs specific frequencies of IR energy resembling its fundamental vibrational modes, representing its bonds or functional groups, the resultant IR absorbance spectrum will be used to identify the molecular contents of an unknown compound and thus the compound itself. Most of the useful diagnostic information from the IR spectrum is provided within the MIR range ($4000\text{--}400\text{ cm}^{-1}$). This has two important regions, the group region ($3600\text{--}1200\text{ cm}^{-1}$) and the so-called fingerprint region ($1200\text{--}600\text{ cm}^{-1}$). Group frequencies are characteristic of molecular groups and are almost independent of the structure of the entire molecule. The amplitude of the group vibration is barely significant for a tiny number of molecules. In contrast, the fingerprint region arises from interactions among vibrational modes and is highly characteristic of the molecule under investigation. Using information from both of those highly specific regions, differences within the structure and composition of compounds is seen, even when these are very small, enabling the identification of the particular compound.

Fourier Transform Infrared Spectroscopy

The original infrared instruments were of the dispersive type. These instruments separated the individual frequencies of energy emitted from the infrared source. This was accomplished by using a prism or grating. An infrared prism works the same way as a visual prism, separating light into its colors (frequencies). A grating could be a more modern dispersive element that better separates infrared frequencies. The detector measures the number of energies at each frequency that the sample has felt. This results in a spectrum, which could be plotted as intensity vs. frequency. FTIR spectrometry was developed to overcome the limitations of dispersive instruments. The most difficult part was the slow scanning process. A technique for measuring all infrared frequencies simultaneously, rather than individually, was needed. An answer was developed which employed a really simple device called an interferometer. The interferometer produces a singular variety of signals that have all of the infrared frequencies “encoded” into it. The signal is measured very quickly, usually on the order of 1 second close to. Thus, the time per sample is reduced to a matter of seconds rather than several minutes. Most interferometers employ a beam splitter, which splits the incoming infrared beam into two optical beams. One beam reflects off a flat mirror, which is fixed in situ. The opposite beam reflects off a flat mirror mounted on a mechanism that allows it to move a very short distance (typically a few millimeters) away from the beam splitter. The two beams reflect off their respective mirrors and are recombined once they meet back at the beam splitter. Because the trail that one beam travels may be a fixed length and therefore the other is consistently changing as its mirror moves, the signal which exits the interferometer is the result of these two beams “interfering” with one another. The resulting signal is termed an interferogram, which has the unique property that each datum (a function of the moving mirror position) that makes up the signal contains information about every wavelength from the source. This suggests that because the interferogram is measured, all frequencies are being measured simultaneously. Thus, the use of the interferometer enables extremely fast measurements. Because the analyst requires a frequency spectrum (a plot of the intensity at each frequency) to create an identification, the measured interferogram signal can't be interpreted directly. A way of “decoding” the individual frequencies is required. This may be accomplished via a mathematical technique called the Fourier transformation. This transformation is performed by the pc which then presents the user with the specified spectral information for analysis.

Advantages of Fourier Transform Infrared Spectroscopy

- 1. Speed:** Because all of the frequencies are measured simultaneously, most measurements by FT-IR are made in an exceedingly matter of seconds instead of several minutes.
- 2. Sensitivity:** Sensitivity is dramatically improved with FT-IR for several reasons. The detectors employed are way more sensitive, and the optical throughput is way higher, resulting in much lower noise levels. Therefore, the fast scans enable the accumulation of several scans to scale back the random measurement noise to any desired level.
- 3. Mechanical Simplicity:** The moving mirror within the interferometer is that the only continuously moving part within the instrument. Thus, there's little possibility of mechanical breakdown.
- 4. Internally Calibrated:** These instruments employ a He-Ne laser as an indoor wavelength calibration standard. These instruments are self-calibrating and do not need to be calibrated by the user.
- 5.** It is a really reliable technique for the identification of virtually any sample.

6. The sensitivity benefits enable the identification of even the smallest of contaminants. This makes FT-IR a useful tool for internal control or quality assurance applications, whether for batch-to-batch comparisons against quality standards or for analysis of an unknown contaminant.
7. Additionally, the sensitivity and accuracy of FT-IR detectors, together with a good style of software algorithms, have noticeably increased the sensitivity of infrared for measurements.
8. Quantitative methods can be easily developed and calibrated and can be incorporated into simple procedures for routine analysis.
9. It is mechanically simple with only one moving part.

Limitations of FTIR

1. It cannot detect atoms or monoatomic ions because single atoms don't contain chemical bonds, and don't possess any vibrational motion. Consequently, they absorb no actinic ray. Homonuclear diatomic molecules- molecules comprised of two identical atoms, like N_2 and O_2 don't absorb infrared emission
2. The spectra obtained from samples are complex and difficult to interpret because it's hard to understand which bands are from which molecules of the sample.
3. Its usage in aqueous solutions is additionally difficult to analyse by means of infrared spectroscopy. Water can be a strong infrared absorber in specific wavenumber ranges, thereby masking regions of the sample spectrum.
4. FTIR spectrometers are a one-beam technique. The samples and the background are measured at different times. To eliminate instrumental and environmental contributions to the spectrum, the sample spectrum is subtracted from the background spectrum. However, spectral artifacts can appear in the sample spectrum due to instrumental or environmental changes in water vapour and CO_2 concentrations between the sample and background. The vapour within the air (humidity) absorbs mainly within the regions $1270-2000\text{ cm}^{-1}$ and $3200-4000\text{ cm}^{-1}$

FTIR Instrumentation

FTIR instrumentation comprises

Source: The source of IR is often an electrically conductive filament of varying type, which supports the IR range to be studied and provides sufficient radiation intensity. For the MIR region, Nernst filaments and Globar filaments composed of carbide are commonly used.

Interferometer: The Michelson interferometer is one of the most widely used interferometers in FTIR. This consists of three components: a beam splitter, a moving mirror and a set mirror. A parallel beam of radiation is transmitted from the source to the interferometer and originally reaches the beam splitter. The beam splitter could be a semi-transparent film that splits the beam into two halves, each receiving 50% of the radiation. The quantity of radiation in each split beam and, therefore, the resultant IR spectral region produced relies upon the beam splitter construction material. Restrainers or calcium iodide substrates coated with germanium or iron oxide are typically used in the MIR region. because the radiation beam is split at the bisecting plane before of the 2 aluminized or silver surfaced mirrors, one in all the split beams is reflected at 90° to the stationary mirror and therefore the half is allowed to pass straight towards the moving mirror. so as to make sure accurate distance scanning and more precise measurements, the moving mirror is continually aligned with the utilization of a visual helium-neon (HeNe) laser which is targeted at the corner of the mirror. Once the 2 radiation beams are reflected by the 2 mirrors, they recombine at the beam splitter and are directed as a single transmitted beam at 90° to the source and towards the sample. Since each beam travels a unique distance due to the relative position changes of the moving mirror relative to the stationary mirror, an interference pattern forms where the beams merge. Depending on the length the second beam has traveled, the radiation waves can recombine in phase, interfering constructively, or out of phase, interfering destructively. IR radiation across all wavelengths is thus achieved. Once the transmitted beam is made, it passes through the sample, where a portion of the energy is absorbed. The remaining portion reaches the detector, where the interferogram is recorded and subsequently translated into the sample absorbance spectrum using the Fourier transformation.

The Sample: The beam enters the sample compartment, where it's transmitted through or reflected off the sample surface, depending on the type of study being conducted. This is often where specific energy frequencies, uniquely characteristic of the sample, are absorbed.

Detectors: IR detectors vary depending on the IR range to be studied. Two main detector styles exist: thermocouple detectors, which measure the heating effect of radiation, and photoconductor detectors, which measure the conductivity induced by the resulting IR radiation. Commonly used detectors for the MIR region of the primary type include the deuterated tri glycine sulphate (DTGS) pyroelectric detector, normally placed in an alkali halide window, which is heat-resistant, and of the second type, mercury cadmium telluride (MCT) photoconductive detectors, requiring, but providing higher sensitivity and faster response times.

The Computer: The measured signal is digitized and sent to the PC, where it is Fourier-transformed. The ultimate spectrum is then presented to the user for interpretation and further manipulation.

Attenuated Total Reflectance (ATR) - FTIR

Most of the fashionable FTIR equipment use ATR. The use of ATR has considerably reduced the sample preparation step. Most recent applications of FTIR involve the use of ATR. In ATR, the sample is placed in contact with a crystal with a high refractive index and low solubility, such as diamond, zinc selenide, or germanium. Beam radiation is then directed towards the crystal from the side. Total internal reflection then occurs when incident radiation reaches the boundary between a medium with a higher index of refraction, such as the ATR crystal, and a medium with a lower index, such as the sample, at an angle greater than the angle of incidence. During the entire internal reflection, the radiation enters the sample and it's partly absorbed while another part is reflected. The radiation which penetrates the boundary is termed 'evanescent wave'. The resultant attenuated reflected radiation is then measured and plotted by the spectrometer. ATR may be a quick and non-destructive sampling technique for obtaining the IR spectrum of a material's surface. Samples examined by FTIR-ATR generally require minimal or no sample preparation.

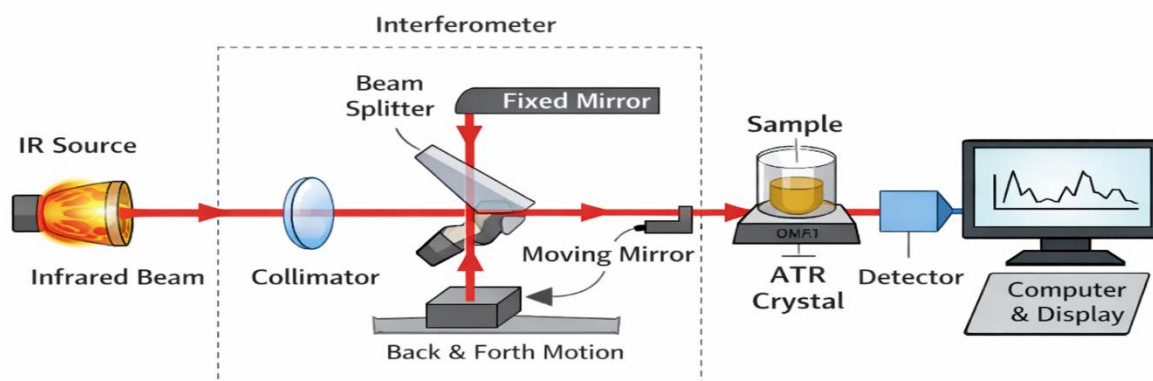


Figure 1. Schematic Diagram of FTIR Components

Applications of FTIR Spectroscopy in Quality Milk and Dairy Products

Recent developments in spectroscopic techniques, along with the availability of affordable hardware for IR measurements and the application of chemometric tools, have enabled numerous applications of FTIR spectroscopy in the identification of dairy products (milk, ice cream, yogurt, butter, cheese, etc.). The following applications are listed below:

Sl No.	Applications of FTIR	Wavelength used	Instrument used	Chemometric technique used	Significant Results
1	Presence of beef fat in butter using FTIR	3873-690 cm^{-1}	Shimatsu	Partial least square (PLS) and principal component regression (PCR)	The low value for detection limit is 3% palm oil in butter and the low limit of quantification is 9.8% palm oil in butter
2	Estimation of cholesterol in dairy products using FTIR	2800 and 3200 cm^{-1}	Bio-Rad FTS 6000	Partial least square (PLS) and principal component regression (PCR)	Results indicate that FTIR spectroscopy can determine the cholesterol content in dairy products in approximately 5 min
3	FTIR for detection of species adulteration of milk	4000 to 600 cm^{-1}	Bruker Equinox 55	PLS regression and nonlinear kernel partial least squares regressions	FT-IR spectroscopy in combination with multivariate analysis such as linear PLS and nonlinear Kernel PLS provides an accurate, simple, and rapid technique for the quantitative assessment of the adulteration of sheep, goat, and cow milks.
5	FTIR to identify adulterated raw milk	5000 - 1000 cm^{-1}	Foss Analytical	Principal Component Analysis	FT-IR can be used for the identification of adulterated milk with 0,05% and 0,075% of sodium bicarbonate and citrate respectively

6	Estimation of milk urea nitrogen using FTIR	-	CombiScope FTIR	-	FTIR showed good precision and accuracy in repeatability and reproducibility for the measurement of raw milk urea nitrogen. However failed to detect addition of 40 mg urea in milk per 100 ml milk.
7	Presence of beef fat in butter using FTIR	1500-1000 cm^{-1}	Nicolet 6700 FTIR with ATR	Partial least square (PLS) regression	2.42% beef could be detected in butter fat
8	Detection of melamine adulteration in dairy milk by FTIR	4000-650 cm^{-1}	Thermo Nicolet Avatar 330 FTIR spectrometer	partial least-squares models	FTIR in combination with partial least-squares models could detect melamine at 2.5 ppm level
9	Determination of solids-not-fat in raw milk using FTIR	3000-920 cm^{-1} and 1800-920 cm^{-1}	Bruker FTIR Spectrophotometer	Partial least squares regression (PLS) and support vector machine (SVM) regression	FTIR spectroscopy coupled to chemometrics techniques like PLS and SVM regressions is an adequate method for the quantification analysis of solids-non-fat (SNF)
10	Detection and quantification of soymilk in cow-buffalo milk using FTIR	1472-1241 cm^{-1}	Bruker with ATR	Principal Component Analysis	The soya milk presence in milk can be predicted in the range of 1472-1241 cm^{-1} using multiple linear regression with coefficient of determination (R^2) of 0.99 and 0.92 for calibration and validation, respectively
11	Detection of the microbial spoilage in milk	4000-600 cm^{-1}	ZnSe Gateway ATR Horizontal 6 reflection accessory	Multivariate statistical method, including Principal Component Discriminant function analysis and partial least square regression	Showed reasonable results for bacterial load above 105cfu/ml

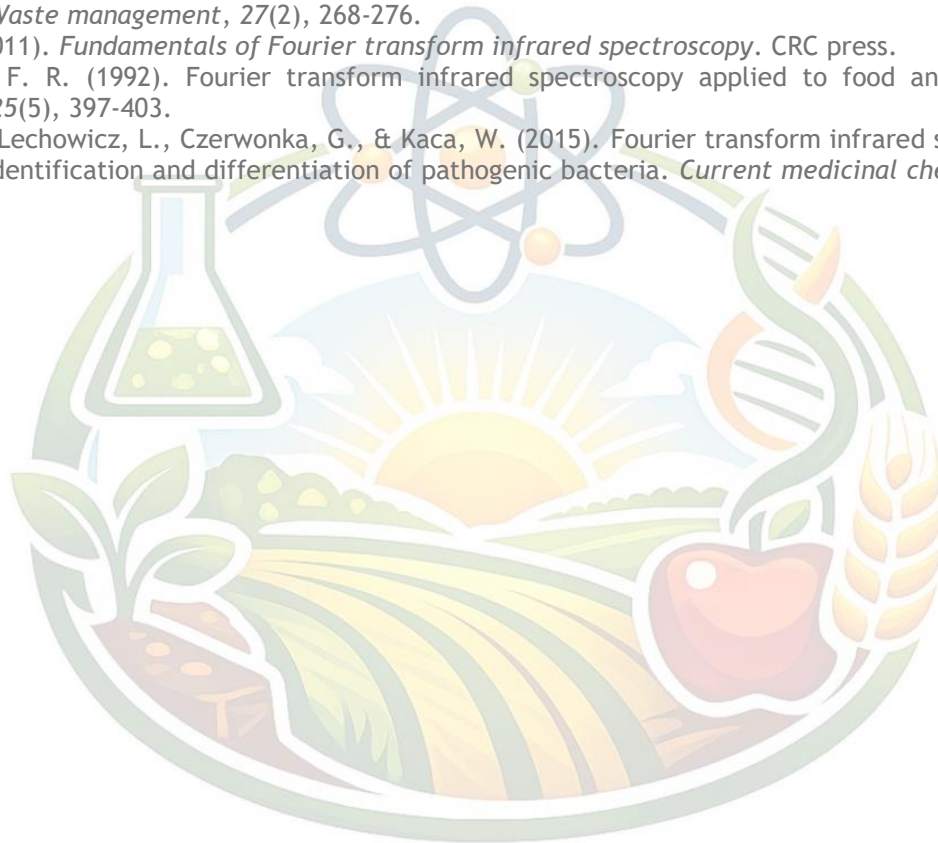
Conclusion

FTIR is gaining popularity as a rapid biochemical fingerprinting technique for food authentication, particularly for milk and milk products. It could be applied to deliver results with the same accuracy and sensitivity, since the reference methods take a short time. However, knowledge of statistical software (chemometric techniques) is crucial to obtain meaningful results. Although sample preparation has been made easier with the advent of ATR-based FTIR, the high cost of the equipment could also be a deterrent to its widespread application in assessing milk quality.

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Human Activities and Forest Productivity: A Comprehensive Analysis of Anthropogenic Impacts

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Abstract

Forest ecosystems cover approximately 31% of the global land surface and play a critical role in carbon sequestration, biodiversity conservation, and hydrological regulation. Escalating human activities have increasingly disrupted forest productivity and the capacity of forest ecosystems to produce biomass and sustain ecological functions. This article examines anthropogenic pressures including deforestation, land-use change, pollution, climate change, and unsustainable forest management, and discusses restoration pathways. Recent studies (2024-2025) confirm accelerating threats: global deforestation total 8.1 million hectares in 2024, the world's forest carbon sink fell to its lowest level in two decades, and Amazon degradation surged 152% in a single year.

Keywords: Forest productivity, deforestation, carbon sink, climate change, fragmentation, forest degradation, net primary productivity, REDD+

Introduction

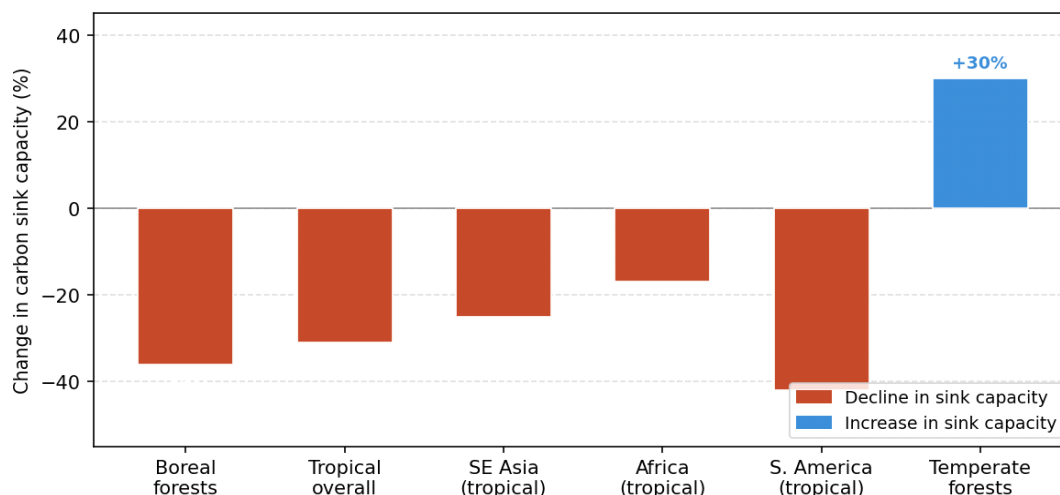
Forest productivity, broadly defined as the net primary productivity (NPP) of forested ecosystems, reflects the rate at which trees and associated vegetation convert solar energy and atmospheric CO₂ into organic matter. Healthy forests contribute immensely to global biogeochemical cycles, supporting approximately 80% of terrestrial biodiversity and storing an estimated 662 gigatons of carbon worldwide (Pan *et al.*, 2011).

Despite their ecological importance, forests worldwide are under unprecedented pressure from human activities. The Forest Declaration Assessment (2025) reported that global deforestation total 8.1 million hectares in 2024 alone, leaving the world 63% off-track from the pledge made by world leaders to halt deforestation by 2030. Atmospheric CO₂ concentrations surpassed 420 ppm in 2023 (Pan *et al.*, 2024), and climate change is approaching potential tipping points that portend considerable future impacts on forest function.

Deforestation and Land-Use Change

Deforestation remains the most direct and pervasive human threat to forest productivity. A landmark study published in *Nature* (Pan *et al.*, 2024), spanning 15 co-authors from 11 countries, found that tropical forests have seen a 31% decrease in carbon-absorbing capacity directly attributable to deforestation. South America recorded the largest reduction (-42%), driven by loss of intact Amazonian forest and drought-induced increases in tree mortality. Figure 1 illustrates the regional divergence in carbon sink trends across major forest biomes.

Figure 1. Decline in Forest Carbon Sink Capacity by Biome

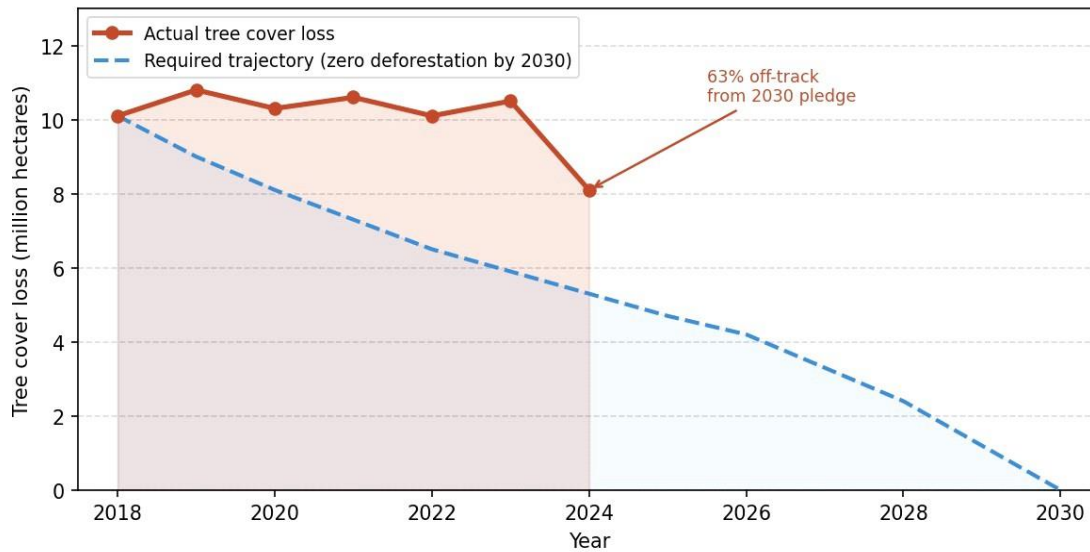


Source: Pan *et al.*, *Nature*, 2024 (USDA Forest Service / Woodwell Climate Research Center)

Figure 1. Decline in forest carbon sink capacity by biome. Percentage change in carbon absorption capacity over recent decades, showing South American tropical forests as the most severely impacted (-42%) and temperate forests as the only biome showing gains (+30%). Source: Pan, Y., Birdsey, R.A., *et al.* (2024). *The enduring world forest carbon sink. Nature*, 631, 563-569.

Figure 2 shows the trajectory of global tree cover loss compared to the required reduction pathway to reach zero deforestation by 2030. The data confirm that despite modest improvement in 2024, the world remains 63% off-track from the declared target (Forest Declaration Assessment, 2025).

Figure 2. Global Tree Cover Loss vs. Required Trajectory to End Deforestation by 2030



Source: Forest Declaration Assessment 2025; WRI Global Forest Watch

Figure 2. Global tree cover loss (actual, 2018-2024) versus the required trajectory to achieve zero deforestation by 2030. The dashed blue line represents the annual 10-20% reduction needed; the red line shows actual progress, which remains far above the required level. Source: Forest Declaration Assessment (2025); WRI Global Forest Watch / Land & Carbon Lab (2025).

Pollution and Atmospheric Nitrogen Deposition

Industrial activity, vehicle emissions, and agricultural runoff have substantially altered the chemical environment in which forests grow. Nitrogen deposition presents a documented paradox: while moderate nitrogen enrichment can initially stimulate tree growth in nitrogen-limited forests, chronic deposition leads to nitrogen saturation, soil acidification, loss of plant biodiversity, and increased vulnerability to drought and storm damage (Aber *et al.*, 1998). A comprehensive framework published in *Nature Communications* (Cen *et al.*, 2025) confirmed that excessive reactive nitrogen significantly disrupts below-ground carbon dynamics a critical finding for long-term soil fertility. Ground-level ozone further damages leaf tissue, reduces photosynthetic efficiency, and weakens tree immune responses.

Climate Change as an Anthropogenic Driver

Climate change, driven primarily by fossil fuel combustion and land-use change, represents one of the most complex threats to global forest productivity. A 2024 PNAS study (Hogan & Lichstein) used U.S. Forest Service data to demonstrate that climate change produces sharply divergent productivity trends within a single country (Figure 3). Eastern forests benefited from mild warming and increased precipitation, while western forests declined due to intensifying drought, wildfire, and disease.

Figure 3. Diverging Forest Productivity Trends Across the USA (1999-2020)

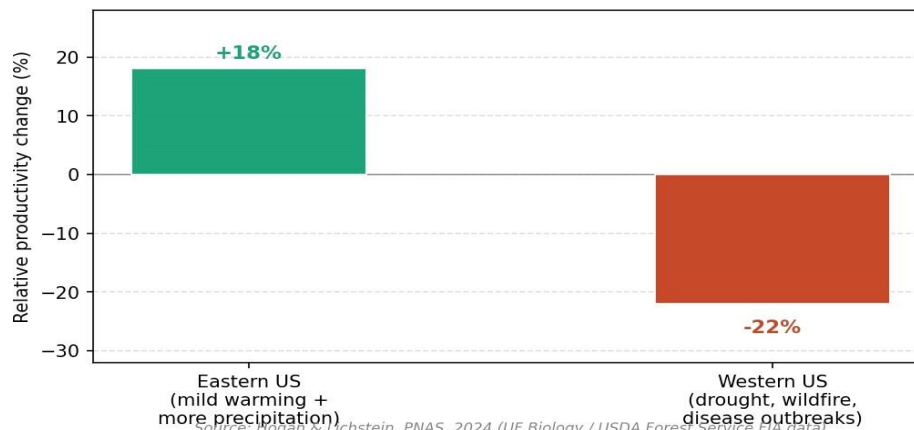


Figure 3. Diverging forest productivity trends across the United States (1999-2020). Eastern forests show an estimated +18% relative productivity gain under mild warming and increased precipitation, while western forests show approximately -22% decline due to drought, wildfire, and disease outbreaks.

Source: Hogan, J.A. & Lichstein, J.W. (2024). Climate change determines the sign of productivity trends in US forests. PNAS, 121(4). <https://doi.org/10.1073/pnas.2311132121>

Drought stress, intensified by climate change, is now recognized as a leading cause of forest dieback globally. A 2025 review in *New Phytologist* (Groover *et al.*) confirmed that droughts of increasing severity are the primary cause of climate-change-associated forest mortality. A 2025 study in *Global Change Biology* (PMC, 2025) further documented long-term divergence in post-drought resilience between deciduous and evergreen species, with implications for forest composition under future climate scenarios.

Fragmentation, Edge Effects, and Fire-Driven Degradation

Forest fragmentation - the division of continuous forest into isolated patches is a pervasive consequence of agricultural expansion, road construction, and urban sprawl. New research combining Landsat imagery with GEDI LiDAR data from the International Space Station found that the spatial impact of fragmentation across global tropical forests is likely 200% greater than previously estimated, and that recovery from degradation may take decades or centuries (Conservation Corridor, 2024).

Fire-driven degradation reached crisis levels in 2024. Research published in *Bio geosciences* (Bourgoin *et al.*, 2025) documented a 152% surge in Amazon forest disturbances, with large-scale fire-driven degradation increasing by over 400%. Figure 4 illustrates the conceptual pathways through which these anthropogenic drivers translate into reduced forest productivity and downstream ecological consequences.

Figure 4. Pathways of Human Impact on Forest Productivity



Conceptual diagram based on Pan *et al.* (2024), Bourgoin *et al.* (2025), WRI Global Forest Review (2025)

Figure 4. Pathways of human impact on forest productivity. Five major anthropogenic drivers (amber boxes, left) converge to reduce forest productivity (central red box), producing four categories of ecological consequence (dark red boxes, right).

Arrow thickness indicates the strength and directness of each causal link.

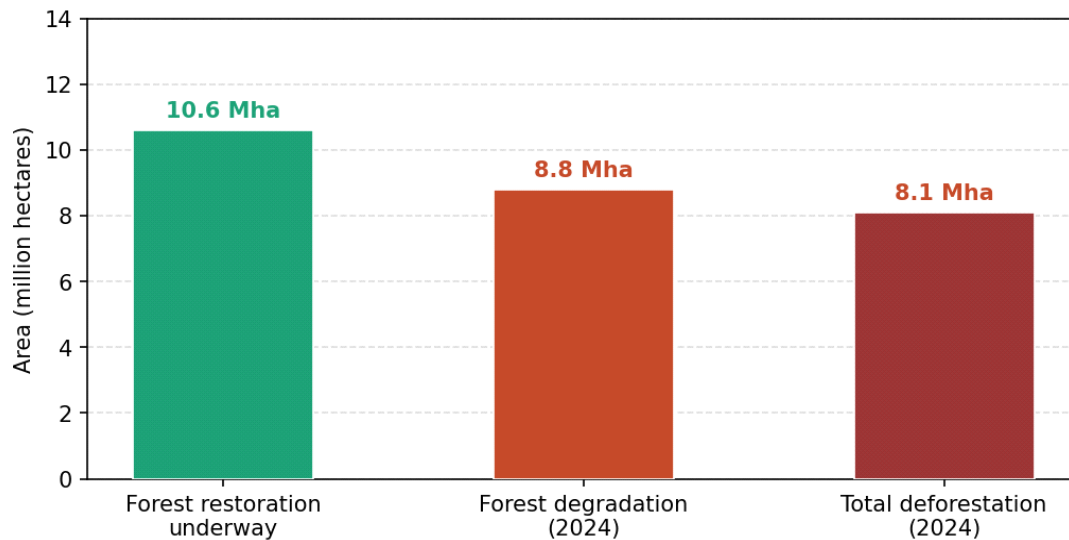
Source: Conceptual diagram based on Pan *et al.* (2024); Bourgoin *et al.* (2025); WRI Global Forest Review (2025); Hogan & Lichstein (2024).

Decline of the Global Forest Carbon Sink

Data from WRI's Global Forest Watch and Land & Carbon Lab (2025) revealed that in 2023 and 2024, forests absorbed only approximately one quarter of the carbon dioxide they absorb in an average year the lowest forest carbon sink in over two decades. This sharp drop reflects both direct deforestation losses and fire-driven emissions and is part of a longer-term narrowing of the margin between forest carbon emissions and removals. Scientists warn that the world's forests risk shifting from a net carbon sink to a net carbon source — a transition with catastrophic consequences for global climate stability.

Pathways for Restoration and Sustainable Management

Despite the scale of human-driven forest degradation, forests possess meaningful resilience. The Forest Declaration Assessment (2025) reported that restoration efforts are expanding, with at least 10.6 million hectares hosting active forest restoration projects worldwide. However, it also noted that harmful subsidies outweigh green subsidies by more than 200:1, and financial flows remain grossly misaligned with forest goals. Figure 5 juxtaposes the scale of restoration against ongoing annual degradation and deforestation.

Figure 5. Forest Restoration vs. Ongoing Forest Loss and Degradation (2024)


Source: Forest Declaration Assessment 2025; WRI Global Forest Review 2025

Figure 5. Forest restoration versus ongoing forest loss and degradation (2024). Restoration projects (10.6 Mha) nearly match the scale of active degradation (8.8 Mha) and deforestation (8.1 Mha), but financial misalignment and structural barriers prevent sufficient scaling of restoration efforts.

Source: Forest Declaration Assessment (2025); WRI Global Forest Review (2025).

Research published in *PNAS* (2024) demonstrated that forest species richness plays a crucial role in suffering against drought-induced productivity loss tree communities with higher species diversity show greater resistance and resilience to prolonged drought at the global scale. This finding reinforces the value of native-species diversity in restoration design over monoculture approaches and aligns with evidence that regrowth in previously abandoned lands has partially offset deforestation losses in the tropics (Pan *et al.*, 2024).

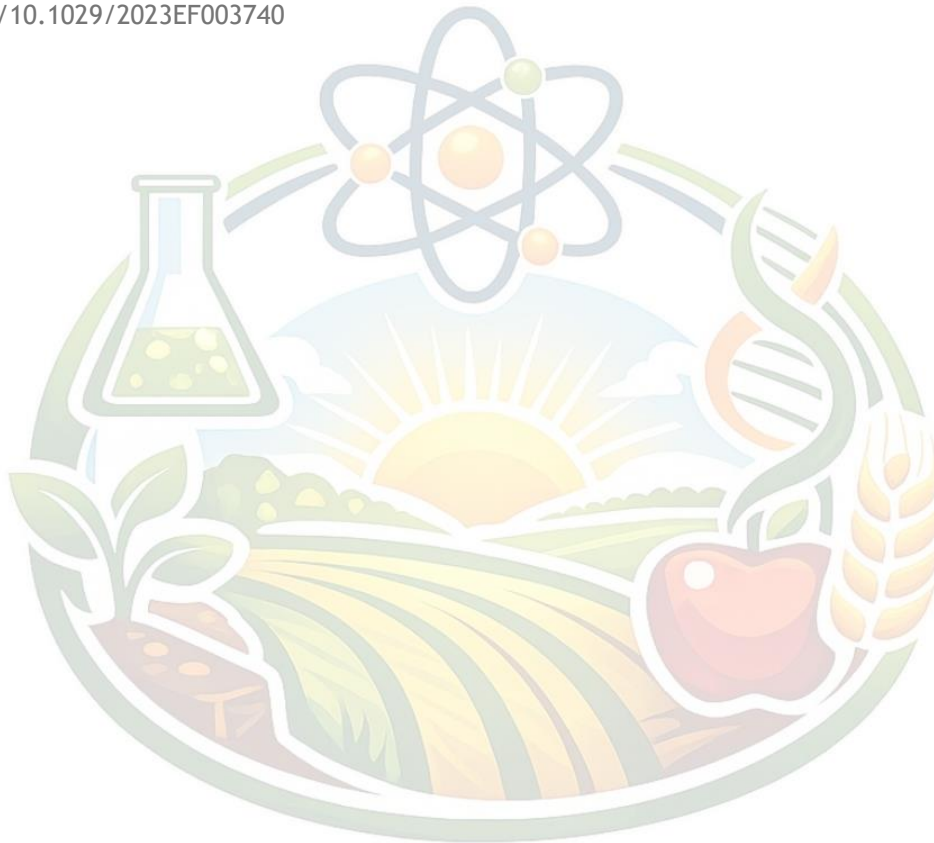
Conclusion

Human activities have profoundly impacted forest productivity across the globe. Deforestation, pollution, climate change, fragmentation, fire-driven degradation, and unsustainable harvesting collectively threaten the ecological functions upon which global stability depends. Recent evidence from 2024 and 2025 spanning landmark studies in *Nature*, *PNAS*, *Earth's Future*, and global monitoring platforms confirms that these pressures are intensifying, and that the world's forest carbon sink is weakening at an alarming rate. Reversing these trends requires integrated approaches combining scientific research, policy reform, financial realignment, community engagement, and international cooperation. The imperative to protect and restore forest productivity has never been more urgent.

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Multiparent Populations versus Biparental Populations in Rice Breeding: A Paradigm Shift for Genetic Improvement

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Introduction

Rice is the staple food for more than half of the world's population and plays a crucial role in global food security. Continuous improvement of rice varieties is essential to meet the growing demand for food under changing climatic conditions. Plant breeders rely on genetic populations to identify genes and quantitative trait loci (QTLs) governing economically important traits such as grain yield, disease resistance, stress tolerance, and grain quality. Traditionally, biparental populations have been the primary resource for genetic analysis and crop improvement. However, advances in molecular genetics and genomics have led to the development of multiparent populations, which offer greater genetic diversity and enhanced mapping resolution. Among these, Multi-parent Advanced Generation Intercross (MAGIC) populations have emerged as powerful tools for modern rice breeding. The comparison between biparental and multiparent populations highlights the evolution of breeding strategies from simple genetic analyses to comprehensive genomic studies.

Biparental Populations in Rice Breeding

Biparental populations are developed by crossing two genetically distinct parents followed by selfing, backcrossing, or inbreeding to generate segregating progenies such as F₂ populations, recombinant inbred lines (RILs), doubled haploids (DHs), and backcross populations. These populations have been extensively used for gene mapping and QTL identification in rice.

The major advantage of biparental populations lies in their simplicity. Since only two parents contribute genetic material, inheritance patterns are relatively easy to analyze. Biparental populations are particularly useful for studying major genes and traits controlled by a few loci. Furthermore, they require less time and fewer resources to develop compared to more complex breeding populations.

Despite their usefulness, biparental populations possess several limitations. Genetic variation is restricted to the alleles present in the two parental lines, resulting in limited genetic diversity. Recombination events are relatively few, leading to large linkage blocks and reduced mapping precision. Consequently, the ability to detect QTLs is confined to polymorphic regions between the two parents, and many potentially useful alleles present in the broader rice gene pool remain unexplored. These limitations become especially significant when studying complex quantitative traits such as grain yield and stress tolerance, which are governed by numerous genes with small effects.

Multiparent Populations: Expanding Genetic Diversity

Multiparent populations are developed by intercrossing several genetically diverse founder lines followed by repeated intermating and selfing. Unlike biparental populations, they incorporate genetic contributions from multiple parents, thereby increasing allelic diversity and recombination frequency.

Among the various multiparent designs, MAGIC populations have gained considerable attention in rice breeding. These populations are created through systematic crossing among several founder lines, often eight or more, followed by multiple generations of random mating and selfing. The resulting lines contain a mosaic of genomic segments derived from all founders.

The primary advantage of multiparent populations is the substantial increase in genetic diversity. Multiple founders contribute favorable alleles for different agronomic traits, creating a broader genetic base for selection and genetic analysis. Increased recombination events break large linkage blocks into smaller segments, enabling high-resolution mapping of QTLs and facilitating the identification of candidate genes. Consequently, multiparent populations provide greater power for dissecting complex traits compared to traditional biparental populations.

Advantages of Multiparent Populations over Biparental Populations

The superiority of multiparent populations arises from several genetic and practical advantages. First, they capture a much wider range of allelic variation, which improves the probability of identifying novel and favorable alleles. Second, extensive recombination generates finer genetic maps and enhances the precision of QTL localization. Third, multiparent populations allow the simultaneous evaluation of multiple beneficial alleles within a single genetic background.

Another important advantage is their compatibility with genome-wide association studies (GWAS). The high level of recombination and genetic diversity present in MAGIC populations significantly increases mapping resolution, enabling researchers to identify genomic regions associated with complex traits more accurately. Furthermore, unlike natural association panels, MAGIC populations exhibit reduced population structure, thereby minimizing false-positive associations and improving the reliability of GWAS results.

From a breeding perspective, multiparent populations serve as valuable pre-breeding materials because they contain diverse combinations of favorable alleles originating from multiple elite parents. This feature enhances the likelihood of developing superior lines possessing high yield potential, improved grain quality, and resistance to biotic and abiotic stresses.

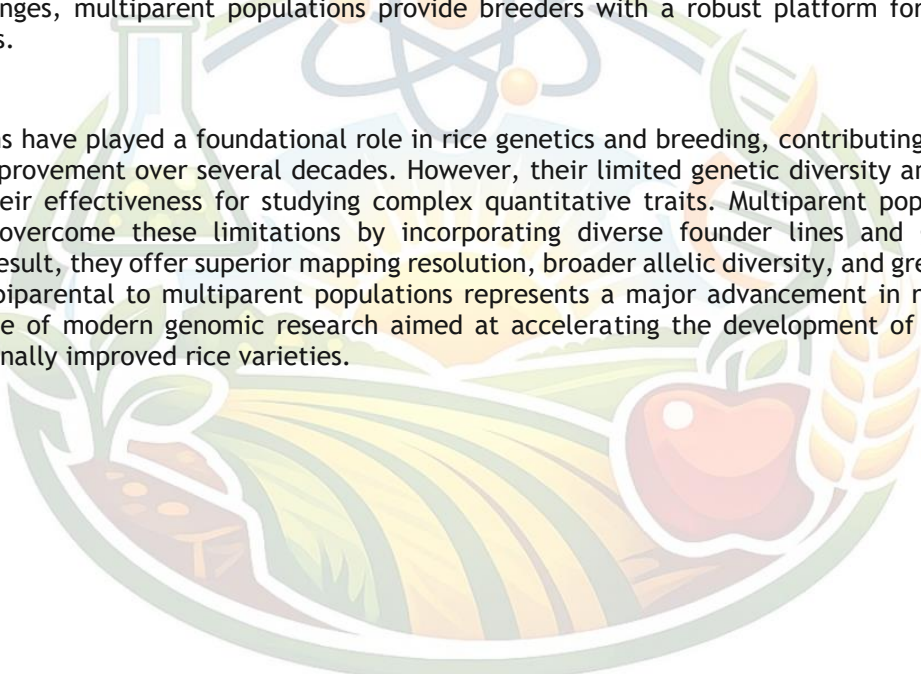
Applications in Modern Rice Improvement

The increasing complexity of breeding objectives necessitates the use of populations capable of capturing extensive genetic variation. Multiparent populations have been successfully utilized to identify QTLs controlling grain yield, flowering time, drought tolerance, salinity tolerance, disease resistance, and grain quality traits in rice. They have also facilitated the discovery of candidate genes through high-density genotyping and advanced genomic analyses.

In recent years, rice MAGIC populations developed from diverse indica and japonica founders have become valuable resources for gene discovery and genomic-assisted breeding. These populations are particularly useful for integrating phenotypic and genotypic data to uncover the genetic architecture of complex traits. As climate change intensifies environmental challenges, multiparent populations provide breeders with a robust platform for developing climate-resilient rice varieties.

Conclusion

Biparental populations have played a foundational role in rice genetics and breeding, contributing significantly to gene mapping and crop improvement over several decades. However, their limited genetic diversity and low recombination frequency restrict their effectiveness for studying complex quantitative traits. Multiparent populations, particularly MAGIC populations, overcome these limitations by incorporating diverse founder lines and generating extensive recombination. As a result, they offer superior mapping resolution, broader allelic diversity, and greater breeding utility. The transition from biparental to multiparent populations represents a major advancement in rice breeding and has become a cornerstone of modern genomic research aimed at accelerating the development of high-yielding, stress-resilient, and nutritionally improved rice varieties.

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From Subsidy to Sustainability: Transforming Indian Agriculture through Farmer-Centric Initiatives

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Abstract

Indian agriculture is transitioning from an input subsidy-driven model to a sustainability-oriented and farmer-centric approach. While traditional subsidies enhanced production, they also led to resource degradation, environmental stress, and fiscal burden, necessitating a shift toward outcome-based support through targeted incentives and strengthened Direct Benefit Transfer (DBT) systems. The new paradigm promotes sustainable practices such as natural farming, organic agriculture, integrated farming systems, and agroecology, alongside efficient water management and crop diversification to improve resilience, soil health, and income stability. Farmer Producer Organizations (FPOs) are strengthening collective action and market access for smallholders, while digital agriculture and ICT tools are enhancing informed decision-making. Financial inclusion, improved crop insurance, market reforms, and value chain development are further stabilizing farm incomes. Supported by strengthened extension services and capacity-building initiatives, this transformation positions farmers as active stakeholders, ensuring a resilient, resource-efficient, and economically viable agricultural system that supports long-term food security, environmental sustainability, and inclusive rural development.

Introduction

Indian agriculture has been the backbone of the economy, supporting millions of livelihoods and ensuring food security for the nation (Government of India, 2023). For many years, the government has relied heavily on subsidies such as fertilizers, electricity, irrigation, and Minimum Support Price (MSP) to support farmers. While these subsidies have helped increase production, they have also created challenges like soil degradation, overuse of water, and financial burden on the government. A major shift is taking place from a subsidy-based approach to a sustainability-focused model. This transformation emphasizes farmer-centric initiatives, where farmers are not just beneficiaries but active participants in building a resilient and sustainable agricultural system.

Rethinking Subsidies: From Input Support to Outcome-Based Approach

The current transformation does not aim to completely remove subsidies but to make them more efficient and targeted. Earlier, subsidies were mainly input-based, encouraging excessive use of fertilizers and water. Now, the focus is on outcome-based support, where farmers are rewarded for adopting sustainable practices. Direct Benefit Transfer (DBT) systems are being strengthened to ensure transparency and reduce leakages. Financial support is also being linked with practices like organic farming, water conservation, and climate-smart agriculture. This change encourages farmers to use resources wisely while still receiving government support (FAO, 2021).

Promotion of Sustainable Farming Practices

Sustainability is becoming a key focus in Indian agriculture due to climate change and environmental concerns. Farmer-centric initiatives are promoting practices such as natural farming, organic farming, integrated farming systems, and agroecology. These methods reduce dependency on chemical inputs and improve soil fertility and biodiversity. States like Andhra Pradesh have shown success in natural farming, where farmers have reduced costs and increased profitability. These practices are not only environmentally friendly but also economically beneficial in the long run.

Strengthening Farmer Producer Organizations (FPOs)

Small and marginal farmers form the majority in India, and they often face difficulties in accessing markets and resources. Farmer Producer Organizations (FPOs) are being promoted to overcome these challenges. FPOs allow farmers to work collectively, purchase inputs at lower costs, and sell produce at better prices. The government is focusing on expanding FPOs by providing financial assistance, training, and market linkages. This collective approach enhances farmers' bargaining power and ensures better income opportunities (World Bank, 2020).

Role of Digital Agriculture and ICTs

Digital technology is playing a crucial role in transforming agriculture. Through mobile apps, online platforms, and satellite-based tools, farmers can access real-time information about weather, crop management, and market prices. Platforms like e-NAM are helping farmers connect directly with markets, improving price realization. Agri-tech startups and digital advisory services are also supporting farmers in decision-making. This digital shift is making agriculture more efficient, transparent, and knowledge-based.

Efficient Water Management Practices

Water scarcity is a major issue in Indian agriculture, especially due to overuse encouraged by earlier subsidy systems. New initiatives focus on efficient water management through micro-irrigation techniques like drip and sprinkler systems. These methods help conserve water while maintaining productivity. Programs related to watershed development and rainwater harvesting are also being promoted. Such practices ensure sustainable use of water resources and reduce environmental stress.

Crop Diversification for Sustainability and Income

Traditional farming systems have focused mainly on crops like wheat and rice, leading to monocropping and ecological imbalance. The government is now encouraging crop diversification by promoting pulses, oilseeds, millets, and horticultural crops. This not only improves soil health but also increases farmers' income and nutritional security. Millets, in particular, are gaining importance due to their climate resilience and health benefits. Diversification helps farmers reduce risks associated with climate and market fluctuations.

Financial Inclusion and Risk Management

Farmer-centric initiatives also focus on improving access to financial services. Schemes like crop insurance, easy credit facilities, and digital banking are helping farmers manage risks more effectively. The Pradhan Mantri Fasal Bima Yojana (PMFBY) is being improved with better claim settlement systems. Financial inclusion reduces farmers' dependence on informal lenders and ensures economic stability during crop failures or natural disasters.

Market Reforms and Value Chain Development

Another important step towards sustainability is improving market access and infrastructure. Farmers often face problems like price fluctuations and lack of storage facilities. Government initiatives are focusing on building better supply chains, storage systems, and transportation networks. Digital platforms are also enabling direct marketing and reducing middlemen. These reforms help farmers get better prices and reduce post-harvest losses, leading to higher incomes.

Capacity Building and Role of Extension Services

Agricultural transformation cannot succeed without proper knowledge and training. Extension services play a key role in educating farmers about new technologies and sustainable practices. Extension systems are being strengthened through digital tools, community participation, and public-private partnerships. Special attention is also being given to women farmers, recognizing their significant contribution to agriculture.

Conclusion

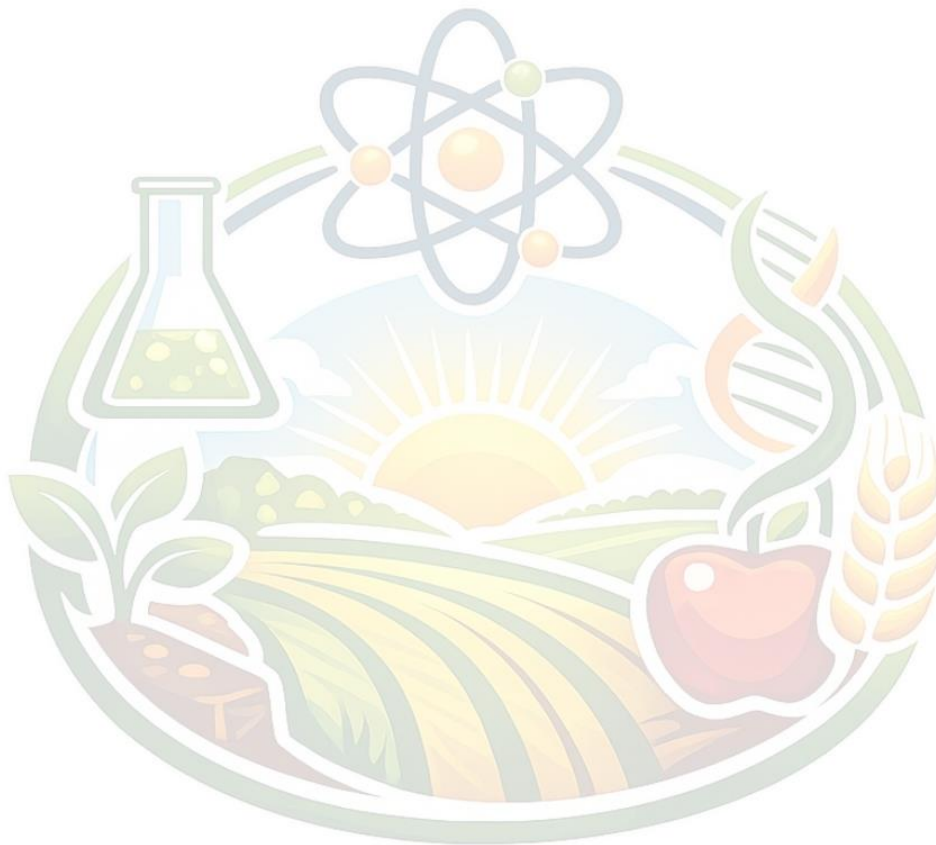
The transition from subsidy to sustainability is reshaping Indian agriculture into a more resilient and farmer-centric system. By promoting sustainable practices, digital tools, and collective approaches, farmers are becoming active drivers of change. This shift ensures better resource use, higher income, and long-term environmental balance. Ultimately, it lays the foundation for a sustainable and secure agricultural future.

“The true strength of a nation lies in its villages, and the right initiatives turn resilience into sustainable growth.”

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Haploid and Double Haploid Technology in Fruit Crops: Revolutionising Breeding for a Faster, Purer Future

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Introduction: From Single Cells to Superior Varieties

When a plant breeder crosses two elite fruit varieties, the resulting offspring are a genetic patchwork, heterozygous, unpredictable, and far from the uniform lines needed for commercial cultivation. To develop a pure-breeding variety, breeders traditionally rely on generations of selfing, a process that can span 7-9 years. For fruit crops with inherent biological hurdles, long juvenile phases, large plant size, cross-incompatibility, and high heterozygosity, this timeline is even more daunting. Here comes the role of haploid and doubled haploid (DH) technology.

A haploid plant contains only one set of chromosomes (n), while a doubled haploid is produced by artificially doubling those chromosomes to restore the diploid (2n) state, but with complete homozygosity. In a single generation, DH plants achieve what conventional breeding requires a decade to accomplish. Since the first reported haploid in fruit crops was induced in kiwifruit using gamma-irradiated pollen in 1971, the field has grown considerably, yielding DH reference genomes for banana, pear, apple, peach, and orange.

Why Do Fruit Crops Need Haploid Technology?

The biological complexity of fruit crops creates formidable barriers to rapid genetic improvement:

1. Most fruit trees take years to reach flowering, delaying selection cycles.
2. High heterozygosity means desirable traits are often masked by dominant alleles or lost through segregation.
3. Self-incompatibility in species like apple and citrus prevents conventional inbreeding.
4. Large genome sizes and polyploidy in banana, kiwifruit, and strawberry add further complexity.

DH technology sidesteps these barriers by enabling the single-step production of completely homozygous lines from any genotype. Once obtained, these lines serve as stable genetic platforms for breeding, genomics, and functional studies.

How are Haploids Produced in Fruit Crops?

Several approaches have been developed to induce haploids in fruit species, each with its own strengths and limitations:

Method	Fruit Crops Applied
Anther/microspore culture	Citrus, apple, pear, peach, banana
Irradiated pollen parthenogenesis	Kiwifruit, mandarin, walnut, loquat, pear
Intraspecific hybridization	Citrus (diploid × tetraploid)
CENH3-mediated genome elimination	Banana (research stage)
Spontaneous / twin seedling	Blueberry, almond, date palm, citrus

Among these, anther culture and irradiated pollen-induced parthenogenesis are the most widely practiced. In anther culture, immature pollen grains (microspores) are excised and cultured on a specialized medium to trigger embryogenesis, the process by which a single gametic cell reprogrammes itself to form an embryo. The stage of microspore development at harvest is critical; the late uninucleate to early bicellular pollen stage is most responsive. In irradiated pollen parthenogenesis, pollen DNA is damaged by gamma rays (typically from Cobalt-60) or UV radiation so it cannot contribute its genome, yet it still stimulates the egg cell to divide and form a haploid embryo.

Completing the Journey: Chromosome Doubling

Haploid plants, while genetically valuable, are typically infertile and weakly growing. Chromosome doubling converts them into vigorous, fertile DH plants. The most common agent is colchicine, which inhibits spindle formation during cell division, allowing chromosome replication without cell separation. Safer alternatives such as oryzalin and amiprophos-methyl (APM) are gaining preference due to lower phytotoxicity. In some species, particularly pollen-derived plants, spontaneous doubling occurs naturally through endomitosis or nuclear fusion during early in vitro development.

Where has DH Technology Made an Impact?

1. Accelerating Breeding Cycles: DH plants attain 100% homozygosity in a single generation. Mathematical analysis shows that as the number of genes involved increases, DH populations are exponentially more efficient than F2

populations, up to 1024 times more efficient when 10 genes are segregating. DH lines like DH Phang in banana, Bartlett. DH in pear, DH Golden Delicious in apple, and DH Peach v2.0 in peach have already demonstrated this in practice.

2. Unlocking the Genome: DH lines provide homozygous templates ideal for whole-genome sequencing. The doubled-haploid Bartlett pear genome assembly achieved a scaffold N50 of 6.5 Mb, a nearly 1,000-fold improvement over its predecessor, and identified 37,445 protein-coding genes across a 496.9 Mb genome.

3. Precision QTL Analysis: Using a fertile DH line of apple, researchers identified 19 QTLs for 13 distinct traits. Notably, acidity, juice browning, and skin splitting each showed 1:1 segregation ratios, indicating single-gene inheritance, a finding only possible through the genetic clarity provided by DH populations.

Challenges: What Still Stands in the Way?

Despite clear advantages, several hurdles limit the routine application of DH technology in fruit crops:

1. Low induction frequencies, particularly in polyploid species like banana and kiwifruit.
2. Albinism in regenerated plantlets, caused by plastid abnormalities, is common in cereals and increasingly noted in woody plants.
3. Genotype-specificity: protocols optimised for one cultivar often fail in another, demanding laborious re-optimisation.
4. Long juvenile periods in fruit trees delay the evaluation of DH lines under orchard conditions.
5. Aneuploidy (abnormal chromosome number) can occur in up to 15% of androgenesis-derived plants, complicating downstream use.
6. Chemical chromosome doubling agents like colchicine are toxic and require careful dose optimisation.

The Road Ahead: Emerging Technologies

The next frontier in haploid technology lies at the intersection of molecular biology and precision breeding. CENH3-mediated genome elimination, pioneered in Arabidopsis and now being explored in banana, offers the prospect of haploid induction without in vitro culture by modifying the centromere-specific histone protein. Minichromosome technology, using engineered B chromosomes as 'super vectors' for multi-gene transfer, could create 'super haploid inducers' that autonomously trigger genome elimination without toxic chemicals. B chromosomes, which naturally occur in citrus, banana, and pomegranate, are attractive platforms for this approach.

CRISPR-based editing of haploid lines is also gaining traction. Because DH plants are fully homozygous, edited traits are immediately fixed without the need for additional backcrossing, dramatically compressing the timeline from gene editing to cultivar release. Combining these technologies with advances in high-throughput genomic selection and digital phenotyping promises to fundamentally reshape how fruit varieties are developed in the coming decades.

Conclusion

Haploid and doubled-haploid technologies represent among the most transformative tools available to the modern fruit-crop breeder. By compressing decades of conventional breeding into a single generation, DH lines unlock genetic potential that would otherwise remain inaccessible. From sequencing the apple genome to dissecting apple fruit quality traits, the impact of this technology is already tangible. As molecular tools mature and protocols become more robust, haploidisation in fruit crops is set to move from a specialised research technique to a mainstream breeding strategy, delivering better varieties, faster, for growers and consumers alike.

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Prickly Pear - A Promising Underutilized Arid Fruit Crop

Article ID: 74031

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Introduction

Prickly pear (*Opuntia ficus-indica* (L) Mill.), belongs to cactaceae family, are a type of fruit that develops on the leaves of Nopales cactus. It is locally known as Sappathikalli or Nagathali. Its vibrant, edible fruit is referred to as Kalli Pazham or Sappathikalli Palam. Prickly pear is also known as Barbary fig, Indian fig, Indian fig prickly-pear, mission cactus, mission prickly pear, smooth mountain prickly pear, smooth prickly pear, spineless cactus, sweet prickly pear, tuberous prickly pear, tuna cactus. The word Cactus is derives from the Ancient Greek word kaktos, a name used for a plant having spines and whose identity is not certain. The genus is named for the Ancient Greek city of Opus, where, according to Theophrastus, an edible plant which could be propagated by rooting its leaves.

Prickly pear is native to Mexico and accidentally introduced into India and South Asian countries by early European travelers, who used to carry these plants for use as vegetable to prevent scurvy during their long voyages. The genus *Opuntia* has about 300 different species of cacti that are found all over the world. The fruit comes in various colors, including purple, red, orange, yellow and green. The most popularly cultivated and available variety of cactus pear across the world is the *Opuntia ficus indica*. Several species of cactus are well-known worldwide, including, *Opuntia ficus indica*, *O. dillenii* Haw, *O. vulgaris*, *O. elatior*, *O. aurantiaca*, *O. polyacantha*, *O. lindheimeri* and *O. phaeacantha*. In India, three primary species of cactus pear are distributed across different regions *Opuntia dillenii* Haw. (Southern parts), *Opuntia vulgaris* Mill. (Northern areas) and *Opuntia elatior* Mill. (Western regions, including Kutch and Saurashtra).

Prickly pear fruit has an oval shape and weighs 100-200 g. The pulp of the prickly pear makes up 60%-70% of the total fruit weight and contains numerous small hard seeds, ranging from 100 to over 400 per fruit. As a non-climacteric fruit, prickly pear has a low respiration rate. The prickly pear fruit taste is similar to those of strawberry, watermelon, honeydew melon, fig and banana. The fruits contains important bioactive phytochemicals like, polyphenols, colored pigments, minerals and some vitamin. The skin of this fruit has tiny spines (also known as glochids) that need to be carefully removed before eating. The fruit is perishable and seasonal.

Prickly pear can naturally grow in arid and semi-arid region, where water availability can be a limiting factor for cultivation. These plants can thrive in dry, even desert conditions, making their cultivation particularly valuable in marginal and subsistence agriculture economies. Thus, progressing from promising small exotic fruit crops to developed cash crops.

Cactus pear is traditionally cultivated for fresh fruit production under rainfed conditions, where annual rainfall reaches up to 600 mm with a well-defined dry season that may last 2 to 5 months. Where the rainfall is below 300 mm, additional irrigation is needed to ensure economically profitable cropping, especially during fruit development, which requires 50-80 mm supplemented irrigation to achieve superior commercial market value. Cactus pear can withstand long drought periods, although possibly suffering severe impairment to plant growth, anatomy and physiology. For fruit cultivation purposes, an optimal temperature range of about 25/15°C day/night is required for plant growth and fruit production. Daily temperatures below 15°C delay fruit growth and maturation time, resulting in reduced soluble solid content and a thicker peel. Cactus pear is grown over a wide range of soils. However, for commercial cultivation, soils with poor drainage should be avoided. In addition, cactus pear grown under high salinity conditions is not suitable for commercial production as a level above 2.4 dS m⁻¹ may decrease its growth and productivity.

Prior to planting, the soil should be ploughed to a depth of 60-80 cm or cross ripped with a chisel to ensure both good drainage and the development of the shallow root system. In sandy, weed-free soils, pre-planting operations are reduced to single pits or furrows. Before planting, 6 to 10 t ha⁻¹ of well de-composted FYM is recommended, followed by 300 to 400 kg ha⁻¹ P₂O₅ and 300 to 500 kg ha⁻¹ K₂O. The yield of cactus pear depends on orchard design (plant spacing), cultural practices, environmental conditions and cultivars. Plants begin to yield 2-3 years after planting and reach their maximum potential 6-8 years after planting and remain productive for 25-30 years.

Nutritional Value of Prickly Pear

Prickly pear is a rich source of several minerals, including magnesium, amino acids, antioxidants, vitamins C and B, beta-carotene, iron, calcium and potassium.

Health Benefits of Prickly Pear

1. Increases immunity: Consumption of prickly pear fruit, which is rich in vitamins C and E, has been associated with improved detoxification and antioxidant performance. The vitamin C content of only one serving of prickly pears is enough to provide more than a third of the average person's daily needs. Vitamin C, also called ascorbic acid, helps the body fight off infections by strengthening the immune system and encouraging the creation of white blood cells. Vitamin C also plays a role in the development of bone and muscle, among other metabolic and enzymatic activities.

2. Improves bone density and dental health: Prickly pears have a high calcium content, which is essential for healthy bone development. Inadequate calcium intake has been linked to tooth decay, osteoporosis and other bone diseases associated with ageing.

3. Helps in digestion: Like other fibrous produce like fruits and vegetables, prickly pears aid in digestion thanks to their high fibre content. Constipation, bloating and more serious gastrointestinal problems including colon cancer and gastric ulcer can all be prevented by increasing your fibre intake.

4. Prevents heart diseases: High fibre content has been shown to reduce LDL (bad) cholesterol levels. The high potassium content has been shown to reduce blood pressure by relieving strain on the heart and blood vessels. Finally, the betalains in prickly pear have been linked to a reduction in the risk of weakening of the circulatory system by strengthening the endothelial walls of blood vessels. Generally speaking, the cactus fruit can protect against atherosclerosis, coronary heart disease, and stroke.

5. Prevents Cancer: There are many beneficial compounds, including betalains, polyphenols, and flavonoids, in prickly pears. These molecules prevent normal cells from mutating into malignant ones by acting as antioxidants. People who consume these antioxidants on a daily basis have been found to have a reduced risk of developing cancer.

6. Rich in Antioxidant: Prickly pears are rich in antioxidants, which preserve the skin, delay the onset of ageing, sharpen vision, ward off macular degeneration, and fortify and improve brain function, among other benefits. Dementia and Alzheimer's disease are caused, in part, by free radicals oxidising brain cells. Researchers have found a correlation between polyphenolic chemicals and improved brain function.

7. Promotes weight loss: Prickly pears can help you maintain a healthy weight because they are rich in fibre and nutrients yet low in calories and saturated fat. The carbs and fibre help you feel full without eating too much.

Nutritional Content of Prickly Pear

Macronutrients	Vitamins	Minerals
Calories: 61 kcal	Vitamin C: 20.9 mg (23%)	Magnesium: 127 mg (30%)
Carbohydrates: 14 g	Vitamin B6: 8%	Copper: 0.119 mg (13%)
Dietary Fiber: 5 g	Riboflavin: 8%	Potassium: 328 mg (7%)
Protein & Fat : 1 g	Vitamin A: 3%	Calcium: 6%

“A Gem Among the Thorns.”

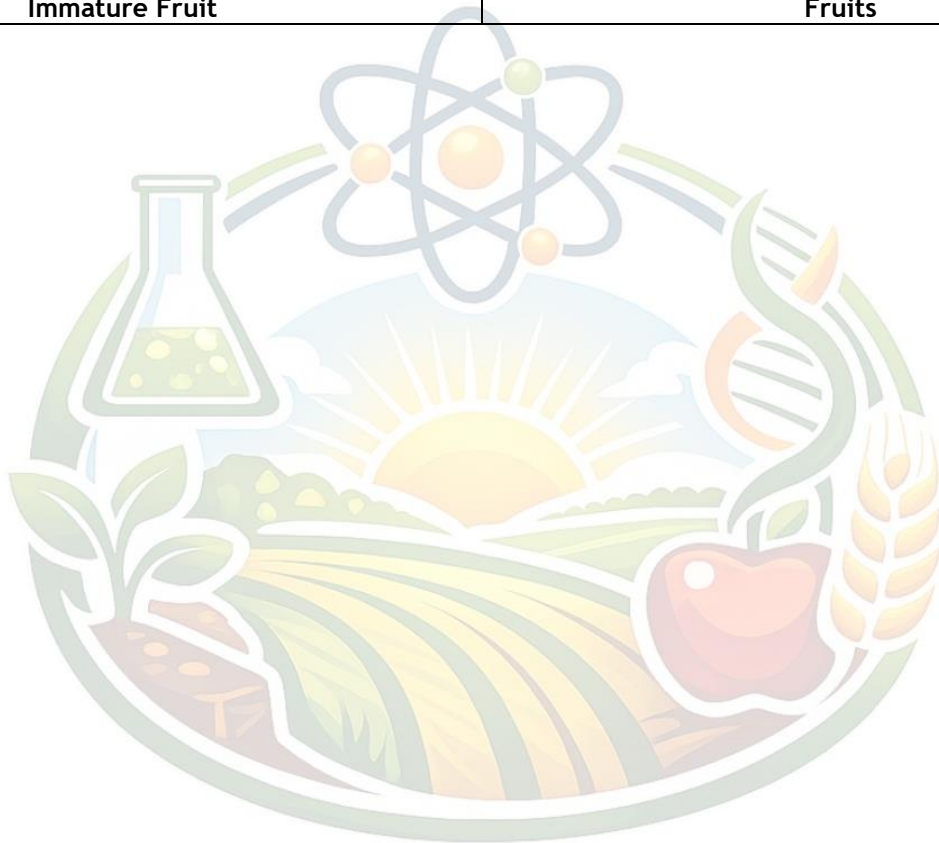
	
Plants	Flowers



Immature Fruit



Fruits



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Silvopastoral Systems for Land Restoration: Biodiversity, Livestock Productivity, and Soil Health Synergies

Article ID: 74032

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Abstract

Land degradation, biodiversity loss, declining soil fertility, and climate change have emerged as major challenges threatening the sustainability of agricultural and livestock production systems worldwide. Conventional grazing systems often contribute to soil erosion, vegetation degradation, nutrient depletion, and reduced ecosystem resilience when poorly managed. In this context, silvopastoral systems have gained increasing attention as a sustainable land-use strategy that integrates trees, shrubs, forage species, and livestock within the same management unit. These systems provide multiple ecological, economic, and social benefits by enhancing biodiversity conservation, improving livestock productivity, restoring degraded lands, and strengthening soil health. The integration of woody perennials with pasture ecosystems promotes nutrient cycling, carbon sequestration, microclimate regulation, water conservation, and habitat creation for diverse flora and fauna. Simultaneously, livestock benefit from improved forage availability, thermal comfort, and enhanced feed quality. Silvopastoral systems are increasingly recognized as nature-based solutions capable of addressing global challenges related to food security, climate resilience, ecosystem restoration, and sustainable livestock production. This review examines the principles, ecological mechanisms, biodiversity benefits, livestock productivity impacts, soil health improvements, land restoration potential, challenges, and future prospects of silvopastoral systems.

Introduction

The global demand for livestock products continues to increase due to population growth, urbanization, rising incomes, and changing dietary preferences. Livestock production contributes significantly to food security, rural livelihoods, and agricultural economies. However, conventional livestock systems frequently exert substantial pressure on natural resources through overgrazing, deforestation, soil degradation, biodiversity loss, and greenhouse gas emissions. Unsustainable grazing practices have resulted in the degradation of millions of hectares of grasslands and rangelands worldwide, reducing their productivity and ecological functionality. Land degradation represents one of the most severe environmental challenges of the twenty-first century. It encompasses a range of processes including soil erosion, nutrient depletion, desertification, salinization, compaction, and loss of biological diversity. These processes diminish ecosystem services and threaten the long-term sustainability of agricultural production systems. Restoration of degraded landscapes has therefore become a global priority under international initiatives such as the United Nations Decade on Ecosystem Restoration.

Silvopastoral systems offer a promising approach for simultaneously restoring degraded lands and enhancing agricultural productivity. These systems intentionally combine trees, shrubs, forage crops, and grazing animals in a spatially or temporally integrated manner. Unlike conventional monoculture pastures, silvopastoral systems create multifunctional landscapes capable of delivering diverse ecosystem services while maintaining productive livestock enterprises. The integration of woody vegetation into grazing lands modifies ecological processes and interactions. Trees improve soil structure, enhance nutrient cycling, increase organic matter accumulation, and regulate microclimatic conditions. Shrubs and legumes contribute additional forage resources and biological nitrogen fixation. Together, these components create synergistic interactions that benefit both livestock and ecosystem health. Increasing evidence suggests that silvopastoral systems can contribute substantially to biodiversity conservation, carbon sequestration, climate adaptation, and sustainable intensification of livestock production.

Concept and Principles of Silvopastoral Systems

Silvopastoral systems are a specialized form of agroforestry that integrates trees, forage plants, and livestock within a single land-use system. The primary objective is to maximize ecological and economic benefits through positive interactions among system components. The fundamental principle underlying silvopastoral systems is ecological complementarity. Different biological components utilize resources such as light, water, nutrients, and space at varying

temporal and spatial scales. Trees typically access deeper soil layers, while forage grasses exploit surface nutrients and moisture. This resource partitioning reduces competition and enhances overall system productivity.

Another key principle is diversification. By incorporating multiple plant species and livestock enterprises, silvopastoral systems reduce production risks associated with climate variability, pests, diseases, and market fluctuations. Diversification also enhances ecosystem stability and resilience. The multifunctional nature of silvopastoral systems distinguishes them from conventional grazing systems. These systems simultaneously produce livestock products, timber, fuelwood, fodder, fruits, medicinal plants, and environmental services such as carbon sequestration and biodiversity conservation.

Types of Silvopastoral Systems

Silvopastoral systems exhibit considerable diversity depending on climatic conditions, management objectives, and available resources. Scattered tree systems represent one of the most common forms, where trees are maintained or planted within grazing lands. Species such as *Acacia*, *Leucaena*, *Albizia*, *Prosopis*, *Dalbergia*, and *Faidherbia* are commonly used due to their forage value and ecological benefits.

Live fence systems involve planting trees or shrubs along pasture boundaries. These living barriers provide shade, fodder, fuelwood, and habitat connectivity while reducing fencing costs. Intensive silvopastoral systems incorporate high densities of fodder shrubs and trees combined with improved pastures and rotational grazing. Such systems are particularly prominent in tropical regions and have demonstrated remarkable improvements in livestock productivity and ecosystem services. Riparian silvopastoral systems focus on integrating vegetation along streams, rivers, and water bodies. These systems protect water quality, stabilize riverbanks, and create wildlife corridors. Forest grazing systems involve controlled livestock grazing within forested landscapes. When properly managed, these systems can support both livestock production and forest conservation objectives.

Biodiversity Enhancement through Silvopastoral Systems

Biodiversity conservation represents one of the most significant ecological benefits of silvopastoral systems. Conventional monoculture pastures often support relatively low levels of biological diversity because of their structural simplicity and limited habitat availability. The introduction of trees and shrubs dramatically increases habitat complexity and ecological niches. Trees provide nesting sites, shelter, food resources, and movement corridors for numerous bird species. Studies have shown that silvopastoral landscapes support substantially higher avian diversity than open pastures. Pollinators such as bees, butterflies, and other beneficial insects also benefit from increased floral diversity and habitat availability.

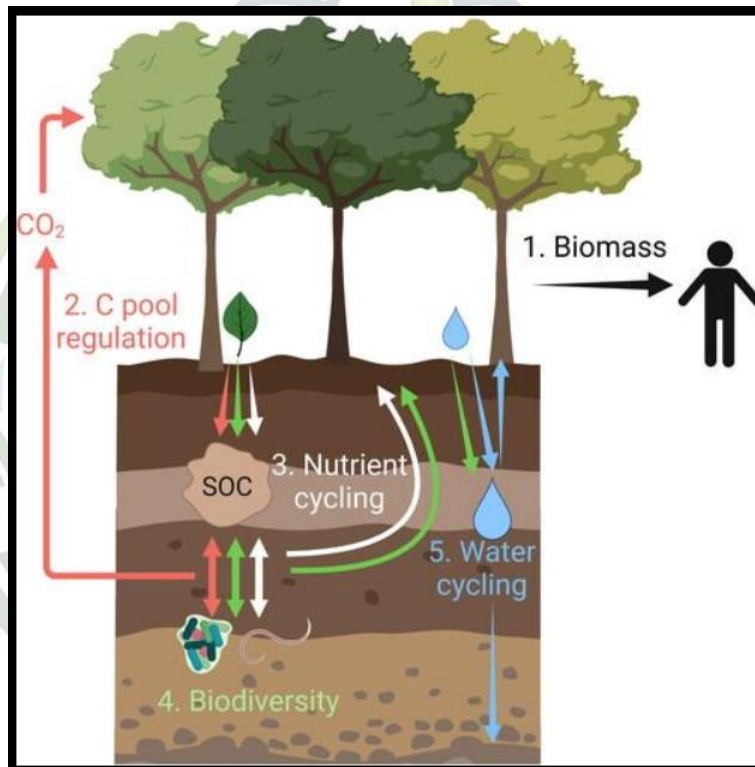
The enhanced vegetation structure promotes greater mammalian diversity, including small mammals, bats, and other wildlife species. Reptiles and amphibians similarly benefit from improved microhabitats created by tree cover and litter accumulation. Plant biodiversity increases considerably within silvopastoral systems due to the coexistence of trees, shrubs, grasses, legumes, and herbaceous species. This botanical diversity contributes to ecosystem stability and resilience. Soil biodiversity also improves significantly. Enhanced organic matter inputs support diverse communities of bacteria, fungi, nematodes, earthworms, and arthropods. These organisms play critical roles in nutrient cycling, soil formation, and ecosystem functioning. Numerous studies have reported that silvopastoral systems function as biodiversity reservoirs within agricultural landscapes. They can serve as ecological stepping stones and habitat corridors that facilitate species movement and genetic exchange.



Livestock Productivity Benefits

The integration of woody perennials into grazing systems provides multiple benefits that enhance livestock productivity and welfare. One of the most important advantages is improved thermal comfort. Livestock exposed to high temperatures often experience heat stress, reduced feed intake, lower growth rates, impaired reproduction, and decreased milk production. Trees provide shade that moderates ambient temperatures and improves animal welfare. Research has demonstrated that shaded grazing environments can reduce body temperature, respiratory rate, and physiological stress indicators in cattle. Improved thermal comfort often translates into higher feed conversion efficiency and productivity.

Fodder trees and shrubs contribute valuable feed resources throughout the year. Species such as *Leucaena leucocephala*, *Gliricidia sepium*, *Sesbania sesban*, and *Morus alba* provide high-protein forage that supplements pasture nutrition. The inclusion of nitrogen-fixing legumes enhances forage quality by increasing crude protein concentrations and digestibility. Improved nutritional status supports higher milk yields, faster weight gain, and enhanced reproductive performance. Silvopastoral systems frequently extend forage availability during dry seasons when conventional pastures become less productive. Deep-rooted trees maintain productivity under drought conditions by accessing water reserves unavailable to shallow-rooted grasses. Enhanced pasture productivity often allows increased stocking densities without compromising environmental sustainability. Consequently, farmers can achieve greater production per unit area while maintaining ecosystem integrity.



Soil Health Synergies in Silvopastoral Systems

Soil health constitutes a fundamental pillar of sustainable agricultural production. Silvopastoral systems significantly improve physical, chemical, and biological soil properties through multiple ecological mechanisms. Tree litter contributes substantial quantities of organic matter to the soil. Leaves, twigs, fruits, and roots undergo decomposition, enriching soil organic carbon pools and improving nutrient availability. Increased organic matter enhances soil aggregation, water-holding capacity, and cation exchange capacity. Root systems play a crucial role in soil improvement. Deep-rooted trees transport nutrients from deeper soil layers to the surface through biological pumping mechanisms. These nutrients become available to pasture plants following litter decomposition.

Nitrogen-fixing tree species contribute biologically fixed nitrogen, reducing dependence on synthetic fertilizers and enhancing soil fertility. This process is particularly valuable in nutrient-poor and degraded landscapes. Soil microbial communities flourish under silvopastoral systems due to increased organic matter inputs and favorable microclimatic conditions. Enhanced microbial activity promotes nutrient mineralization, organic matter decomposition, and soil structure formation. Earthworm populations frequently increase under silvopastoral management. Their activities improve soil aeration, infiltration, aggregation, and nutrient cycling. Soil erosion is substantially reduced because tree canopies intercept rainfall, roots stabilize soil particles, and litter layers protect the soil surface. Improved infiltration reduces runoff and enhances groundwater recharge.

Silvopastoral Systems for Land Restoration

Land restoration is among the most important ecosystem services provided by silvopastoral systems. Degraded lands often suffer from reduced vegetation cover, soil erosion, nutrient depletion, compaction, and diminished biological activity. The establishment of trees and shrubs initiates ecological restoration processes by improving microclimatic conditions and enhancing soil quality. Increased vegetation cover protects soil from erosive forces while facilitating natural regeneration. Root systems break compacted soil layers and improve porosity, allowing better root penetration and water infiltration. Enhanced organic matter accumulation supports the recovery of soil biological communities. Nutrient cycling processes become progressively restored as litter production increases and microbial activity intensifies. Over time, degraded lands regain productivity and ecological functionality. Silvopastoral systems are particularly effective in restoring tropical and subtropical grazing lands affected by overgrazing. Numerous restoration projects have demonstrated substantial improvements in vegetation cover, biodiversity, soil fertility, and livestock productivity.

Climate Change Mitigation and Adaptation

Silvopastoral systems contribute significantly to climate change mitigation through carbon sequestration. Trees capture atmospheric carbon dioxide and store carbon in biomass and soils. Carbon stocks in silvopastoral systems are generally much higher than those in conventional pastures. The accumulation of soil organic carbon further enhances carbon sequestration potential. Improved soil management practices associated with silvopastoral systems contribute to long-term carbon storage. Climate adaptation benefits are equally important. Diversified vegetation improves resilience to droughts, extreme temperatures, and rainfall variability. Deep-rooted trees maintain productivity during adverse climatic conditions and provide shelter against extreme weather events.

SOCIOECONOMIC BENEFITS

Beyond ecological advantages, silvopastoral systems generate substantial socioeconomic benefits. Farmers gain diversified income streams from livestock products, timber, fuelwood, fruits, fodder, and ecosystem services. Improved productivity increases farm profitability and economic resilience. Reduced expenditure on fertilizers and supplemental feed lowers production costs. Enhanced environmental sustainability may also create opportunities for participation in carbon markets and payment-for-ecosystem-services programs. Rural communities benefit from improved employment opportunities, enhanced food security, and greater resilience to environmental and economic shocks.

Challenges and Constraints

Despite their numerous benefits, silvopastoral systems face several adoption barriers. Initial establishment costs can be substantial, particularly for tree planting, fencing, and infrastructure development. Farmers may be reluctant to invest due to delayed economic returns from tree components. Knowledge gaps and limited technical expertise also constrain adoption. Successful implementation requires careful species selection, grazing management, and system design. Competition for light, water, and nutrients may occur if tree densities are excessively high or poorly managed. Inappropriate species selection can negatively affect pasture productivity. Policy and institutional barriers, including inadequate extension services and limited access to financial support, further restrict widespread adoption.

Future Prospects

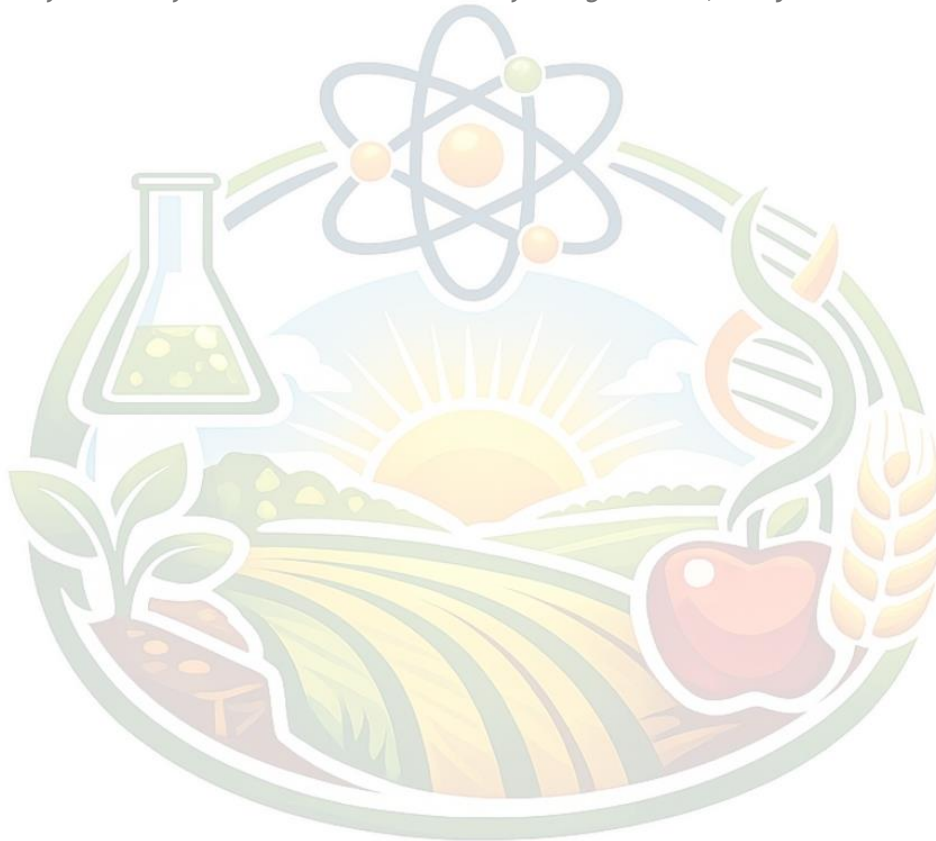
Future development of silvopastoral systems will likely be driven by advances in agroecological research, precision agriculture, remote sensing, and climate-smart livestock management. Improved understanding of tree-pasture-animal interactions will facilitate optimized system design. Emerging technologies such as GIS, drones, artificial intelligence, and remote sensing can support monitoring and management of silvopastoral landscapes. Integration with regenerative agriculture and ecosystem restoration initiatives is expected to expand adoption globally. Growing recognition of nature-based solutions for climate change mitigation, biodiversity conservation, and sustainable agriculture further strengthens the prospects of silvopastoral systems as key components of future land-use strategies.

Conclusion

Silvopastoral systems represent a highly effective and sustainable approach for restoring degraded lands while simultaneously enhancing biodiversity, livestock productivity, and soil health. The integration of trees, forage species, and livestock creates synergistic interactions that improve ecosystem functioning, nutrient cycling, carbon sequestration, and agricultural resilience. These systems provide habitat for diverse plant and animal species, improve animal welfare and productivity, enhance soil quality, and contribute to climate change mitigation and adaptation. Although challenges related to establishment costs, management complexity, and policy support remain, the long-term ecological and economic benefits far outweigh these limitations. As global efforts intensify toward sustainable agriculture, ecosystem restoration, and climate resilience, silvopastoral systems are poised to play an increasingly important role in creating productive, resilient, and environmentally sustainable agricultural landscapes.

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Post-harvest Edible Coatings and Cold Chain Technologies in Fruit and Vegetable Crops

Article ID: 74033

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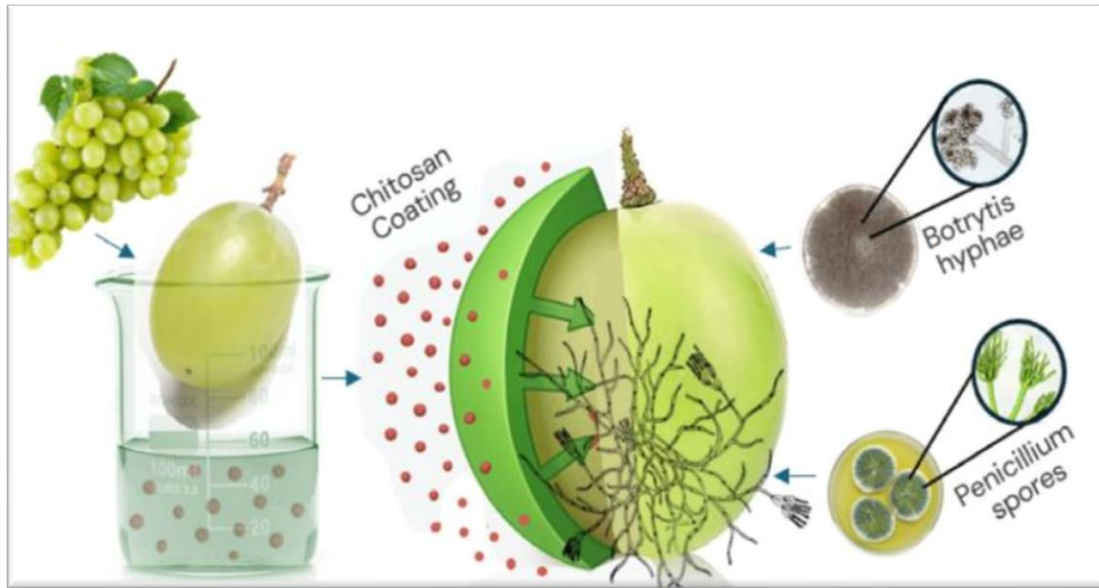
Abstract

Post-harvest losses of fruits and vegetables remain one of the most critical challenges affecting global food security, farmer income, nutritional availability, and sustainability of agricultural systems. Fruits and vegetables are highly perishable commodities that continue metabolic activities after harvest, leading to rapid deterioration in quality through respiration, transpiration, ethylene production, microbial infection, physiological disorders, and senescence. Recent advances in post-harvest technology have emphasized the use of edible coatings and cold chain technologies as sustainable approaches to prolong shelf life, preserve quality, reduce losses, and improve marketability. Edible coatings derived from natural biopolymers such as polysaccharides, proteins, lipids, and composite materials create semi-permeable barriers around produce, thereby regulating gas exchange, moisture loss, oxidation, and microbial growth. Simultaneously, cold chain systems maintain optimal temperature and humidity conditions throughout harvesting, storage, transportation, distribution, and retail operations. The integration of edible coating technologies with efficient cold chain management has demonstrated remarkable effectiveness in maintaining freshness, nutritional quality, sensory attributes, and safety of horticultural produce. Emerging innovations involving nanotechnology, active packaging, intelligent coatings, antimicrobial agents, and digital cold chain monitoring are further transforming modern post-harvest management. This review comprehensively discusses the principles, materials, applications, mechanisms, advantages, limitations, and future prospects of edible coatings and cold chain technologies for fruit and vegetable crops.

Introduction

Fruits and vegetables constitute indispensable components of human nutrition owing to their richness in vitamins, minerals, dietary fiber, antioxidants, phytochemicals, and numerous health-promoting compounds. Despite substantial advancements in agricultural production technologies, a considerable proportion of harvested fruits and vegetables is lost before reaching consumers. These losses occur due to improper harvesting, handling, storage, transportation, packaging, and marketing practices. Globally, post-harvest losses of fruits and vegetables are estimated to range from 20-50%, depending upon commodity type, climatic conditions, infrastructure availability, and supply chain efficiency. In developing countries such as India, losses are particularly severe because of inadequate cold storage facilities, poor transportation infrastructure, lack of temperature-controlled logistics, and insufficient awareness regarding post-harvest management practices. According to Kader (2005), minimizing post-harvest losses represents one of the most effective approaches to improving food availability without increasing agricultural land or resource utilization.

After harvest, fruits and vegetables remain physiologically active. Respiration, transpiration, enzymatic reactions, ethylene biosynthesis, microbial infection, and biochemical degradation continue, ultimately resulting in loss of freshness and market value. Therefore, technologies capable of slowing these physiological processes are crucial for extending storage life and maintaining quality. Among modern post-harvest technologies, edible coatings and cold chain systems have emerged as highly promising and environmentally sustainable solutions. Edible coatings provide protective barriers that reduce moisture loss, modify internal atmospheres, and inhibit microbial growth. Cold chain technologies maintain optimal temperature conditions from farm to consumer, significantly slowing metabolic and microbial activities. Together, these technologies form the foundation of contemporary post-harvest management systems.



Importance of Post-Harvest Management in Fruits and Vegetables

The significance of post-harvest management extends beyond simple preservation of produce quality. Effective post-harvest handling directly influences food security, farmer profitability, market competitiveness, consumer satisfaction, and environmental sustainability. Fresh fruits and vegetables possess high moisture content, typically ranging from 70% to 95%, making them highly susceptible to microbial spoilage and physiological deterioration. Even minor deviations from recommended storage conditions can accelerate quality degradation.

The increasing globalization of horticultural trade has intensified the need for technologies capable of maintaining quality during long-distance transportation and prolonged storage. International markets demand produces with excellent appearance, texture, flavour, nutritional quality, and safety standards. Consequently, post-harvest technologies have become essential components of modern horticultural supply chains. Furthermore, reducing post-harvest losses contributes significantly to sustainability by lowering food waste, conserving agricultural resources, reducing greenhouse gas emissions, and improving resource-use efficiency throughout food production systems.

Nature and Causes of Post-Harvest Losses

Post-harvest losses can be categorized into quantitative and qualitative losses. Quantitative losses involve physical reduction in produce weight, volume, or marketable quantity. Qualitative losses refer to deterioration in appearance, texture, flavour, nutritional value, and consumer acceptability. Major factors responsible for post-harvest losses include physiological, pathological, environmental, mechanical, and biochemical factors. Physiological losses occur through respiration, transpiration, senescence, and ethylene-induced ripening. Respiration consumes stored carbohydrates and organic acids, resulting in loss of dry matter and quality. Transpiration causes water loss, leading to wilting, shrivelling, and weight reduction.

Pathological losses arise from fungal, bacterial, and viral infections. Common post-harvest pathogens include species of *Botrytis*, *Penicillium*, *Alternaria*, *Colletotrichum*, *Rhizopus*, and *Aspergillus*. Mechanical injuries resulting from improper harvesting, handling, packaging, and transportation create entry points for pathogens and accelerate deterioration. Environmental factors such as temperature fluctuations, humidity imbalances, oxygen deficiency, and excessive carbon dioxide accumulation further contribute to quality losses.

Concept and Principles of Edible Coatings

Edible coatings are thin layers of edible materials applied to the surface of food products to provide protection against physical, chemical, and biological deterioration. They are consumed along with the food and therefore must be safe, biodegradable, non-toxic, and environmentally friendly. The concept of edible coatings dates back several centuries. Historical evidence indicates that waxes were used in ancient China to preserve citrus fruits. Modern edible coating technology has evolved significantly with advances in food science, polymer chemistry, nanotechnology, and biotechnology.

The primary objective of edible coatings is to create a semi-permeable barrier between the produce and surrounding environment. This barrier regulates transfer of moisture, oxygen, carbon dioxide, volatile compounds, and solutes. According to Baldwin et al. (2011), edible coatings function similarly to modified atmosphere packaging by altering internal gas composition and reducing respiration rates. An ideal edible coating should possess good film-forming ability,

transparency, flexibility, mechanical strength, adhesion, safety, biodegradability, and compatibility with produce surfaces.

Classification of Edible Coatings

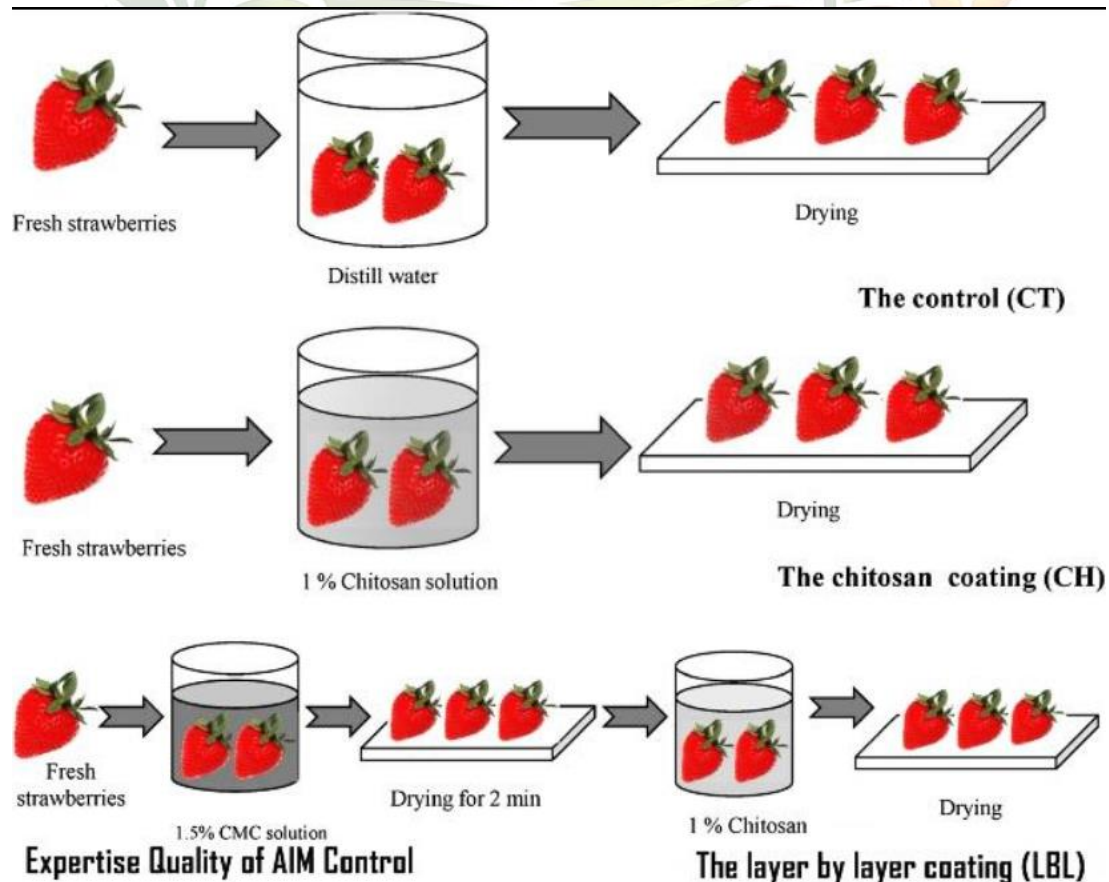
Edible coatings are generally classified according to their composition into polysaccharide-based, protein-based, lipid-based, and composite coatings.

1. Polysaccharide-Based Coatings: Polysaccharides represent one of the most widely used categories of edible coating materials due to their abundance, biodegradability, non-toxicity, and excellent film-forming properties. Common polysaccharides include chitosan, starch, cellulose derivatives, pectin, alginate, carrageenan, xanthan gum, and pullulan. Chitosan has gained particular attention because of its inherent antimicrobial properties. Derived from chitin present in crustacean shells, chitosan effectively inhibits numerous fungal and bacterial pathogens while simultaneously reducing respiration and moisture loss. Alginate coatings derived from brown seaweeds exhibit excellent barrier properties and have been successfully applied to strawberries, apples, pears, mangoes, and tomatoes. Pectin-based coatings are widely used because of their compatibility with fruit tissues and ability to form transparent films.

2. Protein-Based Coatings: Protein-based coatings provide excellent gas barrier properties due to their highly ordered molecular structures. Common protein sources include whey protein, soy protein, gelatin, zein, casein, and gluten. Whey protein coatings exhibit strong oxygen barrier characteristics, helping reduce oxidative deterioration and maintain colour stability. Gelatin coatings have been widely investigated for preserving strawberries, grapes, cherries, and other highly perishable fruits. Soy protein coatings offer favourable mechanical properties and biodegradability while enhancing shelf-life extension.

3. Lipid-Based Coatings: Lipid coatings primarily function as moisture barriers due to their hydrophobic nature. Common lipid materials include beeswax, paraffin wax, carnauba wax, shellac, fatty acids, and vegetable oils. Wax coatings are extensively used in commercial citrus industries worldwide. Application of wax significantly reduces moisture loss, delays shriveling, enhances gloss, and improves market appearance. However, lipid coatings generally exhibit poor gas permeability characteristics and may sometimes induce anaerobic respiration if applied excessively.

4. Composite Coatings: Composite coatings combine polysaccharides, proteins, and lipids to achieve balanced barrier properties. These coatings often provide superior performance compared to single-component systems because they simultaneously improve moisture resistance, gas regulation, mechanical strength, and sensory quality. Modern commercial edible coatings increasingly employ composite formulations tailored to specific commodities and storage conditions.



Mechanisms of Action of Edible Coatings

The effectiveness of edible coatings results from multiple physiological, biochemical, and microbiological mechanisms. The first mechanism involves reduction of water loss. By creating a protective barrier against transpiration, coatings maintain cell turgidity and prevent shrivelling. The second mechanism involves modification of internal gas composition. Reduced oxygen availability and increased carbon dioxide concentrations slow respiration rates, thereby delaying ripening and senescence. The third mechanism involves inhibition of ethylene biosynthesis and action. Lower ethylene activity delays ripening processes and prolongs storage life in climacteric fruits such as mango, banana, papaya, avocado, and tomato. The fourth mechanism involves suppression of microbial growth. Certain coatings, particularly chitosan-based formulations, exhibit intrinsic antimicrobial properties. Additionally, coatings can serve as carriers for antimicrobial agents, essential oils, organic acids, and bioactive compounds. The fifth mechanism involves reduction of oxidative reactions. Coatings can limit oxygen penetration and preserve antioxidants, vitamins, pigments, and other sensitive compounds. Research by Valencia-Chamorro et al. (2011) demonstrated that edible coatings effectively reduce physiological deterioration while maintaining sensory and nutritional quality in numerous fruit and vegetable crops.

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Advanced Glycation End Products (AGEs) in Indian Cooking

Article ID: 74034

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Summary

Advanced glycation end products (AGEs) are harmful compounds formed when sugars react with proteins during high-heat cooking (>140°C) via the Maillard reaction. Dietary AGEs from heat-processed foods increase oxidative stress, inflammation and insulin resistance. Dry-heat Indian cooking methods generate 10-100× higher AGEs than moist-heat methods, with water-based cooking reducing AGEs by 75-90%. Given India's diabetes epidemic, the landmark ICMR study links AGE-rich fried foods to increased diabetes risk. Traditional Indian practices such as acidic marination reduces formation by 50-70%; anti-glycation spices inhibit glycation by 40-90%; and wet-cooking provides low-AGE options. These strategies helps to prevent type 2 diabetes and cardiovascular disease. Future research should develop AGE databases specific to Indian regional cuisines.

Keywords: AGEs, Maillard reaction, dietary AGEs, Indian cuisine, glycation, oxidative stress, diabetes.

Introduction

Advanced glycation end products (AGEs) are a heterogeneous class of toxic compounds formed through the Maillard reaction which is a non-enzymatic chemical reaction between reducing sugars and the free amino groups of proteins, lipids or nucleic acids. The Maillard reaction occurs naturally during heat processing of food at temperatures above 140°C (284°F) and produces the characteristic brown colour, aroma and provides flavour to the cooked foods but simultaneously generates harmful AGEs.

AGEs arise from two distinct sources: endogenous AGEs, which form within the body under conditions of hyperglycemia, oxidative stress and aging and exogenous/dietary AGEs (dAGEs), which are derived from consuming heat-processed foods, particularly those rich in saturated fats, sugars, meat and cheese. While endogenous formation occurs naturally, exogenous AGEs from modern heat-processed diets contribute more to the human AGE pool and are directly related to AGE levels in circulation.

Studying AGEs in the Indian dietary context is very important due to India's alarming prevalence of type 2 diabetes and cardiometabolic disease. India is now the world's "diabetes capital", with the diabetes epidemic primarily driven by obesity, physical inactivity and unhealthy diets rich in AGEs. A groundbreaking ICMR clinical trial has directly linked consumption of AGE-rich foods such as ultra-processed and fried foods like paratha, samosa and sugary items to India's diabetes burden and chronic inflammation leading to insulin resistance. Dietary AGE intake may act as a modifiable risk factor and act as a potential target for future interventions against these chronic diseases that are increasingly affecting the Indian population.

Factors Influencing AGE Formation During Cooking

1. Cooking Temperature, Duration and Method: Temperature is the most critical factor: AGE formation accelerates dramatically at temperatures above 120-180°C (248-356°F). Dietary AGEs specifically require 140-165°C (284-329°F) to start forming which is why low-temperature cooking methods generate minimal AGEs.

Cooking method creates dramatic differences in AGE levels:

Cooking Method Type	Examples	AGE formation
Dry heat (high AGEs)	Grilling, frying, roasting, baking, barbecuing, broiling, griddle cooking	10-100× higher than raw foods
Moist heat (low AGEs)	Boiling, steaming, poaching, stewing, slow cooking, microwaving, casseroles	<25% of AGEs in dry-heat cooked foods

Duration follows a complex relationship: heating at high temperatures for short time periods enhances AGE formation, while cooking at lower temperatures for longer periods with more moisture reduces it.

2. Role of Ingredient Composition: Foods with higher protein content and available sugars generate more AGEs during cooking. This is evident in pasta and grain products where AGE product formation is favored by higher protein content and lower moisture. Foods rich in saturated fats generate more AGEs than those with unsaturated fats. Meat, fish, cheese and fatty foods are high in AGEs due to their protein and fat composition. The presence of saturated fats and sugars in ultra-processed foods creates AGE-rich matrices. Additionally, trace metals from copperware and ironware facilitate the Maillard reaction and AGE formation.

3. pH and Moisture Content:

- pH level has a profound effect:

The Maillard reaction rate is low at acidic pH (pH <7).

Adding vinegar or lemon juice lowers pH and decreases AGE generation.

Baking soda (sodium bicarbonate) increases pH and increases AGE formation in bakery goods.

- Moisture content significantly modulates glycation rate:

Low water content during cooking enhances AGE formation.

At higher moisture levels, reaction rate decreases due to dilution of reactants in the aqueous phase.

High humidity during cooking reduces AGE formation.

Cooking with liquid presence (stewing, poaching) produces fewer AGEs than dry cooking.

AGE Formation Across Common Indian Cooking Techniques

Cooking Methods	Cooking Temperature	Moisture Level	Relative AGE Levels	AGE Content Examples
Deep Frying	160-190°C (320-374°F)	Very low	Extremely High	Deepfried chicken: 7,760 kU/90g; Potato chips: high acrylamide
Dry Roasting	150-200°C (302-392°F)	Very low	High	Roasted chicken with skin: 6,639 kU/100g; Roasted beef: 6,071 kU/100g; ‘ Dry-heat crackers/ chips: highest AGEs per gram
Pan-Frying	150-180°C (302-356°F)	Low-Moderate	High	Pan-fried poultry: 4,938 kU/100g ; Pan-fried beef: 10,058 kU/100g ; Pan-fried pork: 4,752 kU/100g
Pressure Cooking	115-125°C (239-257°F)	Very High	Low	(No direct database values; moisture-based cooking reduces AGEs by 75-90%)
Steaming	100°C (212°F)	Very High	Very Low	Poached chicken: 1,101 kU/100g ; Steamed chicken: 1,058 kU/100g
Boiling/ Stewing	100°C (212°F)	Very High	Very Low	Boiled chicken: 1,123 kU/100g ; Boiled beef: 1,538 kU/100g ; Stewed beef: 2,007 kU/90g

AGE Content Database Reference: The first Indian AGE database was developed by ICMR-National Institute of Nutrition, Hyderabad, measuring AGE-fluorescence and carboxymethyl-lysine (CML) in 58 Indian foods:

Highest AGE-fluorescence: Biscuits 2 (362 AU)

Highest CML content: Soya milk (659.3 ng/g)

High AGE processed foods: Tomato sauce, chilli sauce, cheese

Modulating Effects of Traditional Indian Ingredients and Practices

	Acidic marination (curd, lemon, tamarind, vinegar) may reduce AGE formation.
	Spices with antioxidant/anti-glycation potential — turmeric (curcumin), ginger, garlic, cinnamon.
	Wet-cooking staples (dals, curries, sambar) are comparatively low-AGE preparations.

Strategies for Reducing Dietary AGE Load in Indian Diets

Practical strategies to reduce dietary AGEs in Indian cooking focus on three key approaches: acidic marination, moderation of high-heat cooking and antioxidant-rich accompaniments. Marinate meats and paneer for at least 1 hour in curd (yogurt) combined with lemon juice, turmeric and ginger before grilling or frying this traditional practice reduces AGE formation by 50-70% as it lowers the pH and inhibits the Maillard reaction. Deep-frying, tandoor/grilling and dry-roasting methods of cooking should be limited while pressure-cooking, steaming and boiling for daily meals which produce

75-90% fewer AGEs due to water's protective buffering effect should be practiced. Enhance high-heat cooked foods with antioxidant-rich spices like turmeric (curcumin: 40-90% inhibition), ginger (63% reduction at 1.0 mg/ml), cinnamon (54% reduction at 1.0 mg/ml), garlic, black pepper and cumin, all of which demonstrate potent anti-glycation activity. Balance meals with fresh vegetables, fruits and whole grains as accompaniments, and incorporate traditional low-AGE preparations like rasam and curd-based salads to counteract oxidative stress from any unavoidable AGE-rich foods.

Conclusion

Advanced glycation end products (AGEs) formed during high-heat Indian cooking methods such as deep-frying (samosas, pakoras), grilling/tandoor (tikkas, kebabs) and dry-roasting (papads) contribute significantly to India's alarming type 2 diabetes and cardiometabolic disease burden, as confirmed by the landmark ICMR clinical trial linking AGE-rich ultra-processed foods to India's diabetes epidemic. While traditional Indian cooking inherently offers protective strategies through acidic marination, anti-glycation spices and wet-cooking staples, bridging the gap between scientific evidence and daily practice requires greater awareness of AGE content across Indian dishes. Future research must prioritize developing a comprehensive, standardized AGE-content database specific to Indian cuisine which can include regional variations, home-cooked versus commercial preparations and the cumulative effect of traditional spice combinations. Longitudinal studies examining the relationship between dietary AGE intake and diabetes/cardiovascular outcomes in Indian populations, along with randomized controlled trials testing low-AGE dietary interventions tailored to Indian food patterns will be essential for translating AGE science into actionable public health guidelines that preserve India's rich culinary traditions while protecting population health.

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Compound Binomial Distribution: Parameter Estimation and Practical Applications

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Summary

The Compound Binomial Distribution arises when the number of trials in a Binomial distribution is itself a random variable following a Poisson distribution. This distribution provides a useful framework for modelling stochastic phenomena where the trial size is uncertain. The present article discusses the concept, mathematical formulation, and parameter estimation of the Compound Binomial Distribution. It also highlights important practical applications, including the estimation of insect populations and the assessment of lightning-induced damage. The distribution serves as an effective statistical tool for analysing complex real-world problems involving random events.

Introduction

Compound distribution is that probability distribution in which assuming that a random variable is distributed to a particular distribution with some parameters and some of the parameters of this distribution are random variable and they follow another distribution. This is also known as mixture or composed or contagious distribution. Let consider a random variable X whose distribution is depend on of the parameter θ . Generally θ is constant but if it is followed another distribution and behave as a random variable, then it can be said that random variable X has a compound distribution.

If random variable X follows Binomial distribution with parameter n, p . And one of the parameter of Binomial distribution n itself is a random variable and follows Poisson distribution. Then X is said to have compound Binomial distribution.

Estimation of Parameter

Let, $X_1, X_2, X_3, \dots, X_n$ are random variables independently and identically follows Bernoulli distribution with parameter $(1, p)$. The distribution function is given by,

$$P(X = x) = p^x(1 - p)^{1-x}; x = 0, 1; 0 < p < 1; \dots (1)$$

For fixed n , $X = X_1 + X_2 + X_3 + \dots + X_n$ follows Binomial distribution with parameter n, p and the probability distribution function is given by,

$$P(X = r) = \binom{n}{r} p^r q^{n-r}; r = 0, 1, 2, \dots, n; 0 < p < 1; q = 1 - p; \dots (2)$$

Here, equation-2 gives the probability of r success in n independent trials with a constant probability p for each of the trials. If parameter n is not a fixed, it is random variable and followed another distribution namely Poisson distribution with parameter λ . Then the distribution function is given by,

$$P(n = k) = \frac{e^{-\lambda} \lambda^k}{k!}; k = 0, 1, 2, \dots, \infty; \dots (3)$$

In this above mentioned case X is said to have followed compound Binomial distribution. From equation-2 and 3, the joint probability distribution function of X and n is given by,

$$\begin{aligned} P(X = r \cap n = k) &= P(n = k) * P(X = r | n = k) \\ &= \frac{e^{-\lambda} \lambda^k}{k!} \binom{k}{r} p^r q^{k-r}; k = r, r + 1, \dots, \infty; \dots (4) \end{aligned}$$

From equation-4, the marginal distribution function of X is given by,

$$\begin{aligned} P(X = r) &= \sum_{k=r}^{\infty} P(X = r \cap n = k) \\ &= e^{-\lambda} p^r \sum_{k=r}^{\infty} \binom{k}{r} \frac{\lambda^k q^{k-r}}{k!} \\ &= \frac{e^{-\lambda} (\lambda p)^r}{r!} \sum_{k=r}^{\infty} \frac{(\lambda q)^{k-r}}{(k-r)!} \\ &= \frac{e^{-\lambda} (\lambda p)^r}{r!} \sum_{m=0}^{\infty} \frac{(\lambda q)^m}{m!} \quad [\text{where, } m = k - r] \end{aligned}$$

$$= \frac{e^{-\lambda}(\lambda p)^r}{r!} e^{\lambda q} = \frac{e^{-\lambda p}(\lambda p)^r}{r!}; \dots (5)$$

Here, equation-5 is the probability function of a Poisson variate with parameter λp .

$$\therefore E(X) = \lambda p; V(X) = \lambda p$$

Application

1. To count the insect population: Let, the probability distribution of laying eggs by insect is followed Poisson distribution. So, the probability of laying n eggs is given by

$$P(X = n) = \frac{e^{-\lambda} \lambda^n}{n!};$$

and p is the probability of an egg is developed and q is the probability of an egg is not developed. If natural independence of egg is assumed, then the probability of a total number of k survivors is followed Poisson distribution with parameter λp .

For a particular species if p is known, then researcher can easily find out the mean for a given total number of k survivors of that particular insect species.

2. To calculate the number of total damage by lightning: Let, for any time interval t , the probability of number of hits by lightning followed Poisson distribution. The probability distribution is given by,

$$P(X = x) = \frac{e^{-\lambda t} (\lambda t)^x}{x!}; x = 0, 1, 2, \dots \infty;$$

and p is the probability of lightning hit and damage an individual. If stochastic independence of lightning is assumed, then the total damage during the time t is followed Poisson distribution with parameter $\lambda t p$.

Conclusion

Compound Binomial distribution is very useful when parameter n of Binomial distribution is itself a random variable and followed Poisson distribution. By using this formulas, it can be easily calculating the total insect population and the number of total damage by lightning. The distribution has practical applications in fields such as entomology, ecology, reliability studies, and risk assessment.

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A Comprehensive Analysis of Water Harvesting for Sustainable Agriculture

Article ID: 74036

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Abstract

The contemporary global agricultural landscape is defined by a paradoxical crisis: while the demand for food and fiber is projected to double by 2050 to sustain a population of nine billion, the freshwater resources required to facilitate this expansion are increasingly sequestered, contaminated, or overexploited. Agriculture currently serves as the primary consumer of the planet's accessible freshwater, accounting for 70% of global annual withdrawals, a figure that escalates to 90% in developing economies. However, the reality of the hydrological cycle is stark; only 3% of the world's water is fresh, and of that, only one-third is accessible for utilization in cities and farms, with the remainder frozen in cryosphere reserves or located at prohibitive depths. As groundwater depletion affects over half of the world's largest aquifers, the transition from conventional, centralized water management toward decentralized, localized water harvesting (WH) has become an ecological and economic imperative. Water harvesting, defined as the deliberate collection and storage of runoff from natural or anthropocentrically modified catchments, offers a "soft path" toward water security. This strategy does not merely supplement existing supplies but actively rejuvenates the landscape's hydrological function by increasing the residence time of water in the terrestrial environment transitioning "blue water" (liquid runoff) into "green water" (soil moisture) and recharging subterranean aquifers. The following analysis evaluates the technical, socio-economic, and agronomic dimensions of traditional and modern water harvesting techniques, synthesizing evidence from high-impact longitudinal studies and meta-analyses to provide a framework for long-term agricultural sustainability.

The Tri-Pillar Framework of Agricultural Sustainability

The evaluation of water harvesting systems must be situated within a robust definition of sustainability, which integrates environmental quality, economic viability, and social equity as shown in Figure 1

Sustainability Pillar	Indicator and Metric	Impact of Water Harvesting
 Environmental	Ecosystem health and biodiversity	Reduction in groundwater over-extraction; preservation of downstream wetland habitats. ¹
 Environmental	Soil conservation and carbon	Mitigation of soil erosion by up to 70%; sequestration of 0.1–2 t C through moisture retention. ¹¹
 Economic	Agricultural productivity and income	Increase in crop yields by an average of 71%; boost in household income by 50–200% in semi-arid tropics. ¹¹
 Economic	Energy efficiency	Energy savings (up to 39 PJ in specific crops) by reducing dependency on deep-well pumping. ²
 Social	Food security and community resilience	Hedging against climate-induced drought; providing local control over water assets. ¹⁴
 Social	Equity and asset distribution	Potential for decentralized power; risks of spatial inequity if placement is not strategically managed. ¹⁶

Figure 1 Water Harvesting Contributions to Environmental, Economic, and Social Sustainability

In the context of the Food, Agriculture, Conservation, and Trade Act (FACTA) of 1990 and guidelines from the National Research Council (NRC), sustainable water management is predicated on the efficient use of nonrenewable resources and the enhancement of the quality of life for producers and society (Ghimire et al., 2014). The environmental dimension extends beyond mere water quantity to include the mitigation of CO₂ emissions and ecotoxicity. Research indicates that systems integrating rainwater harvesting (RWH) with supplemental well-water can significantly reduce the human and environmental impact scores compared to 100% well-water systems. Furthermore, by reducing the velocity of flowing

water, these structures prevent the transport of sediment and pollutants into sensitive aquatic ecosystems (Ghimire et al., 2017).

Traditional Water Wisdom: Indigenous Engineering and Regional Adaptation

Traditional water harvesting systems represent the culmination of centuries of indigenous observation and adaptation to localized hydrogeological conditions. These systems are inherently sustainable, as they typically rely on gravity, local materials, and community management structures.

The Integrated Landscapes of Northeast India and the Himalayas

In the high-rainfall but water-scarce terrains of the Himalayan foothills and the Northeast, traditional knowledge has produced highly sophisticated integrated models as shown in Fig. 2.

1. The Zabo (Ruza) System: Practiced by the Chakhesang tribe in Nagaland, this system organizes the landscape into three distinct vertical zones: protected forests at the hilltop (catchment), cattle yards in the middle (nutrient source), and agricultural terraces at the base (cultivation) (Ruza, 2023). Runoff from the forest passes through the cattle yards, picking up manure before being stored in earthen-embankment ponds for irrigation. This promotes a circular economy of nutrients and water.

2. The Apatani System: Located in the valleys of Arunachal Pradesh, this system utilizes earthen dams (0.6 meters high) reinforced with bamboo frames to create a network of terraced plots. The system is characterized by a "cascading" inlet-outlet architecture where the outlet of a higher plot serves as the inlet for the lower one. This facilitates the transport of nutrient-rich runoff from forested upper slopes directly into paddy fields, maximizing the use of organic sediment (Kana et al., 2025).

3. Bamboo Drip Irrigation: In Meghalaya, perennial springs are tapped using bamboo pipes of varying diameters (Sherief, 2024). These pipes are used to divert water over long distances, delivering it to the base of plants via gravity a low-cost, indigenous precursor to modern drip irrigation.

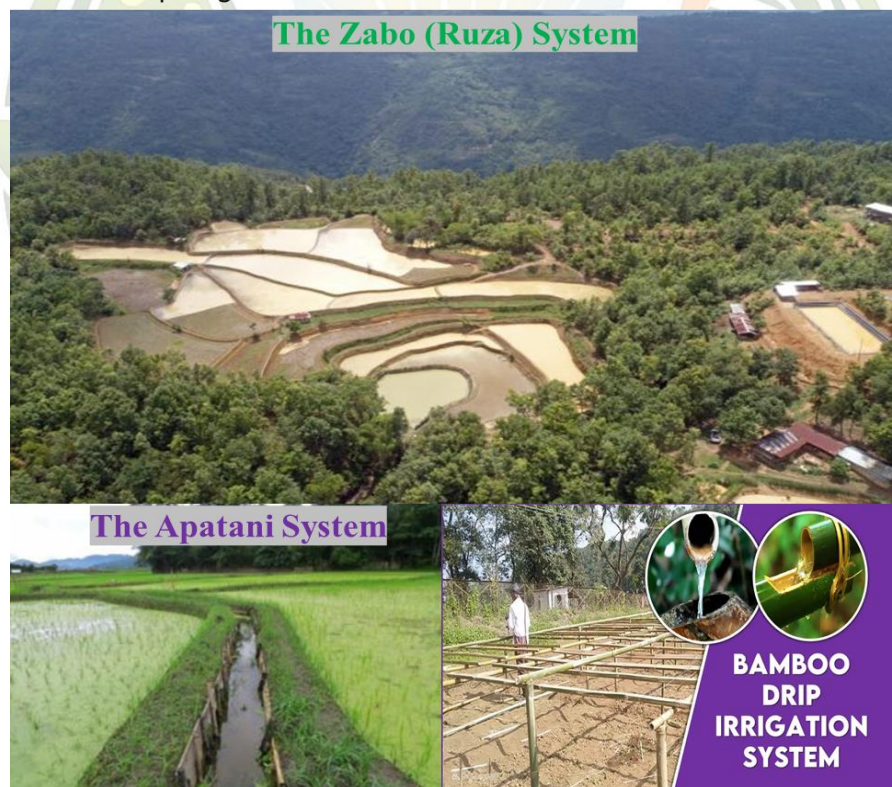


Figure 2 Traditional Indigenous Water Harvesting and Irrigation Systems of Northeast India

Arid Zone Mastery: Khadin, Johad, and Karez

In regions where annual rainfall is minimal (as low as 40mm), survival depends on the ability to capture extreme, episodic runoff as shown in Fig 3.

1. Khadin System: The Khadin system, developed in western Rajasthan, captures monsoon runoff from rocky upland catchments using an earthen embankment built across a valley. The stored water saturates the soil profile, enabling the cultivation of winter crops such as wheat and chickpea on residual moisture after the water recedes (Sharma, 2025.).

2. Johads: These crescent-shaped earthen check dams are built across the contours of hills to arrest surface flow and augment groundwater. The restoration of thousands of Johads in the 1990s in Alwar, India, is credited with raising the local water table by six meters and rejuvenating the once-dead Arvari River (*Johad*).

3. Karez and Qanats: Widely used in the arid Middle East and parts of South Asia, the Karez system consists of gently sloping underground tunnels that tap into the mother well of a distant aquifer. This allows water to be transported over kilometers with zero evaporation loss, providing a stable supply for irrigation in desert climates.



Figure 3. Indigenous Water Management Practices in Arid Regions: Khadin, Johad, and Karez

Dynamic Channel Management: Ahar-Pyne and Ghuls

In regions with gently sloping land and sandy soils, such as Bihar and the Western Himalayas, the challenge is not just capturing water but transporting it across the landscape without loss figure 4.

1. Ahar-Pyne System: This floodwater harvesting system consists of an "ahar" (a catchment basin enclosed on three sides by embankments) and a "pyne" (a diversion channel from a river). These pynes can be up to 20 kilometers long, irrigating crops along their path before storing excess water in the ahar for the post-monsoon season.

2. Ghuls: In the Himalayan region of Northern Uttaranchal and Himachal Pradesh, "ghuls" are stone-lined channels that tap mountain streams. These channels, ranging from 1 to 15 km in length, can carry discharges of 15 to 100 liters per second, providing critical water for terraced agriculture in steep terrain.



Figure 4 Ahar Pyne system in Gaya, South Bihar (Image courtesy: Hindi Water Portal)

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Combating Environmental Hazards through Balanced Fertilizer Use: A Cornerstone of Climate-Smart and Sustainable Agriculture

Article ID: 74037

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Feeding a global population projected to exceed 9.7 billion by 2050 while preserving environmental quality is one of the greatest challenges of the twenty-first century. Fertilizers have been instrumental in enhancing agricultural productivity and ensuring food security, particularly in countries such as India. However, India now consumes more than 60 million tonnes of fertilizers annually, and only 30-45% of the applied nitrogen is effectively utilized by crops. The remainder is lost through leaching, runoff, volatilization, and denitrification, leading to groundwater contamination, eutrophication, soil degradation, and increased greenhouse gas (GHG) emissions. Excessive nitrogen use, coupled with inadequate application of phosphorus, potassium, sulphur, and micronutrients, has further aggravated nutrient imbalances and reduced fertilizer-use efficiency. Agriculture occupies a unique position in the climate system as both a source and a sink of greenhouse gases. While the sector contributes nearly 14% of India's total GHG emissions, largely through nitrous oxide (N₂O) emissions from fertilized soils, it also has significant potential to sequester carbon through improved soil and nutrient management. Since N₂O has a global warming potential about 273 times greater than carbon dioxide, optimizing fertilizer use has become critical for climate change mitigation. Balanced fertilizer use offers a scientifically proven pathway to increase crop productivity, improve soil health, reduce environmental pollution, and strengthen climate resilience while supporting India's food security and Net Zero 2070 goals.

The Growing Challenge of Nutrient Imbalance

India is the world's second-largest consumer of fertilizers, with annual consumption exceeding 60 million tonnes. Fertilizer use remains heavily skewed toward nitrogen, with N:P: K ratios in several regions exceeding 10:4:1 compared to the recommended 4:2:1. This imbalance disrupts soil nutrient balance, reduces fertilizer-use efficiency, and has led to widespread deficiencies of phosphorus, potassium, sulfur, and micronutrients. Over time, such practices contribute to declining soil fertility, reduced soil organic carbon, and lower crop responsiveness to fertilizer inputs, threatening the sustainability of agricultural production systems.

Environmental Consequences of Imbalanced Fertilization

Climate Change and Greenhouse Gas Emissions: Excessive nitrogen fertilization is a major source of nitrous oxide (N₂O), a greenhouse gas with a global warming potential approximately 273 times greater than carbon dioxide. Agricultural soils emit N₂O through microbial nitrification and denitrification processes, which are intensified under surplus nitrogen conditions. In rice-based systems, improper nutrient management can also influence methane (CH₄) emissions, thereby increasing the overall global warming potential of agricultural production. Consequently, improving nutrient-use efficiency is a key strategy for reducing agriculture's climate footprint.

Water Pollution and Ecosystem Degradation: Nutrient losses through leaching and surface runoff transport nitrogen and phosphorus into water bodies, resulting in groundwater contamination and eutrophication. Elevated nutrient concentrations stimulate algal blooms, reduce dissolved oxygen levels, and disrupt aquatic ecosystems. Such nutrient pollution not only threatens water quality and biodiversity but also imposes significant ecological and economic costs on society.

Soil Degradation: Continuous application of nitrogen-dominated fertilizers like Urea without adequate replenishment of other nutrients accelerates soil degradation. Common consequences include:

- Soil acidification
- Nutrient mining
- Micronutrient deficiencies
- Decline in soil organic carbon
- Reduced microbial diversity

Over time, these changes decrease soil productivity and increase dependency on external inputs, creating a cycle of declining nutrient efficiency and rising production costs.

Balanced Fertilizer Use: A Sustainable Solution

Balanced fertilizer use involves supplying all essential nutrients in appropriate quantities, proportions, and timings according to crop demand and soil nutrient status. Rather than focusing solely on nitrogen, balanced fertilization ensures

adequate provision of phosphorus, potassium, sulfur, calcium, magnesium, and micronutrients. The concept aligns with the internationally recognized 4R Nutrient Stewardship framework (Figure 1)



These principles maximize nutrient uptake while minimizing losses to the environment. Balanced nutrition promotes healthier root systems, improved photosynthesis, greater resistance to abiotic stresses, and enhanced nutrient use efficiency. Scientific evidence consistently demonstrates that crops receiving balanced nutrient inputs produce higher yields while generating lower environmental footprints.

The Promise of Balance: Benefits for Yields, Environment, and Food Security

Balanced fertilizer management represents one of the most effective climate-smart agricultural practices available today.

- 1. Reduction in Greenhouse Gas Emissions:** Optimizing nutrient application reduces surplus nitrogen in soils and consequently lowers nitrous oxide emissions. Studies indicate that site-specific nutrient management can reduce fertilizer-related greenhouse gas emissions by 20-40% without compromising crop yields.
- 2. Enhanced Carbon Sequestration:** Balanced nutrition promotes vigorous crop growth and greater biomass production, increasing carbon inputs to soil. Improved root development and organic matter accumulation contribute to long-term soil carbon sequestration and improved soil health.
- 3. Improved Resilience to Climate Stress:** Nutrient-balanced crops exhibit greater tolerance to drought, heat stress, and erratic rainfall. Potassium, for example, improves water-use efficiency and strengthens plant defence mechanisms under adverse environmental conditions.
- 4. Economic Advantages for Farmers:** Environmental sustainability and economic profitability are often viewed as competing objectives. Balanced fertilizer use demonstrates that both goals can be achieved simultaneously.

Improved nutrient use efficiency translates into:

- a. Reduced fertilizer wastage
- b. Lower input costs
- c. Higher fertilizer response efficiency
- d. Increased crop yields
- e. Enhanced farm profitability

Balanced nutrient management also supports the performance of high-yielding and climate-resilient varieties, thereby strengthening food security and rural livelihoods.

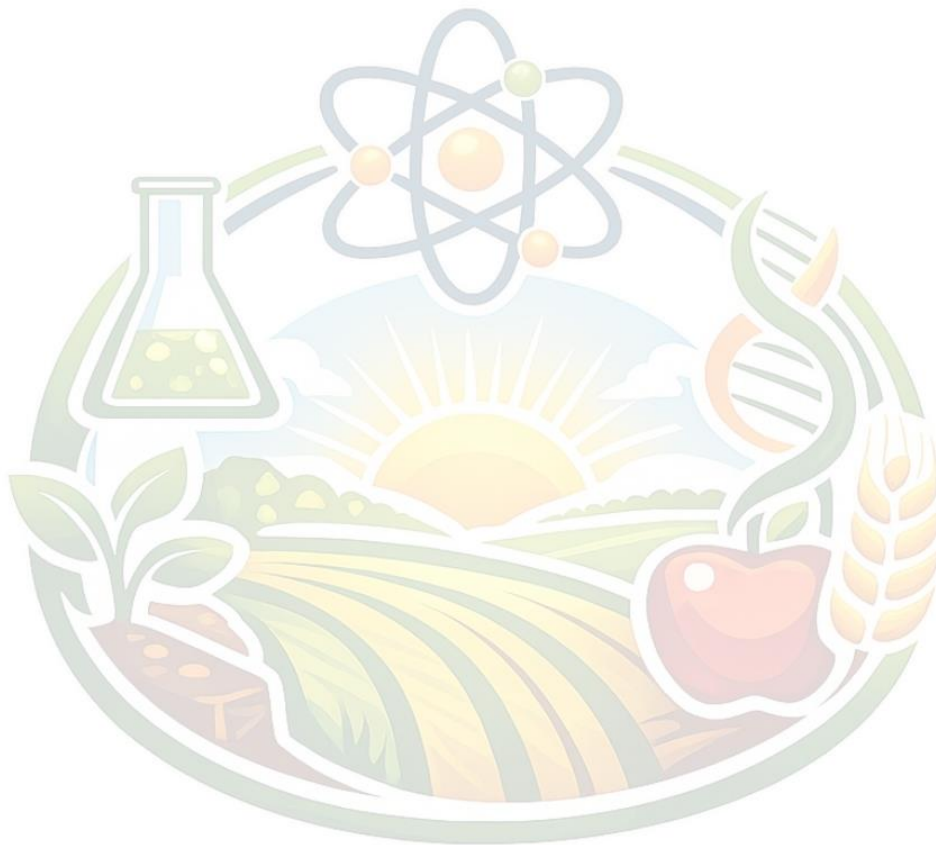
Challenges in Implementation and the Road Ahead

Transitioning to balanced fertilizer practices is not without obstacles. Small and marginal farmers, who constitute over 85% of India's farming community, often face limited access to soil testing labs, quality organic inputs, and technical knowledge. In intensively cultivated regions like Punjab, Haryana, and parts of Bihar, decades of heavy urea subsidies have created severe nutrient imbalances (highly skewed N:P:K ratios), groundwater contamination, and stagnating yields. However, successful models—such as Bihar's Soil Health Card campaign, custom hiring centers for precision equipment, and public-private initiatives promoting neem coated urea, biofertilizers etc. demonstrate that targeted support can overcome these barriers. Integrating digital advisory services, mobile apps, and carbon credit incentives for low-emission farming can make the shift inclusive, economically viable, and scalable across diverse agro-climatic zones.

Balanced fertilizer use is one of the most powerful tool available for combating environmental hazards while sustaining agricultural productivity. This can be achieved through coordinated action among policymakers, researchers, industry stakeholders, extension agencies, and farmers.

Highlight

1. Nitrous oxide is **273 times** more potent than CO₂.
2. India consumes **more than 60 million tonnes** of fertilizers annually.
3. Only **30-45%** of applied nitrogen is utilized by crops.
4. Balanced fertilization can reduce fertilizer-related emissions by **20-40%**.
5. Supports **Net Zero 2070**, **SDGs**, and **Viksit Bharat 2047** goals.
6. Improves yields, soil health, water quality, and farm profitability simultaneously.



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Integrated Makhana-Fish Cultivation: A Sustainable Approach for Enhancing Farm Income

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Abstract

Makhana (*Euryale ferox* Salisb.), popularly known as fox nut or gorgon nut, is an important aquatic crop cultivated predominantly in eastern India, particularly Bihar. Traditionally, makhana is grown in ponds and wetlands for seed production. However, integrating fish culture with makhana cultivation has emerged as an efficient and sustainable farming practice that enhances productivity and profitability from the same water body. In this integrated system, fish are reared beneath the floating canopy of makhana plants, allowing optimum utilization of pond resources. Fish contribute to nutrient recycling, weed suppression, and ecological balance while providing an additional source of income to farmers. The system offers several advantages, including increased resource-use efficiency, diversified farm income, reduced production risks, and improved livelihood security. This article highlights the principles, benefits, management practices, challenges, and future prospects of integrated makhana-fish cultivation as a climate-resilient and economically viable farming system.

Introduction

Makhana is one of the most valuable aquatic crops cultivated in India and is widely recognized for its nutritional and medicinal properties. Bihar contributes more than 80 per cent of the country's total makhana production and has become the centre of commercial cultivation. Makhana is traditionally cultivated in ponds, wetlands, and low-lying water bodies where a significant portion of aquatic resources often remains underutilized.



Figure 1. Makhana plant and edible popped makhana.

Integrated farming systems are increasingly being promoted to improve farm profitability and sustainability. Among these, integrated makhana-fish cultivation has gained considerable attention due to its ability to generate dual outputs from a single water body. In this system, fish utilize the water column below the floating makhana leaves, thereby enhancing biological productivity without adversely affecting crop growth. The system not only improves economic returns but also contributes to environmental sustainability through efficient nutrient cycling and resource conservation.

Major Components of Integrated Makhana-Fish Cultivation

The success of integrated farming depends on the compatibility of both enterprises and proper pond management.

1. Makhana Cultivation: Makhana plants grow on the water surface and produce seeds that are processed into popped makhana. The crop requires standing water and fertile pond conditions for optimum growth.

2. Fish Culture: Fish occupy different ecological niches within the pond ecosystem. Composite fish culture involving surface, column, and bottom feeders ensures efficient utilization of available food resources and pond productivity.



Figure 2. Integrated Makhana-Fish Cultivation system

Benefits of Integration

Integrated makhana-fish farming provides multiple benefits:

1. Better utilization of pond resources
2. Additional income through fish production
3. Improved nutrient recycling
4. Enhanced biological productivity
5. Reduced economic risk through enterprise diversification
6. Increased employment opportunities
7. Sustainable and eco-friendly farming system.

Suitable Fish Species for Integration

Composite fish culture is generally recommended because different species utilize different feeding zones of the pond ecosystem.

Table 1. Recommended Fish Species for Integrated Makhana Cultivation

RECOMMENDED FISH SPECIES FOR INTEGRATION			
	Fish Species	Feeding Habit	Role in Pond Ecosystem
	Catla	Surface feeder	Utilizes upper water layer
	Rohu	Column feeder	Utilizes middle layer
	Mrigal	Bottom feeder	Utilizes bottom resources
	Common Carp	Bottom feeder	Improves nutrient recycling
	Grass Carp	Herbivorous	Controls aquatic weeds
	Silver Carp	Plankton feeder	Utilizes plankton efficiently

Table 1. Recommended fish species for integrated makhana cultivation.

Management Practices

- 1. Pond Preparation:** The pond should be cleaned and desilted before cultivation. Excessive aquatic weeds should be removed and liming may be carried out based on soil and water conditions.
- 2. Stocking of Fish:** Healthy fish fingerlings of suitable size should be stocked after the establishment of makhana plants. Appropriate stocking density helps maintain pond productivity without creating competition for resources.
- 3. Feeding and Water Management:** Supplementary feed such as rice bran and oil cake may be provided to fish. Water quality, pond depth, and fish health should be monitored regularly to ensure optimum growth.
- 4. Harvesting:** Fish can be harvested periodically or at the end of the production cycle. Makhana seeds are collected from mature fruits and processed for popping and marketing.

Economic and Environmental Benefits

The integrated system provides significantly higher returns than sole makhana cultivation. Fish serve as an additional source of revenue and improve cash flow throughout the production cycle. Moreover, nutrient recycling by fish contributes to pond fertility and reduces waste accumulation.

Table 2. Comparative Advantages of Integrated Makhana-Fish Cultivation:

Parameter	Sole Makhana Cultivation	Integrated Makhana-Fish Cultivation
Resource Utilization	Moderate	High
Farm Income	Single source	Multiple sources
Production Risk	Higher	Lower
Employment Generation	Limited	Higher
Sustainability	Moderate	High

Challenges in Adoption

Despite its advantages, farmers face several constraints:

1. Limited availability of quality fish seed
2. Lack of technical knowledge regarding integrated management
3. Difficulty in harvesting fish under dense makhana cover
4. Inadequate extension support and training facilities

Addressing these challenges through training, demonstrations, and institutional support can enhance adoption among farmers.

Future Prospects

With increasing demand for both makhana and fish, integrated cultivation offers substantial opportunities for improving farm profitability and livelihood security. The system aligns with the principles of climate-smart agriculture and sustainable resource management. Promotion of this technology through extension programmes, farmer training, and policy support can contribute significantly to rural development.

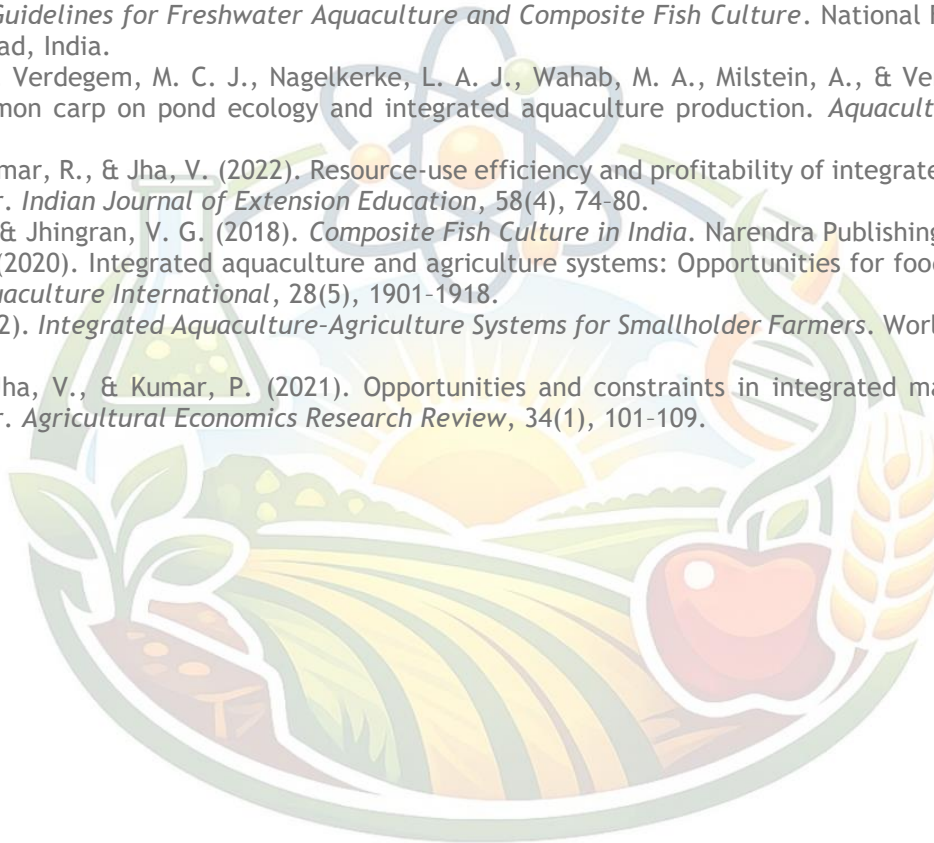
Conclusion

Integrated makhana-fish cultivation represents a profitable, resource-efficient, and environmentally sustainable farming system. By combining two complementary enterprises within the same pond ecosystem, farmers can maximize productivity, diversify income sources, and improve resilience against market and climatic uncertainties. Wider adoption of this integrated approach can play a crucial role in enhancing rural livelihoods, promoting sustainable aquaculture, and strengthening the makhana-based economy of eastern India.

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Nutrition Security and Livelihood Enhancement through Fruit Plantations

Article ID: 74039

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Abstract

Nutrition security and sustainable livelihood generation remain major challenges in developing economies, particularly in rural regions where malnutrition, underemployment, and income instability persist. Fruit plantations offer a dual solution by improving dietary diversity and generating long-term economic opportunities. Fruits are rich sources of essential vitamins, minerals, dietary fiber, and bioactive compounds that play a crucial role in preventing micronutrient deficiencies and non-communicable diseases. Simultaneously, fruit-based production systems provide stable income, employment, and scope for value addition due to their perennial nature and increasing market demand. This article examines the role of fruit plantations in enhancing nutrition security and livelihoods, highlighting their nutritional, economic, environmental, and social benefits. It also discusses policy support, institutional interventions, and strategic approaches required for effective implementation. The study emphasizes that nutrition-sensitive horticulture, supported by scientific management and market integration, can significantly contribute to sustainable rural development.

Keywords: Nutrition security, fruit plantations, livelihood enhancement, horticulture, sustainable agriculture, value addition.

Introduction

Nutrition security encompasses not only the availability of sufficient food but also access to safe, diverse, and nutrient-rich diets essential for a healthy and productive life. Despite progress in food grain production, malnutrition in the form of micronutrient deficiencies, anemia, and poor dietary diversity remains a major public health concern. This paradox highlights the need to shift focus from calorie-centric food security to nutrition-sensitive agricultural systems.

Fruit crops play a pivotal role in addressing this challenge due to their high nutritional value and adaptability across agro-climatic regions. In recent years, fruit plantations have gained importance as a sustainable agricultural enterprise capable of improving household nutrition while strengthening rural livelihoods. The integration of fruit cultivation with income generation, employment creation, and environmental sustainability makes it a strategic intervention for holistic rural development.

Role of Fruits in Nutrition Security

Fruits are widely recognized as “protective foods” because of their rich composition of essential nutrients. They are major sources of vitamins such as vitamin C (citrus, guava), provitamin A carotenoids (mango, papaya), and folates, along with minerals like potassium, calcium, and iron. Dietary fiber present in fruits improves digestive health and reduces the risk of lifestyle-related diseases. Horticulture is a key agricultural enterprise that provides nutrient security to rural, semi-urban, and urban populations. Fruits are rich sources of naturally available vitamins (A, B1, B12, C, E), minerals, dietary fibre, phytonutrients, carbohydrates, and antioxidants—often referred to as protective foods. The nutraceutical properties of coloured fruits also help reduce the risk of heart disease, anaemia, diabetes, and chronic ailments.

Fruit crops supply essential micronutrients that are often missing in the diets of economically weaker populations. According to the Indian Council of Medical Research (ICMR), the daily requirement of fruit is 100 g per capita, but only about 80 g per capita is available. Despite technological advancements in horticultural production, meeting the nutritional needs of an ever-growing population remains a major challenge. To bridge the gap between fruit availability and consumption, it is essential to establish fruit plants in backyard kitchen gardens, village common lands, schools, community and government areas, roadside plantations, and industrial zones. While space availability is often not a limitation, the lack of knowledge about proper planning, planting, and selection of geographically suitable cultivars is a significant drawback. In recent years, trends have been changing—both rural and urban populations are increasingly utilizing available space to grow fruit crops in kitchen gardens. The successful establishment of fruit trees in kitchen or nutrition gardens, ensuring year-round fresh and nutritious produce, ultimately depends on the size of the available plot.

Regular consumption of fruits enhances immune function, supports child growth, and helps prevent chronic conditions such as cardiovascular diseases, diabetes, and obesity. Promoting fruit plantations at household, community, and institutional levels ensures year-round access to fresh fruits, particularly in rural and tribal areas where market availability may be limited. Thus, fruit cultivation directly contributes to improved dietary diversity and nutrition security.

Fruit Plant Distribution and Terrace Gardening Promotion

SAGE University of Indore, through the Institute of Agricultural Sciences, promotes fruit plant distribution and terrace gardening as part of its extension and outreach activities to enhance nutritional security, environmental sustainability, and livelihoods in Madhya Pradesh. Fruit plants suitable for evergreen and deciduous crops are distributed during appropriate planting seasons through Kisan Melas, farmers' training programs, and university-led extension events, in collaboration with Krishi Vigyan Kendras, the State Department of Horticulture, and local agricultural agencies. Faculty members regularly conduct lectures, demonstrations, and field-level awareness programs to encourage kitchen gardening, terrace gardening, tube-well and boundary plantation, and the establishment of commercial orchards among farmers, students, and urban households, thereby strengthening sustainable horticulture practices in the region.

Vines can be grown on rooftops in large pots, boxes, or drums using basal spur-pruned varieties. In some cases, grapes are planted in backyard or roadside spaces, with the vine trained to grow onto rooftops, allowing for proper canopy development using the Bower or Y-trellis system.

Fruit Plantations as a Source of Livelihood Enhancement

Fruit plantations offer multiple livelihood benefits due to their long productive life, high value, and increasing domestic and export demand.

Income Stability and Economic Returns: Compared to seasonal field crops, fruit plantations provide higher and more stable returns once the orchards reach bearing stage. Crops such as mango, banana, citrus, guava, papaya, and pomegranate are economically viable and suitable for small and marginal farmers. The perennial nature of fruit crops ensures sustained income over several years, reducing vulnerability to market and climatic risks.

Employment Generation: Fruit cultivation is labor-intensive and generates employment throughout the year in activities such as nursery raising, planting, training and pruning, harvesting, grading, packaging, and marketing. This contributes to rural employment, reduces seasonal migration, and strengthens local economies.

Scope for Value Addition and Entrepreneurship: Post-harvest processing and value addition significantly enhance income from fruit crops. Processing fruits into juices, jams, jellies, pulp, dehydrated products, and pickles creates additional employment opportunities and promotes rural agro-industries. Women and rural youth can actively engage in processing, packaging, and marketing enterprises, thereby fostering inclusive growth and entrepreneurship.

Environmental and Sustainability Benefits: Fruit plantations contribute positively to environmental sustainability and climate resilience. Tree-based systems help in soil conservation by reducing erosion and improving soil organic matter. Fruit trees act as carbon sinks, contributing to climate change mitigation. Orchards also enhance on-farm biodiversity by supporting pollinators, birds, and beneficial insects. Adoption of resource-efficient technologies such as drip irrigation, mulching, and integrated nutrient management improves water-use efficiency and reduces production costs. Integration of fruit crops with agroforestry, intercropping, and organic farming further strengthens ecological sustainability while maintaining productivity.

Social and Community-Level Impacts: Fruit plantation initiatives generate significant social benefits when implemented at community and institutional levels. Household nutrition gardens improve family nutrition and reduce dependence on market-purchased fruits. School and Anganwadi fruit plantations support child nutrition programs while serving as learning platforms for nutrition education. Community orchards promote collective ownership, equitable access to nutritious food, and social cohesion. Participation of women through self-help groups in fruit production and processing enhances financial independence and decision-making power. Such initiatives contribute to awareness about balanced diets, sustainable agriculture, and health-oriented food choices.

Policy Support and Institutional Interventions: Government policies and institutional support play a critical role in promoting fruit plantations. National and state horticulture missions provide subsidies for planting material, irrigation systems, and infrastructure development. Capacity-building programs, farmer training, and promotion of Farmer Producer Organizations (FPOs) strengthen production and marketing capabilities. Academic institutions, research organizations, and extension agencies contribute by developing improved varieties, providing technical guidance, and disseminating best management practices. Collaboration among farmers, institutions, and policymakers is essential for scaling up fruit-based nutrition and livelihood initiatives.

while deciduous fruit plants are usually planted before the dormancy period ends or before the onset of new growth. Proper planning regarding irrigation channels, planting distance, and garden demarcation is essential. Pits measuring 1 m × 1 m × 1 m should be dug and filled with a mixture of equal parts topsoil and dry farmyard manure, along with 15 ml Chloropyriphos 20 EC in each pit to protect against white ants. After refilling, the pits should be irrigated to allow the soil to settle. The budded portion of the fruit plant should remain 6 to 9 inches above ground level, and plants should be supported with sticks for upright growth. Planting material must be procured from reliable nurseries of SAU/ICAR institutes, the state horticulture department, or accredited private nurseries, ensuring that the plants are budded or grafted on suitable rootstocks and free from pests, nematodes, and diseases. The trunks of young plants should be whitewashed with a mixture of 25 kg slaked lime, 500 g CuSO₄, and 500 g gum or *suresh* and dissolved in 100 l of water.

Eco-friendly measures such as non-woven bags, fruit fly traps, slippery bands for mealy bug control, and neem-based formulations should be adopted for pest and disease management. To conserve moisture and suppress weeds, paddy straw or plastic sheets may be used around plant basins. A fruit nutrition garden not only provides fresh produce and nutritional security but also helps save the expenses a family would otherwise incur on purchasing fruits from the market. During the pre-bearing stages, the vacant space between rows and plants can be used for growing annual fruit crops such as Cape gooseberry and strawberry, along with seasonal pulses and vegetables. Strawberries can be planted between rows at a spacing of 30 cm × 30 cm in September-October, with harvesting from December to March when fruits reach the pink or three-fourths coloured stage, ensuring they are picked with the cap or calyx and a small stalk of one to two inches.

Strategies for Effective Implementation

To maximize the impact of fruit plantations on nutrition security and livelihoods, the following strategies are recommended:

1. Selection of location-specific fruit crops based on agro-climatic suitability
2. Promotion of high-yielding, nutrient-rich, and climate-resilient varieties
3. Integration of fruit production with nutrition awareness and behavior change programs
4. Adoption of climate-smart and sustainable cultivation practices
5. Strengthening post-harvest management, value addition, and market linkages
6. Active involvement of women and youth through skill development and entrepreneurship

A participatory, nutrition-sensitive horticulture approach ensures long-term sustainability and wider adoption.

Challenges and Way Forward

Despite their advantages, fruit plantations face challenges such as long gestation periods, pest and disease pressure, post-harvest losses, and market price fluctuations. Limited access to credit, insurance, storage, and cold chain facilities further constrain profitability.

Addressing these challenges requires investment in research and development, improved extension services, access to institutional credit, crop insurance, and development of efficient supply chains. Digital platforms and farmer collectives can enhance market access and price realization. Aligning agricultural production with nutrition outcomes through policy and planning is essential for sustained impact.

Young plants should be irrigated as needed, depending on soil and climatic conditions, with a preference for using a drip irrigation system for efficient water management. It is advisable to remove dead wood, diseased branches, and intermingling shoots to promote healthy growth. Water shoots or suckers emerging below the bud union should be removed immediately. In deciduous fruit plants, training and pruning are essential to develop a strong framework. Branches should be oriented evenly in all directions, with the main stem headed back at a height of 75-90 cm from the ground. In the following year, 3-4 well-spaced shoots should be selected in different directions, maintaining a gap of 15-20 cm between them. The first shoot should be positioned about 45 cm above the ground. Phalsa plants should be trained in a bush form and pruned annually in January-February to a height of around 1 m from the ground level. Fruits should be ripened using indigenous, safe, and eco-friendly ripening technologies to ensure quality and consumer safety.

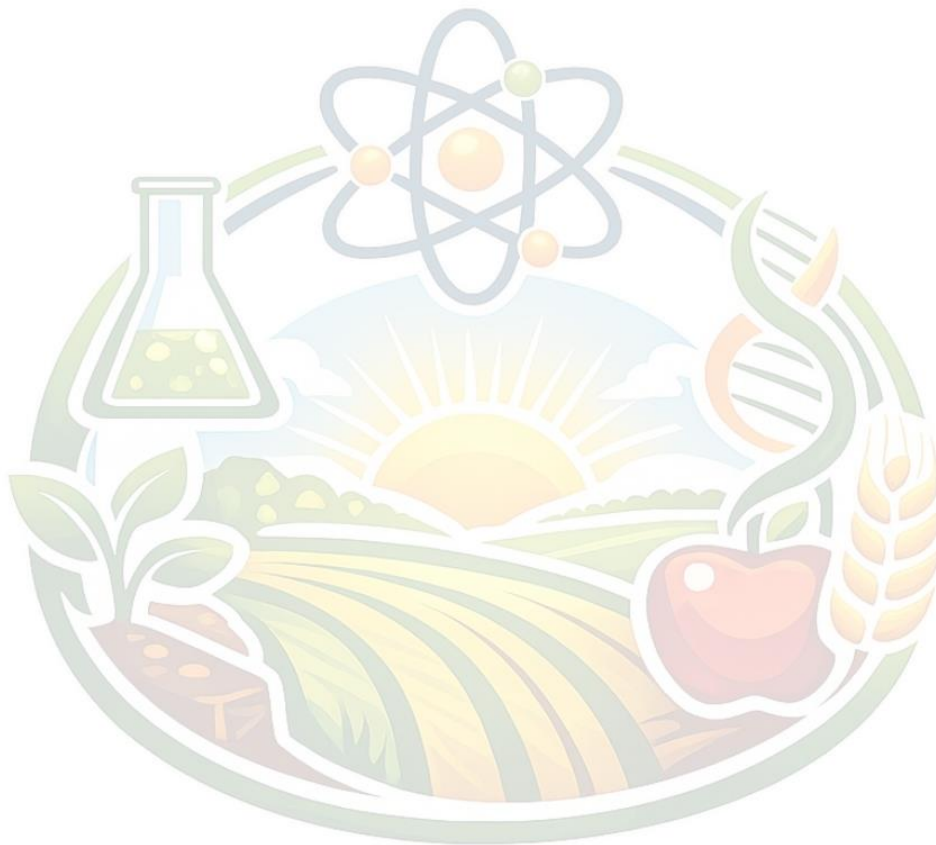
Conclusion

Fruit plantations represent a sustainable and effective pathway for achieving nutrition security and livelihood enhancement. By providing nutrient-rich foods and stable income opportunities, fruit-based farming systems address key challenges of malnutrition, poverty, and environmental degradation. Large-scale and community-based fruit plantation initiatives, supported by scientific management, policy backing, and institutional collaboration, can significantly contribute to improved health, economic resilience, and sustainable rural development. Strengthening nutrition-sensitive horticulture should therefore be priority in future agricultural and rural development strategies.

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Global Seed Market: The Backbone of Sustainable Agriculture & Food Security

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Introduction

The global seed market is the commercial sector aimed to the research, production, distribution and sale of plant seeds. The global seed market is becoming increasingly important in ensuring food security and sustainable farming. It includes agricultural crops, horticultural varieties and specialized genetically modified (GM) crops to supply farmers and agricultural enterprises with high quality and yield.

Recent Market Reports

According to IMARC Group - The global seed market size was valued at **USD 46.7 Billion** in 2025, and it's expected to reach **USD 53.2 Billion** by 2034, exhibiting a growth rate (CAGR) of 1.47% from 2026 to 2034

INDIA: The seed market size: **USD 8.6 billion**; **CAGR:9.68%** (2026-2034)

Major Countries in Global Seed Trade and their Share

Rank	Country	Share of global seed market value %
1	USA	25-30%
2	China	20-25%
3	France	5-7%
4	Brazil	5-6%
5	India	4-6%
6	Canada	4-5%
7	Japan	3-4%

Share of Various Crops in Global Seed Market

Crop	Market Share (%)	Market value (USD billion)
Cereal & grains	47-48%	33.95-34.75
Oil seeds & pulses	28-31%	20.12-22.30
Fruits & veg	15-17%	10.83-12.41
Other crops	6-7%	4.73-5.17%

Major International Institutes and Organizations involved in Global Seed Trade

1. ISF - International Seed Federation
2. FAO - Food and Agriculture Organization
3. OECD - Organisation for Economics Cooperation and Development
4. ISTA - International Seed Testing Association.

India's Role in Global Seed Market

India has been in 5th largest position in seed market globally. Being a significant exporter of vegetables with 15-17%, cotton with 6-8%, rice and millets with 47-48% and pulses with 28-31%. Country benefits from diverse agro climatic zones, a strong private seed sector increasingly in seed research and development. It's role in global seed market are:

1. Major seed producer
2. Large domestic seed industry
3. Global supplier of hybrid seeds
4. Contributing to food security
5. Research and development.

Potential benefits for developing countries:

- a. Expansion of seed production
- b. Growing demand for quality seeds
- c. Export potential
- d. Employment generation

e. Agricultural productivity improvement

f. Technology transfer like Bt, gene editing, breeding methods are involved

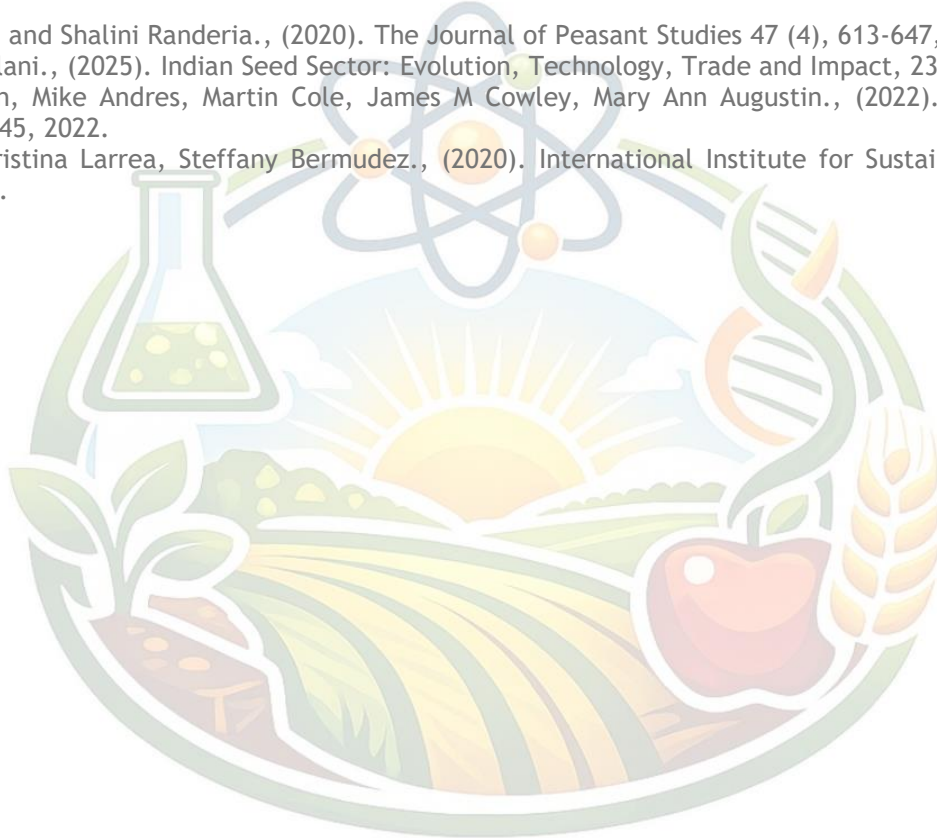
Speed breeding technique extends the photoperiods-controlled temperature and optimized growth condition to fasten the crop growth and reduce the generation time. Crops successfully used in speed breeding are Wheat, Rice, Barley, Chickpea, Pea, Canola and Lentil.

Conclusion

Global seed market plays vital role by providing high quality seeds that enhances crop productivity, food security, and agricultural sustainability. It will be continuing to meet the future food demands, needs and support sustainable agriculture growth with advances in breeding technologies, research and development.

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Commission for Agricultural Cost and Prices

Article ID: 74041

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Introduction

CACP is an advisory body of the Government of India that recommends Minimum Support Prices (MSP) for agricultural crops. It was originally established in the year 1965 as the Agricultural Prices Commission (APC). Later in 1985, APC was renamed as the commission for agricultural cost and prices (CACP). At present, it continues to recommend MSP's for major agricultural commodities like cereals, pulses, oilseeds, cash crops and sugarcane pricing is alone provided under the fair and remunerative strategy. CACP recommends prices for 23 important agricultural commodities as of now in 2026.

Need Behind CACP

India was facing major food shortages during 1960's. It was unable to produce enough food grains to meet the needs of its growing population (436 millions of people as per 1960 census) and mainly it was depending on the PL-480 PROGRAM (This program enables food -deficit countries to purchase to receive surplus American agricultural commodities on highly concessional or grant terms) from the United states. The government noticed the lack of confidence in farmers and wanted to boost it up. So in mid 1960's, India began introducing high yielding varieties of wheat and rice (Rice variety IR8 and wheat variety like Lerma roja 64) along with modern inputs. Adoption of these technologies also had put the farmers at financial burden. Farmers were caught in debt traps which lead them to suicidal thoughts. So, guaranteed support prices were needed to encourage the farmers especially a huge support was needed during the green revolution. So, the farmer saver tool MSP came in act and helped India move towards self sufficiency in food grains.

CACP is headed by Chairman (Senior agricultural economist / Expert) and includes one member secretary, one official member (Senior Gol bureaucrat) and two non - official members (represents farming community). The current chairman of CACP is Prof. Vijay Paul Sharma.

Mandates of CACP

The main functions carried out by CACP is to recommend Minimum Support Prices for major agricultural crops. Mainly, MSP acts as a price guarantee to farmers if market prices had fallen below a certain level. It helps in collecting and analyzing data on the cost of cultivating different crops across the states. CACP acts as advisory body for agricultural pricing issues. Demand and supply conditions are monitored for making realistic price recommendations. By recommending remunerative prices, the commission aims to protect both the farmer's livelihood and consumer's interests.

M. S. Swaminathan Committee on CACP

The M.S. Swaminathan committee (National farmer's commission) recommended major changes in the determination of MSP for farmers. The commission was headed by M.S. Swaminathan and this commission submitted 5 detailed reports during the period 2004-2005. It's main demand was to provide farmers with at least 50% additional profit over the cost of productoin as calculated by the committee on CACP.

Pricing Formula

$MSP = 1.5 \times (A2 + FL)$

A2 - Overall production cost

FL - Family labor cost

M.S. Swaminathan committee - MSP - (C-2 Method) - Recommendation

$MSP = 1.5 \times CC$

Comprehensive Cost = A2 + FL + Rental value of land + Interest in fixed capital.

CACP Success Stories

A notable success of the CACP can be seen in Punjab, often called as the "Granary of INDIA". With CACP's Minimum Support Price for wheat and paddy, farmers in Punjab received assured prices for their produce. This price security encouraged them to adopt high-yielding varieties of seeds, mechanized farming and modern agricultural practices during the green revolution. The Punjab experience is a successful example of how CACP's pricing policies can encourage

production, improve farmer welfare and strengthen national food security. In districts such as Ludhiana and Patiala, farmers significantly increased wheat and rice production through the MSP guaranteed by CACP.

Beneficiaries of CACP

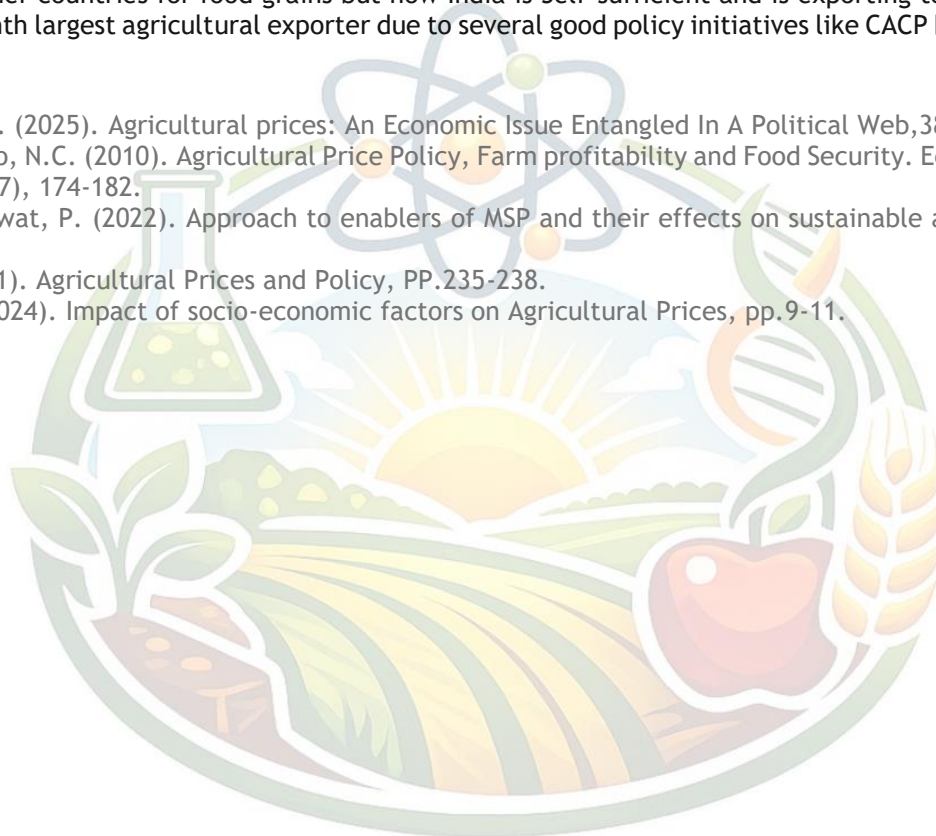
All stakeholders in agriculture are benefitted including Farmers livelihood protection, Consumers are assured with stable food supply at nominal price through scientific pricing recommendations from experts, Agricultural laborers are provided with increased employment opportunities, Input and agro- processing industries are also benefitted by regular inputs availability throughout the year.

Conclusion

Overall for everyone, CACP focuses on supporting the farmers to the consumers including the government. Each of them is benefitted on their own needs regarding the agro related products. CACP not only fixes the MSP but also supports the farmers emotionally and encourages them to move forward with much hopes. Once upon a time, India depended solely on Imports from other countries for food grains but now India is Self-sufficient and is exporting to global markets. Now India is globally eighth largest agricultural exporter due to several good policy initiatives like CACP by Indian government.

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Agricultural Schemes in India for Farmers & Rural Development

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Introduction

Agriculture plays a crucial role in India's economy and serves as the primary source of livelihood for a large share of the population. More than half of the country's people depend directly or indirectly on agriculture for their income and employment. While the sector contributes approximately 16-18% of India's Gross Domestic Product (GDP), its significance extends beyond economic output by ensuring food security and supporting rural development. India is also a leading producer of major agricultural commodities such as rice, wheat, pulses, fruits, milk, and spices, highlighting the sector's importance in sustaining the nation's growth and development.

Why Agriculture - Based Schemes Matters

These agricultural programmes help farmers enhance crop production, manage risks associated with farming, and improve their overall income. They encourage the adoption of modern technologies, sustainable agricultural methods, and the efficient utilization of resources such as water and soil. By supporting the growth of the agricultural sector, these initiatives play an important role in ensuring food availability, creating employment opportunities, reducing rural poverty, and promoting economic development. As a result, such schemes are essential for improving farmers' livelihoods and fostering the sustainable progress of rural communities in India.

Mandates of CACP

The main functions carried out by CACP is to recommend Minimum Support Prices for major agricultural crops. Mainly, MSP acts as a price guarantee to farmers if market prices had fallen below a certain level. It helps in collecting and analyzing data on the cost of cultivating different crops across the states. CACP acts as advisory body for agricultural pricing issues. Demand and supply conditions are monitored for making realistic price recommendations. By recommending remunerative prices, the commission aims to protect both the farmer's livelihood and consumer's interests.

List of Agricultural Schemes

1. Crop Production & Development:

- National Food Security Mission
- Soil Health Card
- Paramparagat krishi Vikas Yojana
- Mission for Integrated Development of Horticulture

2. Crop Insurance & Risk management:

- Pradhan Mantri Fasal Bima Yojana
- Restricted weather Based Crop Insurance scheme
- Kisan Credit Card

3. Machinery & Technology:

- Sub-mission on Agricultural Mechanization
- Namo Drone Didi Scheme
- Agricultural Infrastructure Fund

4. Marketing & Value addition:

- E-NAM
- Integrated Scheme for Agricultural Marketing
- Pradhan Mantri Annadata Aay Sanrakshan Abhiyan
- Mission for 10,000 FPOs

5. Food security & Processing:

- Pradhan mantri kisan Sampada Yojana
- PM POSHAN (formerly mid-day meal scheme)
- National Food Security & Nutrition Mission
- Pradhan Mantri Garib Kalyan Anna Yojana

Important Agricultural Schemes for Farmers in 2026

1. PM Kisan Scheme - Financial assistance for farmers: Under this programme, farmers receive ₹6,000 annually, which is transferred directly to their bank accounts through Direct Benefit Transfer (DBT) in three equal instalments of ₹2,000 each. This financial support helps farmers meet the costs of farming activities, such as purchasing seeds, fertilizers, and other agricultural inputs, while also assisting them in managing their day-to-day household expenses.

2. PMFBY - Protecting farmers against crop losses: PMFBY protects farmers from financial losses when crops are damaged due to natural disasters, pest attacks, or disease outbreaks.

- Provides financial protection against crop losses caused by natural calamities, pests, diseases, and adverse weather conditions.
- Covers losses at different stages of cultivation, including standing crops, prevented sowing, and post-harvest damage for up to 14 days after harvest.
- Farmers pay only:
 - 2% premium for Kharif crops
 - 1.5% premium for Rabi crops
 - 5% premium for commercial and horticultural crops
- The remaining premium cost is shared by the government.
- Helps reduce the financial burden on farmers and ensures income stability during crop failures.

3. Kisan Credit Card Scheme - Easy Farm Credit: It provides affordable and short - term credit to farmers. It supports agricultural growth, increases farmers income and promotes rural development.

How the Kisan Credit Card Helps Farmers

- Under the government's interest support programme, farmers can obtain short-term KCC loans of up to ₹5 lakh.
- The government offers an interest subsidy of 1.5%, reducing the lending rate to 7%.
- Farmers who repay their loans within the stipulated time receive an additional 3% incentive, lowering the effective interest rate to 4%.
- The scheme provides financial assistance not only for crop cultivation but also for animal husbandry, dairy farming, fisheries, and other allied agricultural activities.

4. SMAM Scheme - Promoting modern farm machinery: Sub-Mission on Agricultural Mechanization (SMAM) is a government initiative that encourages farmers to use modern agricultural equipment for better farm management. It offers financial support to purchase machinery and facilitates access to equipment through rental services. The scheme helps farmers complete agricultural operations more efficiently while reducing manual labour requirements. By making mechanization more accessible, it contributes to higher productivity and improved farm income.

- Farmers get financial support of 50 - 80% of the cost of machinery, depending on the type of farmers and areas.
- Reduce the need for manual labour, helping farmers cope with labour shortages.

5. PMKSY Scheme - Irrigation Development: PMKSY (Pradhan Mantri Krishi Sinchai Yojana) is a government initiative aimed at improving irrigation coverage and promoting the efficient use of water in agriculture. The scheme supports the creation and strengthening of irrigation facilities, including canals, check dams, and lift irrigation projects, to ensure reliable water availability for farming.

Objectives of the PMKSY Scheme:

- Enhance water-use efficiency through the "Per Drop More Crop" component, promoting the optimal use of available water resources.
- Help farmers save 30-50% of water while maintaining or improving crop productivity.
- Promote fertigation, where fertilizers are applied through irrigation systems, to improve nutrient utilization and crop quality.
- Improve agricultural output and farmers' income through better irrigation facilities and efficient water management practices.

6. e-NAM Scheme for Digital Agricultural Markets: The National Agricultural Market (e-NAM) is a digital trading platform that links farmers, traders, and agricultural markets across India, enabling farmers to receive better prices for their produce through a transparent marketing system. Introduced by the Government of India, the platform integrates existing Agricultural Produce Market Committees (APMCs) into a unified online marketplace. It allows farmers to sell their produce to buyers across different states, supporting the vision of "One Nation, One Market" and creating wider marketing opportunities for agricultural products.

Benefits of e-NAM for Farmers:

- Wider market opportunities:** Farmers can access a larger customer base beyond their local markets and connect with over 1.83 crore registered participants through 1,473 e-NAM integrated mandis across India.
- Fair and transparent pricing:** The Platform of Platforms (PoP) facilitates online bidding based on market demand, supply conditions, and produce quality, helping farmers secure fair prices.

c. Less reliance on intermediaries: The digital trading system minimizes the role of middlemen, enabling farmers to deal more directly with buyers and retain a greater share of their earnings.

d. Quick and transparent payments: Digital payment methods and Direct Benefit Transfer (DBT) systems ensure secure, timely, and transparent transactions for farmers.

7. Namo Drone Didi Scheme: The Namo Drone Didi Scheme is a central government initiative that aims to empower rural women by introducing them to modern agricultural technology. Under this scheme, 15,000 Women Self-Help Groups (SHGs) are provided with agricultural drones and training to operate them effectively. The programme helps women become skilled drone operators and service providers, enabling them to earn an additional income of around ₹1 lakh per year by offering drone-based services to farmers. The scheme also promotes the use of precision farming techniques, making agriculture more efficient and technology-driven.

Benefits of Namo Drone Didi Scheme:

a. Financial assistance for drone adoption: The government offers an 80% subsidy, up to ₹8 lakh, to support eligible SHGs in purchasing drones and related accessories.

b. Skill development and training: Beneficiaries receive 15 days of specialised training, covering drone operation, pilot certification, and agricultural applications to ensure effective use of the technology.

c. Improved precision in farming: Drones enable uniform spraying of fertilizers and crop protection chemicals, reducing wastage, improving efficiency, and lowering health risks associated with manual spraying.

d. Strong institutional support: Lead Fertiliser Companies (LFCs) provide assistance with drone procurement, maintenance, and the supply of nano-fertilizers, helping ensure the smooth functioning of the scheme.

Success Stories

Agricultural schemes in India have played a major role in strengthening the agricultural sector by providing financial support, improving infrastructure, and promoting the use of modern technologies. Programmes such as the Soil Health Card Scheme have helped farmers use fertilizers more efficiently, leading to lower input costs and improved crop yields. The Agricultural Infrastructure Fund (AIF) has supported the development of essential post-harvest facilities, including warehouses and cold storage units, through large-scale investments. These efforts have contributed to record food grain production of 332.3 million tonnes and increased government investment in agriculture, with the agricultural budget reaching nearly ₹1.27 lakh crore. Higher Minimum Support Prices (MSP) for major crops such as paddy and wheat have also improved farmers' earnings. Over the past decade, substantial payments through MSP procurement have provided income support to millions of farmers. Overall, these initiatives have enhanced farm productivity, strengthened food security, increased rural incomes, and supported the growth of India's agricultural economy.

Conclusion

Agricultural schemes are essential for the development of India's farming sector and the welfare of rural populations. Initiatives such as PM-Kisan, PMFBY, Kisan Credit Card (KCC), PMKSY, and e-NAM provide farmers with financial support, crop insurance, improved irrigation facilities, and better marketing opportunities. These programmes help farmers adopt modern agricultural practices, increase productivity, and manage farming-related risks more effectively. Through sustained government efforts, these schemes strengthen food security, improve rural livelihoods, and contribute to economic progress of the country.

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The Hidden Battle in Seed Storage: Minuscule Pests and Mighty Problems

Article ID: 74043

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Introduction

Tiny pests can create big trouble in stored seeds. Storage of seeds are one of the most valuable aspects of agriculture, more so than storing grain for feed or consumption. Storing of seeds is crucial because unlike edible grains, seeds require intactness, viability and the potential to germinate, usually for a span of months or even years. Lack of an easy means to inspect the storage containers also adds to the problem because different types of seeds are usually stored in small boxes, bags or small containers. Furthermore, seeds are often transported across long distances add risk to pest dissemination.

Storage Pests

In certain types of pest attack, parts of the seed are eaten by both the secondary insects and the mite pests, by feeding either on the seed germ which contains vital nutrients for seed formation or by carving tiny tunnels which leads to a weakened seed and low market value of planting material. The storage pests are classified into two groups depending on how they damage seeds.

Primary feeders: Primary feeders are capable of penetrating and eating the inside of intact and healthy seeds.

Primary feeders	Scientific name	Grain / yield loss
Internal		
Rice weevil	<i>Sitophilus oryzae</i>	5-21%
Lesser grain borer	<i>Rhyzopertha dominica</i>	6-28%
Pulse beetle	<i>Callosobruchus chinensis</i>	1-10%
External		
Khapra beetle	<i>Trogoderma granarium</i>	Upto 75% if long term
Warehouse moth	<i>Ephestia cautella</i>	1-26%

Secondary feeders: Secondary pests cannot attack sound, undamaged grains. They feed exclusively on broken grain, dust, mold or grains that have been already bored by primary pests.

Secondary feeders	Scientific name	Grain / yield loss
Saw toothed grain beetle	<i>Oryzaephilus surinamensis</i>	10-15%
Flat grain beetle	<i>Cryptolestes minutus</i>	1-2.5%
Grain mite	<i>Acarus siro</i>	2-20%

Rodents, mites and insects represent some of the most damaging storage pests. Rodents can damage virtually all storage seeds, especially those stored in bags and piles, whereas mites and psocids commonly damage grass and vegetable seeds through seed quality reduction and lowered germination.

Some major rodent pests are

- Lesser bandicoot (*Bandicota bengalensis*)
- Indian field mouse (*Mus booduga*)
- Rat (*Rattus Rattus*, *Rattus melta*)

Some mites cause extreme seed germinability reduction, while psocids cause damage leading to significant weight loss. Many storage products insects like some beetle species (weevils, flour beetles) and moths are pests of cereals or grains, (wheat, barley, maize).

Storage Methods and Techniques

Using adequate storage methods, seed producers can maintain the quality of their planting material for future use. Preparing the seeds for storage before storing seeds by removal of unwanted materials such as dust, chaff, damaged seeds and infested seeds; reduce their moisture content to an acceptable level (12% for starchy seeds and 9 % for oil-rich seeds). This helps to prevent the development of fungi and store for longer period.

Proper Storage Container

Selecting a suitable container for storage of seeds plays an important role in maintaining seed quality and viability.

Where there is an availability of adequate humidity control, it may be possible to use paper packets but a much safer option for prolonged storage are moisture and airtight storage containers.

The properties of suitable container should be:

- Air tight & durable
- Economical
- Ease of use
- Non-conductors of heat
- Moisture resistance containers like metal bins, glass jars, aluminum cans with properly fitting gaskets.

It is advisable to store only dry seeds in sealed metal bins with loosely fitting lids.

Good Maintenance of Storage

Storage place must also be well-maintained to offer maximum protection from undesirable factors. Storage room must be easily accessible for loading and unloading; it must be clean, dry and also free from termites, rodents and moulds. Floor and walls must be water resistant. No cracks or openings in the storage room must be available because pests may reside in them.

Botanical Plants for Pest Management in Stored Seeds

Common botanicals utilized for stored product pest management include::

Botanicals	Active compound	Mode of action
Neem	Azadirachtin, salannin	Antifeedant
Sweet flag	Beta asarone	Insecticidal, repellent against storage insects like the rice weevil and pulse beetle.
Turmeric	Curcumin	Suppresses feeding
Pyrethrum	Pyrethrins	Contact insecticide
Eucalyptus, Garlic, Lemongrass, Celery	Essential Oils	Strong vapours deter pests from infesting storage bins

Early detection of pests in storage facilities are essential to minimize damage to the stored seed/grain stocks. Some common types of traps developed by TNAU, Coimbatore, commonly used in storage facilities includes:

TNAU Insect Probe Trap: This trap is inserted vertically into grain or seed bags. Insects are attracted towards air and enter the trap through small openings. They then fall into a detachable collection cone at the bottom. The trapped insects can be removed weekly. The trap is highly effective and can eliminate up to 80% of insects within 10-20 days of storage.

TNAU Pit Fall Trap: The pit fall trap has a perforated top and a cone-shaped bottom coated with sticky material. When insects enter through the small holes, they become stuck inside the trap. It is easy to use and suitable for monitoring insect activity in stored grains.

TNAU 2-in-1 Trap: This trap is specially designed for controlling pulse beetles. It consists of a perforated tube, collection chamber, and cone-shaped trap. The design helps attract, capture, and collect insects effectively, thereby reducing pest damage during storage. The use of these traps provides an eco-friendly and efficient method for protecting stored seeds and grains from insect infestation.

Core Environmental Principles of Seed Storage

The golden rule of seed storage is Harrington's Rule of Thumb, which states that halving the seed moisture content or dropping the storage temperature by 5.6°C (10°F) will double the lifespan of the seed.

Moisture Control: Seeds are naturally hygroscopic. Modern storage requires reducing seed moisture content to generally 4-6%. This is achieved using desiccant dryers or vacuum ovens before sealing.

Temperature Control: Storage temperatures vary based on the intended duration:

- Short-term (1-5 years):** Climate-controlled rooms kept at 5°C to 15°C.
- Medium-to-Long-term:** Sub-zero temperatures, often at -18°C to -20°C.
- Cryogenic (Infinite-term):** Vapor phase of liquid nitrogen at -150°C to -196°C.

Modern Storage Structures

Depending on the scale from local farming to global seed vaults different physical mechanisms are utilized:

1. Hermetic & Vapor-Proof Containers: For medium-term storage, seeds are vacuum-sealed in multi-layer foil/plastic pouches or stored in airtight metal drums (e.g., Pusa bins) with polyethylene barriers to prevent humidity swings.

2. Automated Cold Storage Facilities: Commercial and governmental seed depots (like those managed by the FAO or various national agricultural bodies) use warehouse racking inside massive cold-chain rooms. These often feature integrated monitoring sensors, RFID tagging for FIFO (first-in, first-out) inventory, and dehumidifiers.

3. Industrial Silos & Bins: For bulk agricultural seeds, large steel or aluminum bins are fitted with ventilation systems to control temperature and prevent fungal growth.

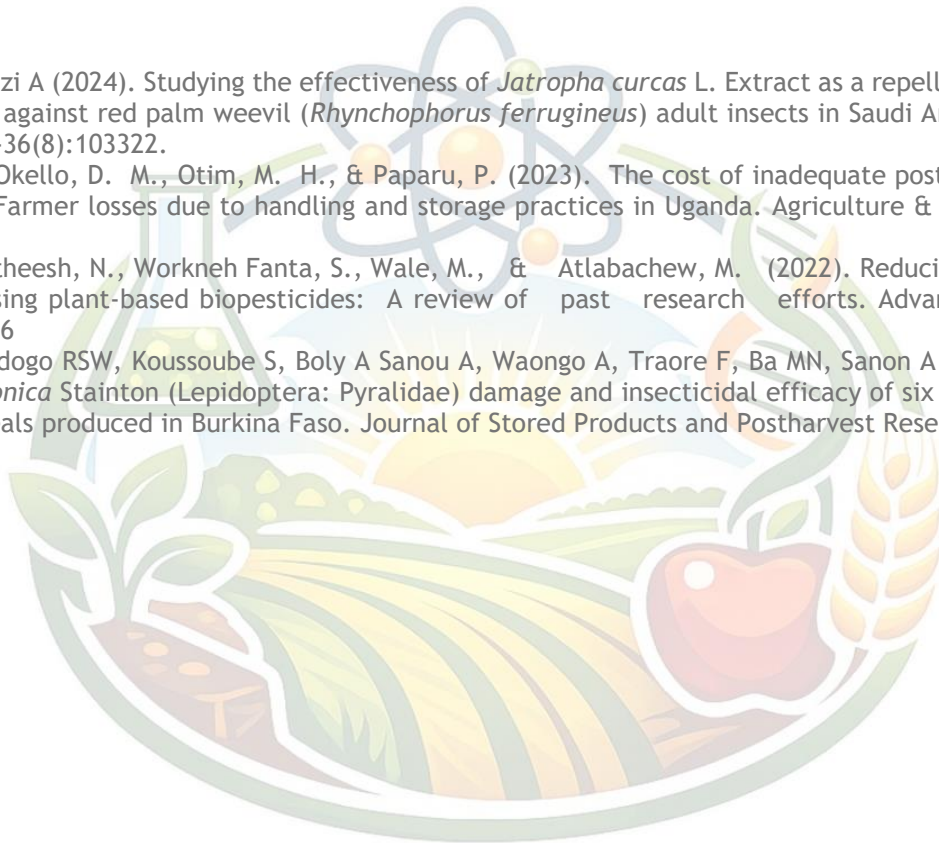
4. Cryogenic Repositories: Used for valuable germplasm and rare plant species. Seeds are flash-frozen and submerged in the gaseous phase of liquid nitrogen. At these temperatures, metabolic reactions come to a virtual standstill.

Conclusion

Maintaining seed quality during storage requires careful attention to moisture management, cleanliness, storage infrastructure and pest control. Traditional practices such as neem-based treatments and herbal fumigation offer cost-effective and environmentally safe solutions for protecting seeds. By integrating these methods with proper storage conditions, farmers can significantly improve seed longevity and safeguard their planting material for future use.

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Sustainable Farming in Indian Alfisols

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Introduction

Many farmers in India grow crops on red soil that depends mainly on rain. Alfisols, commonly referred to as red soils, occupy a significant portion of India's dryland agricultural regions, particularly across South India. These soils, though well-drained and suitable for a variety of crops, have historically been constrained due to low soil organic carbon (SOC), poor nutrient retention and susceptibility to degradation under continuous conventional farming. Prior to the adoption of sustainable farming practices, many Alfisol-dominated drylands exhibited critically low SOC levels, often ranging between 0.2- 0.4%, alongside widespread deficiencies in both essential nutrients such as nitrogen, phosphorus, and micronutrients like zinc and boron. These limitations resulted in low productivity, poor water-holding capacity, and declining soil health. This article is intended to show the ways for farmers to get good results by use the right crop/variety choice, efficient water utilization, rainwater harvesting, improving soil health and adopting low-cost farming methods.

Understanding Sustainable Farming

Sustainable farming refers to an integrated approach of agriculture that aims to meet present food and fiber needs without compromising the ability of future generations to meet their own requirements. It is built on the principles of environmental conservation, economic viability and social responsibility. In contrast to conventional farming systems that often rely heavily on chemical inputs and intensive tillage, sustainable farming emphasizes the efficient use of natural resources while maintaining ecological balance. At its core, sustainable farming focuses on improving soil health, enhancing biodiversity and optimizing resource use efficiency.

Storage Methods and Techniques

Using adequate storage methods, seed producers can maintain the quality of their planting material for future use. Preparing the seeds for storage before storing seeds by removal of unwanted materials such as dust, chaff, damaged seeds and infested seeds; reduce their moisture content to an acceptable level (12% for starchy seeds and 9 % for oil-rich seeds). This helps to prevent the development of fungi and store for longer period.

Strategies for Sustainability

Achieving sustainability in Alfisols (red soils) of dryland regions requires a combination of scientific soil management, efficient resource utilization and supportive policy frameworks. These soils are inherently low in organic matter and nutrient-holding capacity; therefore, long-term sustainability depends on adopting integrated and climate-resilient farming

1. Integrated Nutrient Management (INM): A key strategy for improving Alfisol productivity is the balanced use of organic and inorganic inputs. Application of farmyard manure, compost, green manure, crop residues, and biofertilizers enhances soil organic carbon content and microbial activity. At the same time, judicious use of chemical fertilizers ensures immediate nutrient availability. Government initiatives promoting INM, such as the Soil Health Management component under the Soil Health Card Scheme, help farmers to apply nutrients based on soil testing results, preventing overuse and restoring soil fertility.

2. Organic Farming and Bio-input Use: Transitioning to organic farming is a major pathway towards sustainability in Alfisols. Practices such as vermicomposting, use of biofertilizers and botanical pesticides reduce dependency on synthetic inputs and improve soil structure. The Paramparagat Krishi Vikas Yojana (PKVY) supports this transition by providing financial assistance of about ₹31,500-₹50,000 per hectare over three years for organic inputs, certification and marketing. Additionally, subsidies of up to 25% of project cost are provided for setting up of biofertilizer and biopesticide production units, encouraging local availability of sustainable farm inputs.

3. Conservation Tillage and Residue Management: Minimum tillage and residue retention helps to prevent soil erosion, a major issue in Alfisols due to their loose structure. Conservation practices improves soil aggregation, moisture retention, and carbon sequestration. Retaining crop residues also contributes to gradual nutrient recycling and enhances soil organic carbon levels over the time.

4. Efficient Water Management: Dryland Alfisols are highly dependent on rainfall, making water conservation essential. Techniques such as contour bunding, farm ponds, mulching, and micro-irrigation systems significantly improve water-

use efficiency. The Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), particularly the “More Crop Per Drop” component, provides subsidies for drip and sprinkler irrigation systems, enabling efficient water utilization in dryland farming.

5. Agroforestry and Crop Diversification: Integrating trees with crops (agroforestry) improves soil fertility, reduces erosion and provides additional income sources. Crop diversification with pulses, oilseeds, and drought-tolerant crops enhances resilience and reduces risk in rainfed Alfisols. Government support through the Sub-Mission on Agroforestry (SMAF) promotes tree-based farming systems as part of sustainable agriculture.

6. Climate-Resilient Farming Practices: Sustainable farming in Alfisols must address climate variability. Practices such as drought-resistant crop varieties, intercropping and rainwater harvesting improve resilience. The National Mission for Sustainable Agriculture (NMSA) supports these approaches through programs like Rainfed Area Development and On-Farm Water Management.

7. Government Incentives for Reduced Chemical Use: Recent initiatives such as the PM-PRANAM scheme encourage farmers to reduce chemical fertilizer use by offering incentives linked to savings in fertilizer subsidies. This promotes the adoption of organic and alternative nutrient sources, thereby improving soil health in the long term.

Sustainable Farming Practices

On dryland red soils, farmers should not depend on only one crop or only one methodology. A combination of practices works best. These are the practices that farmers can follow in simple terms.

1. Summer Ploughing: Summer ploughing involves deep tillage during the hot months (April-May). This practice helps in breaking hard soil layers, improving aeration and enhancing water infiltration during the monsoon. It also exposes soil-borne pests, weed seeds and pathogens to high temperatures, thereby reducing their population naturally. In Alfisols, which are prone to crusting and compaction, summer ploughing significantly improves root penetration and moisture conservation.

2. Tied Ridges and Mulching: Tied ridging is a moisture conservation technique where cross-ties are created across ridges to hold rainwater in small basins. This reduces runoff and increases water infiltration in dryland Alfisols. Mulching, using crop residues or organic materials, further conserves soil moisture, reduces evaporation losses, controls weeds and moderates soil temperature. Together, these practices improve water-use efficiency and support crop growth under limited rainfall conditions.

3. Intercropping: Intercropping involves growing two or more crops simultaneously in the same field, such as millets with pulses or groundnuts with red gram. This practice enhances resource use efficiency, reduces risk of crop failure and improves soil fertility through biological nitrogen fixation by legumes. In Alfisols, intercropping systems help to maintain soil cover, reduce erosion and increase overall farm productivity.

4. Green Manuring: Green manuring involves growing specific crops like sunhemp or dhaincha and incorporating them into the soil during flowering. This practice enriches the soil with organic matter and improves soil structure, microbial activity and nutrient availability. In nutrient-deficient Alfisols, green manuring can significantly enhance the soil organic carbon and nitrogen content.

5. Application of Organic Waste Compost: The use of farmyard manure, compost and other organic wastes is essential for restoring soil health in Alfisols. Organic amendments improve the soil structure, increase water-holding capacity and supply essential nutrients in a slow-release form. Regular application can gradually increase SOC levels and enhance microbial diversity, making soils more resilient and productive.

6. Low-Cost Drip Irrigation: Low-cost drip irrigation systems are highly beneficial for dryland Alfisol regions where water availability is limited. These systems deliver water directly to the root zone, minimizing losses due to evaporation and runoff. They improve water-use efficiency up to 40-60% and support better crop growth even under moisture stress condition. Affordable innovations, such as gravity-based drip systems, make this technology accessible to small and marginal farmers.

Latest Improved Varieties

TNAU varieties:

- Groundnut short duration varieties (95-105 days) **VRI 6** and **VRI 10** are highly drought-tolerant and well-adapted to red lateritic soils.
- Blackgram Short duration varieties (70-75 days) **VBN 6** and **VBN 12** have high resistance to root-rot and tolerance to moisture stress.
- Sorghum varieties **K 12** and **CO 30** are deep-rooted C4 crops that are highly resilient to dry spells provides both grain and quality fodder.

IARI varieties:

- Pusa JG 16 (chickpea):** A climate-smart, drought-hardy variety developed using genomic-assisted breeding. It transfers drought-tolerant traits into the plant, helping it survive terminal drought conditions common in India.

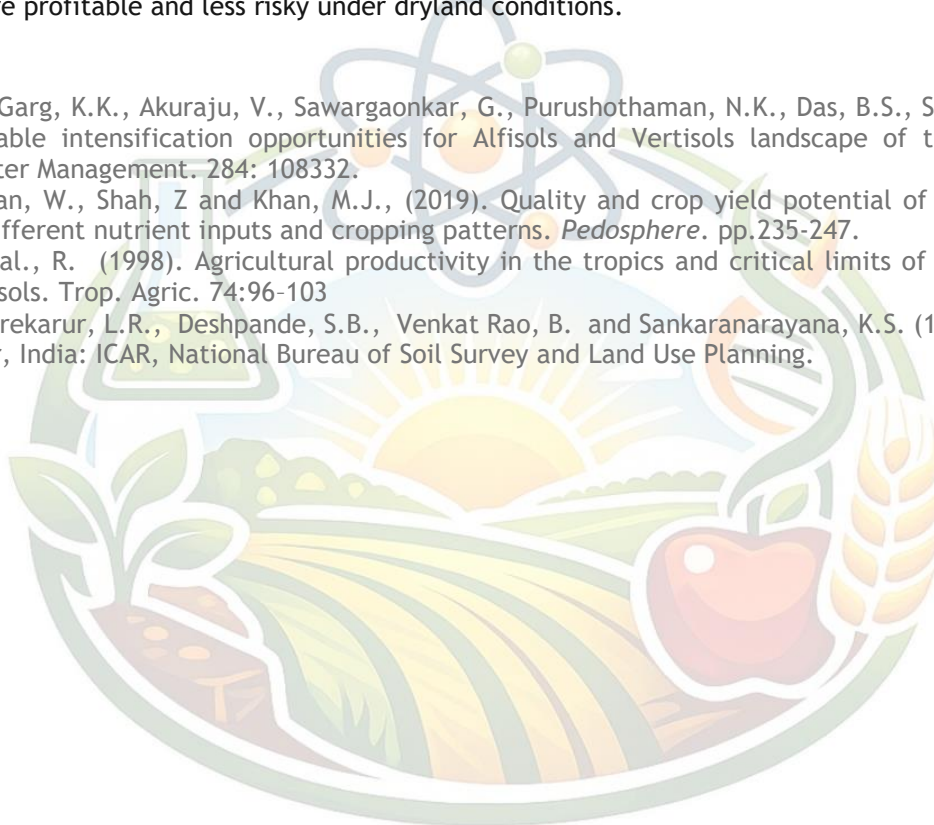
b. Pusa Mustard 34 (Mustard): A low erucic acid variety that thrives in semi-arid environments. It is resilient and well-suited to the moisture -retaining limitations of red soils.

Conclusion

The transformation of Alfisols through sustainable farming practices clearly demonstrates that these traditionally low-fertility red soils can be revitalized into productive and resilient agricultural systems. Long-term adoption of practices such as organic amendments, intercropping, mulching and efficient water management has led to significant improvements in soil health. Studies indicate that soil organic carbon (SOC) levels in Alfisols have increased by 30-70%, rising from critically low levels of about 0.2-0.4% to nearly 0.6-0.9% in well-managed systems. Similarly, improvements in soil attributes such as water-holding capacity (20-40%), microbial activity (25-50%), and nutrient availability—especially nitrogen and phosphorus (20-45%) have contributed to enhanced soil productivity and sustainability. From an economic perspective, sustainable farming has proven beneficial for farmers by reducing dependency on costly chemical inputs and improving yield stability. Crop yields in Alfisol regions have increased by 25-50%, while input costs have decreased due to the use of locally available organic resources. This has resulted in a 15-30% increase in net farm income, making farming more profitable and less risky under dryland conditions.

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Seed Borne Mycoflora of Cereal Crops - Detection and Management

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Introduction

Cereal crops are affected by seed-borne fungi that reduce seed quality, germination, and yield. Major pathogens include *Aspergillus*, *Fusarium*, and *Alternaria*. Early detection and effective management are essential for healthy crop production.

Seed Borne Mycoflora of Major Cereal Crops

Several fungal species are commonly associated with cereal seeds. The most important genera include: *Aspergillus flavus*, *Aspergillus niger*, *Alternaria* spp, *Fusarium* spp, *Curvularia* spp, *Bipolaris* spp, *Penicillium* spp, *Rhizopus* spp, *Trichoderma* spp, *Pythium* spp. Among these, *Aspergillus flavus* and *A. niger* are considered the most destructive storage fungi due to their ability to reduce seed quality and produce harmful mycotoxins.

Important Seed Borne Fungal Diseases

Crop	Disease	Pathogen	Yield Loss	Reference
Wheat	Loose smut	<i>Ustilago tritici</i>	5%	Kumar et al., (2023).
	Karnal bunt	<i>Tilletia indica</i>	0.3% - 1%	
	Stinking smut	<i>Tilletia foetida</i> and <i>T. caries</i>	1 - 7%	
	Seedling blight	<i>Leptosphaeria nodorum</i>	15% - 28%	
	Black point	<i>Alternaria tritici</i>	-	
	Head blight	<i>Fusarium semitectum</i>	0.29%	
Rice	Stack burn	<i>Alternaria padwickii</i>	-	Harborne J.B., (1998).
	Brown spot	<i>Bipolaris oryzae</i>	4% - 5%	
	Bakanae	<i>Fusarium moniliforme</i>	15% - 50%	
	Blast	<i>Magnaporthe/Piricularia oryzae</i>	30% - 70%	
	Kernel smut	<i>Tilletia barclayana</i>	15%	
	Sheath blight	<i>Rhizoctonia solani</i>	20% - 50%	
	Sheath rot	<i>Sarocladium oryzae</i>	10% - 85%	
	False smut	<i>Ustilaginoidea virens</i>	3% - 75%	
Maize	Leaf blight	<i>Bipolaris maydis</i>	15% - 70%.	Jirak-Peterson and Esker (2011).
	White streak	<i>Fusarium moniliforme</i>	Up to 100%	
	kernel rot	<i>Fusarium verticillioides</i>	-	
	Downy mildew	<i>Peronosclerospora maydis</i>	40% - 60%	
Sorghum	Grain smut	<i>Sporisorium sorghi</i>	10% - 80%	Owolade et al., (2011).
	Loose smut	<i>Sporisorium cruentum</i>	15% - 45%	
	Anthracnose	<i>Colletotrichum sublineola</i>	30% - 80%	
	Ergot	<i>Claviceps africana</i>	10% - 80%	
	Grain mold complex	<i>Fusarium</i> and <i>Curvularia</i> species	30% - 100%	

Mechanism of Seed Infection

Seed infection may occur at any stage from ovule formation to seed maturity. Fungal spores germinate and penetrate plant tissues, eventually reaching developing seeds. Two major groups of fungi are involved:

Biotrophic Fungi:

- Depends on living host tissues.
- Cause less visible damage initially.
- Often penetrate deeply into seed tissues and embryos.

Necrotrophic Fungi:

- Kill host cells using enzymes and toxins.
- Cause severe tissue damage.
- Usually remain confined to outer seed tissues.

Detection of Seed Borne Fungi

Conventional Detection Methods:

1. Standard Blotter Method:

- Seeds are incubated on moist blotter paper.
- Fungal growth emerging from seeds is examined microscopically.
- Simple and widely accepted method.

2. Agar Plate Method:

- Seeds are plated on Potato Dextrose Agar (PDA).
- Provides better fungal growth and identification.
- Reported as the most effective method for detecting cereal seed mycoflora.

3. Rolled Towel Method:

- Used to evaluate seed germination and seedling vigour.
- Helps identify fungi associated with abnormal seedlings.

4. Deep Freeze Method:

- Particularly useful for detecting slow-growing pathogens.
- Enhances visibility of several seed-borne fungi.

Recent Trends in Detection of Seed Borne Fungal Pathogens

1. Polymerase Chain Reaction (PCR)-based techniques:

- PCR allows scientists to identify fungal pathogens by detecting their genetic material, even when infections are present at very low levels.
- Advanced versions such as real-time PCR (qPCR) provide faster and more precise results, making them valuable tools for seed health testing laboratories.

2. Loop-Mediated Isothermal Amplification (LAMP): Unlike conventional PCR, LAMP can be performed without sophisticated laboratory equipment and produces results within a short period. This makes it highly suitable for field-level diagnostics and resource-limited environments.

3. Next-Generation Sequencing (NGS): NGS enables the identification of multiple fungal species in a single sample, including previously unknown or difficult-to-culture organisms.

4. Biosensors and nanotechnology-based detection systems: These tools offer rapid, sensitive, and user-friendly detection of fungal pathogens. Nanoparticle-assisted sensors can identify specific fungal biomarkers within minutes, reducing the need for extensive laboratory procedures.

5. Artificial intelligence (AI): Artificial intelligence (AI) and machine learning are being integrated into plant disease diagnostics. High-resolution imaging systems combined with AI algorithms can detect subtle symptoms of fungal infection on seeds that may not be visible to the human eye.

Management of Seed Borne Fungal Pathogen

1. Physical Methods:

a. Hot Water Treatment

- Effective against internally seed-borne fungi.
- Commonly used for rice blast and brown spot management.

b. Dry Heat Treatment: Eliminates certain fungal pathogens without chemicals.

c. Radio-Frequency Heat Treatment: Reduces fungal contamination in rice seeds.

d. Aerated Steam Treatment: Effective against some seed-borne pathogens while maintaining seed quality.

2. Biological Management: Beneficial microorganisms suppress pathogens through competition, antibiosis, and mycoparasitism.

Important Bioagents: *Trichoderma harzianum*, *Bacillus subtilis*, *Pseudomonas fluorescens*, *Streptomyces griseoviridis*

Plant-Based Products: Garlic extract, Peppermint extract, Botanical formulations

3. Chemical Management: Seed treatment remains one of the most effective methods for controlling seed-borne fungi.

Common Fungicides: Captan, Thiram, Mancozeb, Carboxin, Benomyl, Metalaxyl, Tebuconazole, Fludioxonil.

These fungicides effectively manage pathogens such as Fusarium, Rhizoctonia, Pythium, smuts, and bunts.

Recent Trends in Management of Fungal Diseases

Precision Seed Treatment: Polymer-coated fungicides, Controlled-release formulations, Nano-fungicides

RNA-Based Disease Control: RNA interference (RNAi) technology targets pathogen genes, environmentally safer and highly specific.

Nanotechnology: Silver, zinc oxide, and chitosan nanoparticles exhibit antifungal activity, Effective at very low concentrations.

CRISPR and Genome Editing

Integrated Disease Management (IDM):

1. Combines: Healthy certified seed, resistant varieties, Biological agents, Seed treatment fungicides, Good storage practices.
2. IDM is currently considered the most sustainable strategy for managing seed-borne fungal diseases.

Conclusion

Seed-borne fungi pose a serious challenge to cereal production by affecting seed health, germination and overall crop productivity. While traditional detection methods continue to be useful, modern tools such as molecular diagnostics, biosensors and AI have made pathogen detection faster and more accurate. Effective management requires a combination of seed treatments, biological control, resistant varieties and advanced technologies. Adopting these integrated approaches helps ensure healthy seeds, higher yields and sustainable food security.

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Management of Pulses Seed Borne Pathogens

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Introduction

Pulses are essential food crops that provide affordable protein and nutrients, especially for vegetarian populations, while also improving soil fertility through nitrogen fixation. However, their productivity is limited by several stresses, particularly seed-borne diseases, which significantly reduce yields. Major seed-borne diseases in pulses include *Ascochyta* blight, Gray mold, anthracnose, *Alternaria* leaf spots, bacterial blight and mosaic viruses.

Major Seed-Borne Diseases of Pulses

Anthracnose (*Colletotrichum* spp.): Anthracnose is a fungal disease caused by *Colletotrichum* species that affects many crops, especially legumes. Important pathogens include *Colletotrichum lindemuthianum* (bean), *Colletotrichum lupini* (lupin), *Colletotrichum pisi* (pea), and *Colletotrichum truncatum* (soybean and lentil). Symptoms include sunken necrotic lesions on leaves, stems and pods, chlorosis, wilting, defoliation and pod damage. The fungus infects through spores that penetrate plant tissues via appressoria. Under cool and humid conditions, anthracnose can cause severe yield losses, sometimes up to 100%.

Charcoal rot (*Macrophomina phaseolina*): Charcoal rot is caused by *Macrophomina phaseolina*, a soil and seed borne fungus with a wide host range. The pathogen infects roots and stems, causing root rot, stem rot, wilting, and plant death by disrupting water and nutrient transport. It affects major legumes such as *Phaseolus vulgaris*, *Cicer arietinum*, *Pisum sativum*, *Glycine max*, and *Lens culinaris*. The fungus is highly variable genetically and can cause significant crop losses.

Ascochyta blight (*Ascochyta* spp. and *Phoma* spp.): Ascochyta blight is a major disease of cool season legumes caused by host specific pathogens such as *Ascochyta rabiei* (chickpea), *Ascochyta pisi* (pea), *Ascochyta fabae* (faba bean) and *Ascochyta lentis* (lentil). The pathogens survive in seeds, soil and crop residues and spread through infected seeds and airborne spores. Symptoms include dark necrotic leaf, stem and pod lesions, seedling death, reduced germination and plant wilting. Severe outbreaks can cause heavy yield losses and even complete crop failure.

Root rot and Seed rot (*Rhizoctonia solani*): *Rhizoctonia solani* is a widespread soil and seed borne fungal pathogen that causes root rot, stem rot, damping-off, seed decay, and poor germination in legumes. It infects roots and stems, causing dark lesions, root decay, chlorosis, wilting, stunting, and plant death. Major hosts include *Phaseolus vulgaris*, *Cicer arietinum*, *Pisum sativum*, *Lens culinaris*, *Vicia faba*, *Glycine max*, and *Medicago sativa*. Severe infections can cause major yield losses, sometimes up to 100% in susceptible crops.

Gray mold (*Botrytis* spp.): *Botrytis cinerea* and related species cause Gray mold disease in many legumes, including chickpea, lentil, pea, faba bean, soybean, and common bean. The fungus survives as *sclerotia* in soil and plant debris and spreads through airborne conidia and sometimes seeds. Symptoms include water-soaked lesions on stems, leaves, flowers, and pods, followed by Gray fuzzy mold growth, tissue rot, plant breakage, and seed decay. Severe infections can lead to major yield losses (up to ~50%), especially in humid environments.

Bean Yellow Mosaic Virus (BYMV): Bean yellow mosaic virus is a widely distributed viral disease of legumes, especially *Phaseolus vulgaris*, pea, lentil, faba bean, and lupin. The virus is spread mainly by aphids in a non-persistent manner and can also be transmitted through infected seeds and mechanical contact. It has a broad host range of over 200 plant species. Typical symptoms include mosaic and mottled leaves, chlorosis, vein banding, leaf curling and twisting, reduced flowering, poor pod formation, and low seed yield. Disease severity depends on the host variety, virus strain, and stage of infection.

Cucumber Mosaic Virus (CMV): *Cucumber mosaic virus* is a globally distributed virus with a very broad host range (>1000 plant species), including important legumes such as bean, soybean, lentil, and chickpea. Aphids, infected seeds, and mechanical contact mainly spread the virus. Perennial legumes such as clover and alfalfa can serve as reservoirs of infection. Symptoms vary with the host and include chlorosis, mosaic, leaf malformation, stunting, reduced internodes, shoot proliferation, and poor pod development. Yield losses can range from 5% to 75%, depending on the crop, virus strain, and environmental conditions.

Management Strategies of Legume Crops

The management of diseases in legume crops involves an integrated approach combining seed health testing, resistant varieties, chemical treatments, biological control agents, and cultural practices. Healthy, pathogen-free seeds are

essential to prevent the spread of seed-borne diseases. Seed testing programs help ensure seed quality and reduce disease transmission.

1. Development of Resistant Varieties:

- Breeding disease-resistant cultivars is one of the most effective and sustainable methods.
- Wild legume species are often used as sources of resistance genes.
- Marker-assisted selection and modern breeding techniques have improved resistance to fungal and bacterial diseases.

2. Chemical Control:

- Seed treatment fungicides are commonly used to control fungal pathogens.
- Contact fungicides control surface infections, while systemic fungicides can control pathogens present inside seeds.

3. Biological Control:

- Beneficial microorganisms such as *Trichoderma spp.*, *Bacillus spp.*, and Plant Growth-Promoting Rhizobacteria (PGPR) reduce disease incidence and improve seedling growth.
- Natural products such as thyme and garlic oils also suppress pathogen growth.

4. Integrated Disease Management:

- Crop rotation
- Use of certified disease-free seeds
- Field sanitation and crop hygiene
- Proper sowing time and avoidance of unfavourable environmental conditions

5. Management of Viral Diseases:

- Use virus-free seeds.
- Control insect vectors such as aphids.
- Remove weed hosts that act as virus reservoirs.
- Grow resistant cultivars whenever available.

Conclusion

Seed-borne pathogens significantly affect pulse crops by reducing seed quality, plant growth, and yield. Diseases caused by fungi, bacteria, and viruses can spread through infected seeds and field conditions. Effective management involves the use of healthy seeds, resistant varieties, seed treatments, biological control agents, and proper cultural practices. An integrated disease management approach is essential for profitable, eco-friendly and sustainable legume crop production.

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Seed Treatment: The First Line of Defence for Healthy Crops

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Introduction

Healthy crops begin with healthy seeds. Seed treatment is the process of applying chemical, biological, or botanical agents to seeds before sowing to protect them from diseases, insect pests, and other harmful organisms. It is one of the most economical and effective crop protection practices and forms an integral part of Integrated Pest Management (IPM). By protecting seeds and seedlings during their most vulnerable stage, seed treatment improves germination, enhances crop establishment, and contributes to higher yields and sustainable agriculture.

Importance of Seed Treatment

Seeds and young seedlings are highly susceptible to attack by seed-borne and soil-borne pathogens. Such attacks can result in poor germination, seedling mortality, weak plant growth, and reduced yields. Seed treatment provides early protection against diseases and pests, improves seedling vigour, ensures uniform crop establishment, and reduces the need for repeated pesticide applications. Since only small quantities of pesticides are used, it is both cost-effective and environmentally safer than broadcast spraying.

Methods of Seed Treatment

- 1. Chemical Seed treatment:** Seeds are treated with fungicides, insecticides, or bactericides to protect against diseases and pests. *Eg:* Carbendazim, Thiram, Tebuconazole, Chlorpyrifos
- 2. Biological Seed treatment:** Seeds are treated with beneficial microorganisms that suppress pathogens and promote plant growth. *Eg:* *Trichoderma viride*, *Trichoderma harzianum*, *Pseudomonas fluorescens*, Rhizobium
- 3. Botanical Seed treatment:** Plant-based extracts are used for seed protection and disease management. *Eg:* Garlic (*Allium sativum*) extract, Neem-based products
- 4. Physical Seed treatment:** Physical methods are used to eliminate pathogens without chemicals. *Eg:* Hot water treatment, Moist Hot Air Treatment (MHAT), Solar seed treatment
- 5. Nutrient Seed treatment:** Seeds are treated with nutrients or micronutrients to improve germination and seedling vigour. *Eg:* Zinc sulphate, Molybdenum, Micronutrient mixtures
- 6. Seed Priming:** Seeds are partially hydrated before sowing to improve germination and stress tolerance. Types: Hydropriming (water), Osmopriming (salt solutions), Biopriming (beneficial microbes).

Based on Application Methods

- 1. Seed Dressing** - Applying powder, slurry, or liquid directly to seeds.
- 2. Seed Coating** - Covering seeds with a thin protective layer.
- 3. Seed Pelleting** - Enlarging seed size with coating materials.
- 4. Seed Infusion** - Allowing chemicals to penetrate into seeds.
- 5. Film Coating** - Applying a very thin polymer layer containing treatment materials.

Advantages of Seed Treatment

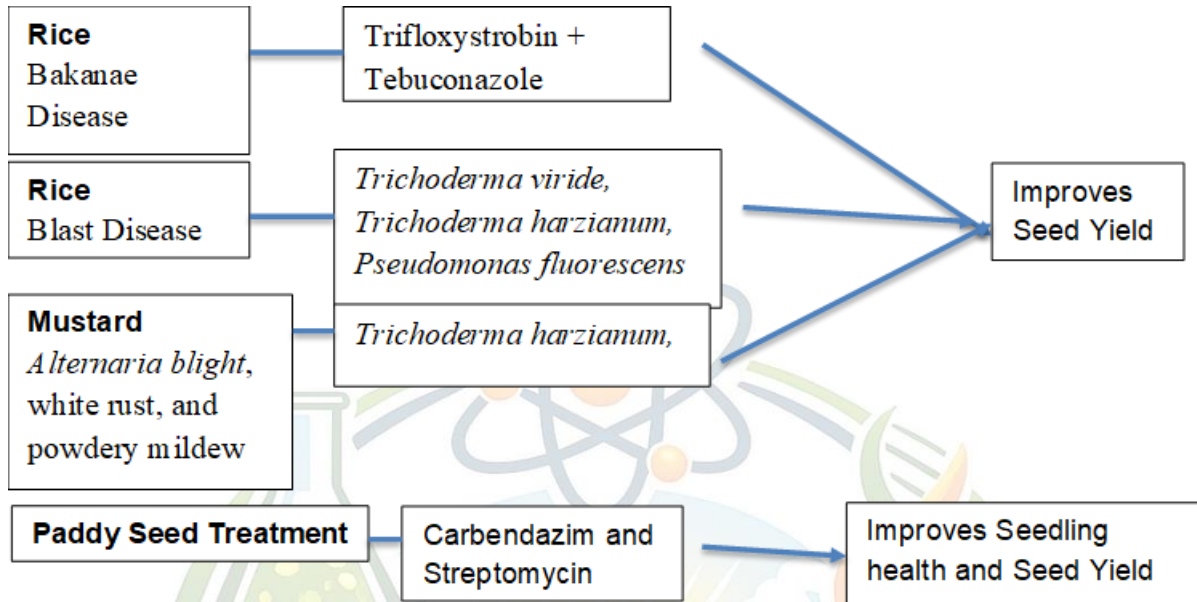
1. Protects seeds and seedlings from diseases and insect pests.
2. Improves germination and seedling vigor.
3. Ensures uniform crop establishment.
4. Reduces pesticide usage and production costs.
5. Minimizes environmental pollution.
6. Enhances crop yield and quality.
7. Promotes sustainable agriculture and food security.

Limitations of Seed Treatment

1. Protection is generally limited to the early growth stages.
2. Excessive dosage may cause phytotoxicity and affect germination.

3. Treated seeds should not be consumed by humans or livestock.
4. Improper handling may expose workers to chemicals.
5. Continuous use of certain pesticides may lead to resistance in pests and pathogens.
6. Some chemical seed treatments have raised concerns regarding their impact on pollinators such as honey bees.
7. Lack of awareness and limited access to quality seed treatment materials remain challenges in many farming regions.

Recent Success Stories



Recent Trends and Developments in Seed Treatment

Seed treatment technology is rapidly evolving from conventional chemical treatments to safer and more sustainable alternatives.

1. Biological seed treatments based on *Trichoderma*, *Pseudomonas*, and other beneficial microorganisms are gaining popularity due to their eco-friendly nature.
2. The Indian biological seed treatment market was valued at approximately USD 27 million in 2024 and is projected to grow rapidly at over 15% annually through 2030.
3. The overall Indian seed treatment market reached about USD 328 million in 2025 and is expected to grow significantly in the coming years due to increasing awareness of crop protection and sustainable agriculture.
4. Researchers are developing advanced seed-coating technologies using beneficial microorganisms and nutrient-enriched coatings to improve germination, seedling vigour, and nutrient uptake in crops such as rice.
5. Emerging technologies such as cold plasma seed treatment are being explored for improving seed germination, vigour, and disease resistance without the use of chemicals.
6. Recent research in rice has demonstrated that microbe-based seed treatments using *Trichoderma* and other beneficial microorganisms can effectively manage sheath blight disease while improving yield, supporting the shift toward sustainable agriculture.

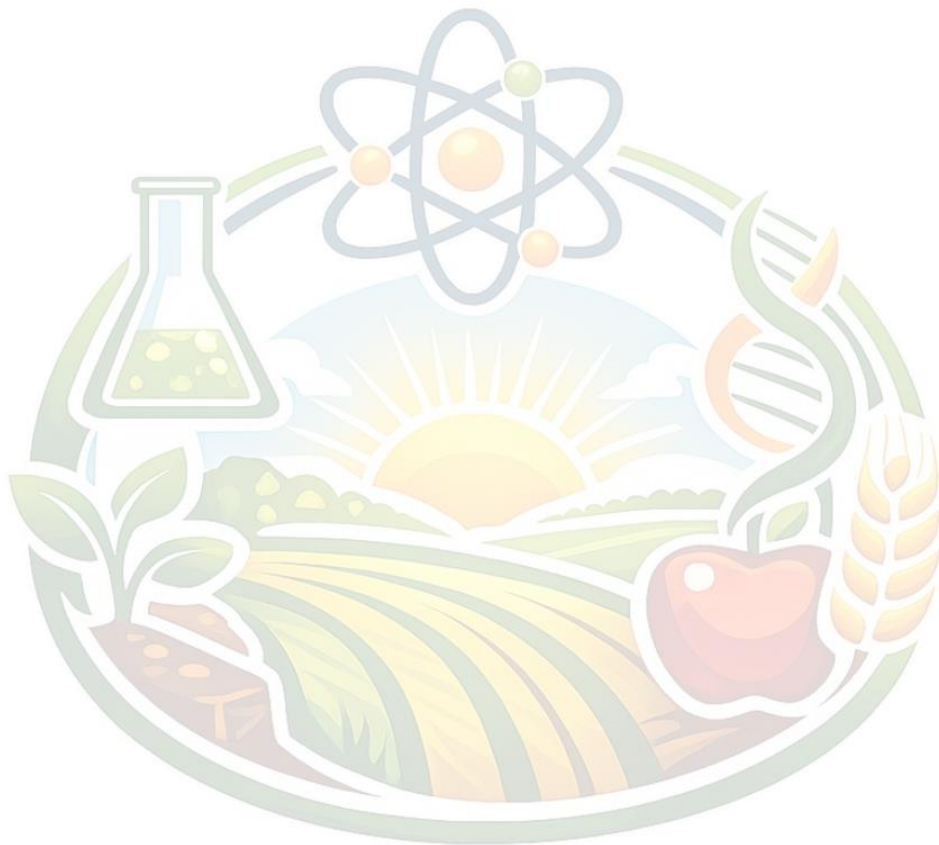
Conclusion

Seed treatment is a simple, economical, and environmentally friendly technology that plays a crucial role in crop health management. By protecting seeds and seedlings from diseases and pests during the critical early stages of growth, it improves crop establishment, productivity, and profitability. Recent advances in biological seed treatments and innovative technologies further highlight its importance in sustainable agriculture. Therefore, wider adoption of seed treatment practices can significantly contribute to enhanced crop production, food security, and environmental conservation.

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The Role of Mycorrhiza in Myconanotechnology and Environmental Resilience

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Abstracts

Mycorrhizae act as vital "biofactories" in myconanotechnology, managing nanostructures and environmental toxicity. Forming partnerships with over 90% of land plants, their extensive hyphal networks secrete proteins that safely transform toxic ions into stable, biocompatible nanoparticles. In agriculture, these nano-formulations function as smart biofertilizers, boosting crop yields by 5% to 20%, cutting synthetic chemical costs by 30%, and capturing a third of global fossil fuel CO₂. Furthermore, they drive phytostabilization in mining zones. By using proteins like glomalin, mycorrhizae immobilize toxic heavy metals like lead and nickel by up to 77%, preventing critical food-chain contamination.

Keywords: Mycorrhizae, Biofactories, Glomalin, Environmental toxicity and Toxic heavy metals.

Introduction

Mycorrhizal fungi, forming symbiotic associations with over 90% of terrestrial plants, serve as critical "biofactories" for nanoparticle (NP) synthesis and as biological buffers against environmental nanotoxicity. The intersection of these functions defines their role in myconanotechnology, leveraging fungal biomass and metabolites to produce and manage nanostructures (Galiano *et al.*, 2026). Mycorrhizal fungi act as highly efficient nanofactories. Their extensive hyphal networks secrete specific proteins and extracellular enzymes that reduce toxic metal ions into biocompatible nanostructures. Research shows that arbuscular mycorrhizal fungi (AMF) can safely transform toxic, cationic copper into metallic copper nanoparticles, neutralizing its active environmental toxicity (Mohammed, 2024, Van Der Heijden *et al.*, 2015).

When integrated into soil systems, mycorrhizal nano-formulations function as smart, targeted biofertilizers. The application of mycorrhizae helps plants navigate severe climate stressors i.e. Yield Enhancements, Input Reduction and Carbon Sequestration. Standard agricultural field data demonstrates that mycorrhizal inoculation consistently boosts crop yields by 5% to 20%. Enhanced root vascularity allows farmers to cut synthetic nitrogen and phosphorus input costs by up to 30%. Globally, mycelial biomass acts as a massive sink, drawing down roughly one-third of annual global fossil fuel CO₂ emissions into the soil network (Dyshko, *et al.*, 2024, Putzke *et al.*, 2026).

In highly contaminated industrial or mining zones, mycorrhizae drive phytostabilization by immobilizing heavy metals (HMs) in the root zones via proteins like glomalin. The glomalin proteins was reduced Cadmium (Cd- 59.1%), Copper (Cu- 69.7%), Lead (Pb- 77.2%) and Nickel (Ni- 77.8%). By binding these toxic elements, mycorrhiza-driven myconanotechnology prevents toxic runoff, blocks food-chain contamination, and actively restores ecological health (Mishra, *et al.*, 2019).

Mechanisms of Green Nanoparticle Synthesis

Mycorrhizal and other filamentous fungi are preferred for nanoparticle synthesis due to their ability to secrete large quantities of extracellular enzymes and their high mycelial surface area, which facilitates metal ion interaction.

1. Enzymatic Reduction: The synthesis primarily involves the NADH-dependent nitrate reductase enzyme, which facilitates the bioreduction of metal ions (e.g., Ag⁺ to Ag⁰) into elemental nanoparticles.

2. Biological Pathways: The process typically begins with ion trapping on the mycelial surface through electrostatic interactions with negatively charged functional groups in the cell wall, followed by enzymatic conversion into nuclei that grow into nanoparticles.

3. Capping and Stability: Secreted fungal proteins and enzymes act as natural capping agents, preventing nanoparticle aggregation and ensuring long-term stability (Galiano *et al.*, 2026, Mishra, *et al.*, 2019).

Scientific Data on Fungal Nanoparticle Production

Fungi are utilized to fabricate a diverse range of metallic and oxide nanoparticles with specific morphological characteristics.

1. Silver (AgNPs): *Fusarium oxysporum* produces AgNPs ranging from 5 to 50 nm. *Aspergillus fumigatus* has been documented to reduce silver ions into spherical nanoparticles (5-25 nm) in as little as 10 minutes (Patel *et al.*, 2021).

2. Other Structures: Fungi have been used to synthesize gold (Au), platinum (Pt), and bimetallic alloys like Au-Ag. Additionally, *F. oxysporum* can produce complex oxides such as silica and titania (5-15 nm) and zirconia nanoparticles (Van Der Heijden *et al.*, 2019).

Mitigation of Nanoparticle Toxicity in Plants

Arbuscular Mycorrhizal Fungi (AMF) actively alleviate the phytotoxic effects induced by high concentrations of metal-based nanoparticles.

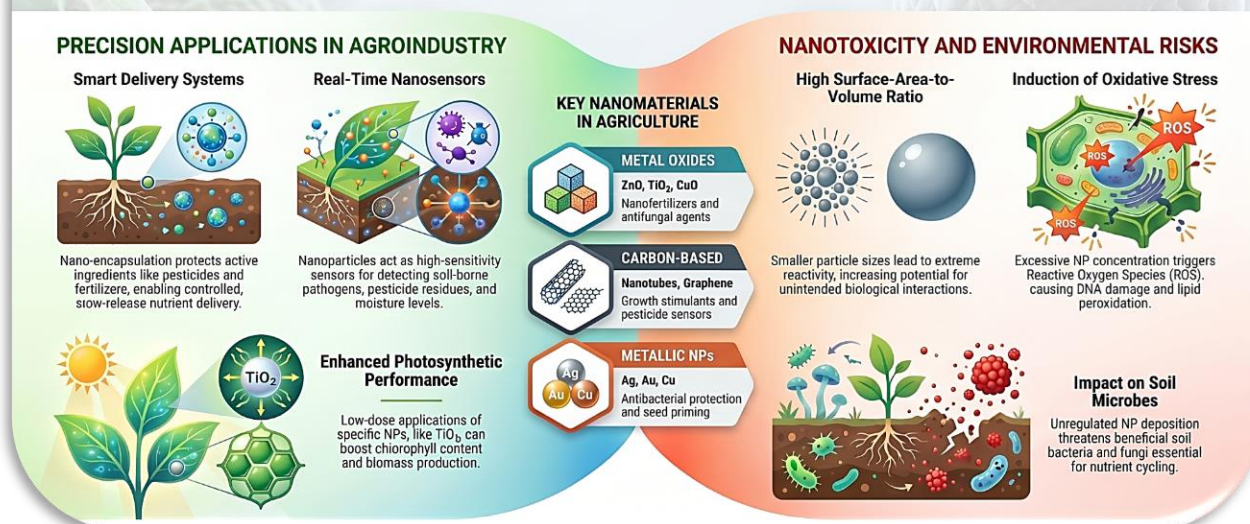
1. Biomass Protection: In experiments with iron oxide (Fe_3O_4) NPs, high concentrations (10 mg/kg) caused a 17.0% decrease in shoot biomass and a 19.6% decrease in root biomass in non-inoculated maize; however, AMF-inoculated plants showed no significant biomass changes (Patel *et al.*, 2021).

2. Reduction in Bioavailability: AMF decrease the translocation of toxic elements through hyphal sequestration. For example, mycorrhizal tomato plants exposed to 36 mg/kg of Ag-NPs accumulated 14% less silver in their shoot tissues compared to non-mycorrhizal plants.

3. Genetic Regulation: AMF colonization has been shown to down-regulate the expression of membrane transport protein genes (e.g., PIP and TIP) involved in silver uptake, actively reducing the plant's internal toxin exposure (Patel *et al.*, 2021).

The Nano-Agri Frontier: Balancing Innovation and Environmental Safety

Nanotechnology utilizes engineered materials under 100nm to revolutionize agricultural productivity through precision delivery and sensing. However, their unique physicochemical properties—such as high reactivity and surface area—induce environmental stress that can threaten crop health and soil microbial diversity.



Safeguarding the Soil Microbiome and Nutrient Cycles

Mycorrhizae act as a biological shield for the broader soil bacterial community against nanoparticle-induced degradation.

1. Maintaining Bacterial Abundance: High concentrations of Fe_3O_4 -NPs significantly decrease soil bacterial abundance in non-AMF soils, whereas AMF-inoculated soils maintain stable community structures (Xu *et al.*, 2023).

2. Preserving Keystone Guilds: Mycorrhizae protect keystone microbial groups responsible for carbon (C) and nitrogen (N) cycles, such as *Nitrospira* and *Anaerolineae*, which are otherwise suppressed by nanoparticle stress (Wang, *et al.*, 2024).

3. Buffering Soil DOC: AMF prevent the decline of soil dissolved organic carbon (DOC); in non-inoculated soils, Fe_3O_4 -NPs reduced DOC by 13.7%, a loss that was entirely mitigated in the presence of AMF (Bennett and Groten, 2022).

Glomalin and Heavy Metal Remediation

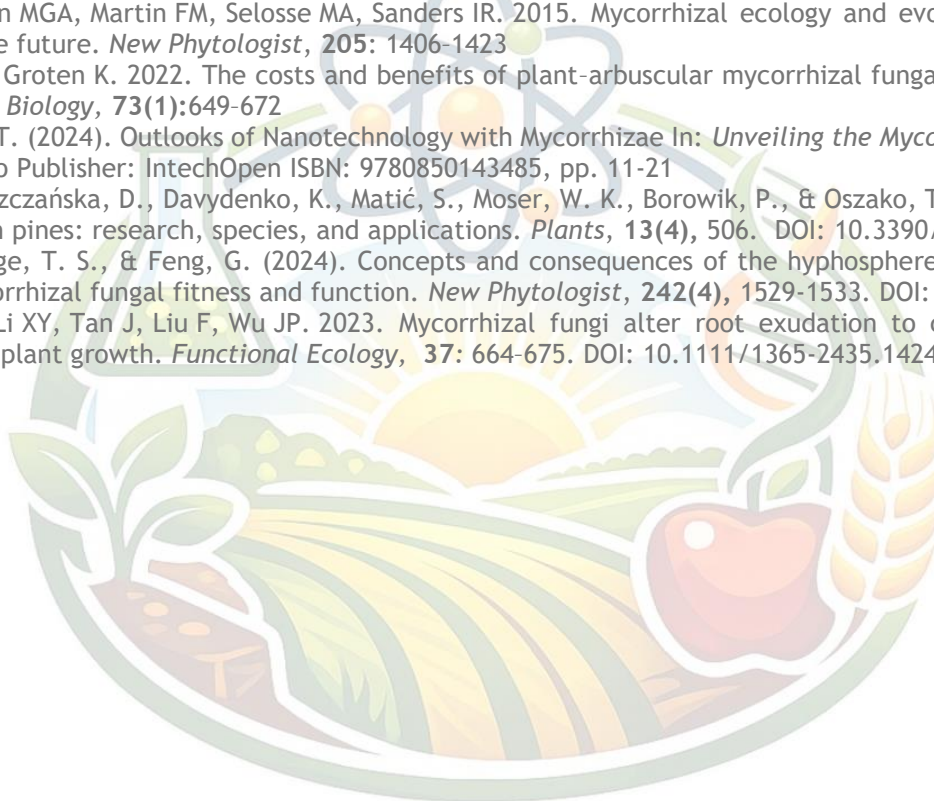
AMF produce glomalin-related soil protein (GRSP), a specialized glycoprotein that is essential for soil health and heavy metal detoxification.

1. Carbon and Metal Storage: In undisturbed soils, GRSP accounts for 30-40% of total organic carbon and possesses a high capacity for binding heavy metals, thereby reducing their toxicity and movement in the soil matrix (Dyshko, *et al.*, 2024).

2. Vulnerability to NPs: Despite its protective role, glomalin production is susceptible to high nanoparticle stress; for instance, Ag-NPs at 800 mg/kg have been shown to significantly stunt glomalin content and mycorrhizal colonization (Putzke *et al.*, 2026).

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***Physalis peruviana*: Evaluating the Postharvest Physiology and Phytochemical Potential of an Emerging Cash Crop**

Article ID: 74049

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Summary

Physalis peruviana (Golden Berry, Cape Gooseberry) is a fruit crop of commercial potential, medicinal properties and nutritional value, attracting international interest. The fruit is native to the Andean ranges of South America, but has adapted well in other parts of the world, mainly in the tropical and sub-tropical climate and is being increasingly cultivated in different parts of India. The cape gooseberry is rich in vitamins, minerals, antioxidants and some unique bioactive substances and is regarded by researchers as a promising functional food. The growing popularity of the fruit has not addressed the problem of postharvest quality retention. Its postharvest physiology and phytochemical composition are very important to improve its shelf life and decrease losses, allowing to maximise its economic value.

Introduction

Cape Gooseberry has become a suitable choice for sustainable farming and nutritional security as the world's agriculture moves toward diversified and economically viable horticulture crops (Ramadan, 2011; Puente *et al.*, 2011). The fruit, commonly known as Cape gooseberry, golden berry, or rasbhari, is a member of the Solanaceae family and has received major attention from researchers, consumers, and entrepreneurs.

The increased interest in Cape gooseberry is due to its excellent nutritional value, medicinal properties, and adaptation to less favourable environmental conditions. The fruit is consumed fresh and processed into a range of products, while its bioactive properties have been associated with many health-promoting qualities. The increased consumer demand for functional foods and natural health products creates huge opportunities for both farmers and the food sector regarding Cape gooseberry.

Taxonomy and Botanical Features

Physalis peruviana is a herbaceous perennial generally grown as an annual crop. It usually grows to 1-2 m tall and has soft heart-shaped leaves and lovely yellow flowers with dark purple dots. The plant is very adaptable to different climatic conditions and can be grown in tropical and sub-tropical regions.

The fruit is a small round berry, 1.5-2 cm in diameter. As the fruit matures it changes from green to a bright golden-orange colour indicating ripeness. The most characteristic feature of this crop is the presence of its papery inflated calyx which completely encloses the fruit as a protective barrier against pests, viruses and mechanical injury and also contributes towards moisture conservation and longer shelf life.

Under ideal growing conditions, the crop has a huge production potential and it is a promising alternative revenue generating crop for small and medium scale farmers.

Cultivation and Crop Management

Cape gooseberry grows well in a wide range of soils but best growth and productivity is obtained in well drained rich soil. The crop is generally propagated through seeds but vegetative multiplication is practiced through stem cutting to get uniform plant growth and early fruiting.

Proper management of nutrients is one of the factors influencing high yields and quality of crops. Balanced fertiliser treatments and application of organic manures stimulate vigorous vegetative growth and increase the fruit yield. Mulching is generally advocated as it conserves soil moisture, suppresses weeds and avoids direct contact of soil with the fruits.

The crop is reasonably hardy but suffers from a number of diseases and pests. Insects that are common pests are fruit borers, flea beetles, cutworms and leaf-feeders. Important yield reducing factors are disease such as powdery mildew and root rot. For sustainable farming, good field sanitation, drainage and integrated pest management practices are a must.

Phytochemical Potential and Nutritional Importance

The unique phytochemical profile of the cape gooseberry makes it a promising and emerging crop. It contains high composition of dietary fibre, essential minerals, vitamins A and C and various bioactive compounds that make it a good nutritional and medicinal value.

The major phytochemicals present in this plant are withanolides, carotenoids, polyphenols and flavonoids. These compounds are good antioxidants, scavenging free radicals and reducing oxidative stress in the human body (Ramadan, 2011; Yen *et al.*, 2010). Scientific studies have proved that the bioactive components have anti-inflammatory, antibacterial, immunomodulatory and possible anti-cancer properties (Wu *et al.*, 2004).

It is also a rich source of essential minerals like potassium, magnesium, phosphorus and copper that are key for cell function, metabolism and cardiovascular health. The cape gooseberry has been identified as a functional food with the potential to offer significant benefits for nutrition and preventive healthcare because of its unique combination of nutrients and bioactive compounds.

Postharvest Physiology and Quality Preservation

Cape gooseberries have several postharvest problems that affect their marketability and economic viability despite their nutritional and financial benefits. It is a climacteric fruit that is sensitive to ethylene and continues to ripen after harvest and produce more ethylene and respiration during storage. These physiological changes accelerate the development of pigmentation, softening and metabolic changes that ultimately affect fruit quality (Fischer *et al.*, 2014).

Harvest ripeness is an important determinant of postharvest performance. The quality retention and storage behaviour of fruits harvested at the proper stage of maturity (golden-orange berry colour with starting yellowing of the calyx, not green) is generally superior to that of fruits picked too early or too late.

The papery calyx acts as a natural modified atmosphere packaging by reducing moisture loss and preventing microbial invasion of the fruit. But, a decline in the quality of fruits exposed to adverse environmental circumstances can still happen. Temperature and relative humidity are particularly important factors in maintaining postharvest quality. It is generally accepted that the ideal storage temperature range to extend shelf life and minimise physiological problems is between 4 °C and 8 °C.

Routine physiological parameters monitored during storage are fruit hardness, total soluble solids, titratable acidity, weight loss and colour development. These measurements give important information about the ripening process and the overall quality of the fruit. Recent advances in postharvest technology have looked at the use of edible coatings, immersion treatments and vacuum impregnation techniques to further increase shelf life (Valdenegro *et al.*, 2012; Herrera *et al.*, 2011). These treatments improve consumer acceptability and economic value by reducing water loss, delay senescence and preservation of vital phytochemicals.

Value Addition and Economic Potential

Cape gooseberry has potential as a high value horticultural crop. The fruit is consumed raw and is processed for jams, jellies, juices, beverages, dried fruits, candies, sauces and nutraceuticals products. In addition, its unique sweet-sour taste and beautiful appearance make it very popular in both high-end domestic and foreign markets.

The increasing demand for natural and health-promoting consumables has increased the market opportunity for products based on Cape gooseberry (Puentes *et al.*, 2011). Export-oriented production can have excellent prospects for rural development and agricultural diversification. Small-scale processing businesses can add value and generate extra revenue.

However, in order to unlock the crop's full economic potential, more market linkages, cold-chain infrastructure and efficient postharvest handling practices are needed. One of the most important ways to improve profitability along the value chain is to reduce post-harvest losses.

Challenges and Future Prospects

A number of problems remain in the way of the successful commercialisation of the huge potential of Cape gooseberry. Producers have to deal with key issues like poor postharvest infrastructure, low consumer awareness, changing market demand and lack of standardised production procedures.

Also, climate change and altered environmental conditions can affect blooming, fruit set and postharvest quality. Hence, future research should be concentrated on developing better cultivars with higher yield, disease resistance and storage capacity. Long-term success will require even greater emphasis on breakthrough postharvest technology, precision nutrient control and sustainable farming approaches.

Further work on phytochemical composition of the fruit and its health benefits may help to further boost its status in the fast-growing functional food and nutraceutical businesses.

Conclusion

Physalis peruviana is more than an exotic fruit. It is an important source of nutrients, bioactives and commercial value. It is one of the most promising developing horticultural crops of modern era due to its rich phytochemical profile and increasing consumer demand for health promoting foods.

However, commercialisation of cape gooseberry is dependent on effective postharvest management strategies to maintain fruit quality and phytochemical integrity. This amazing fruit can play a great role in food security, rural livelihoods and sustainable agricultural development through improved farming practices, state of the art storage technology and value addition activities.

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From Fresh to Pickled: Study of Biological Composition of Cucumber and Its Importance in Food Processing and Health

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Abstract

The research “From Fresh to Pickled: Study of Biological Composition of cucumber and its Importance in Food Processing and Health” overview the significance of Cucumber as an important Vegetable crop. It highlights the nutritional and processing value of Cucumber. It is rich in antioxidants, vitamins, minerals, fiber, and water, which make it ideal for hydration and overall health. Pickling is the widely popular practice among different preservation techniques as it increases shelf life, flavour and acceptability of the product. The study Highlights the processing of cucumber to produce value-added products which Contribute to the food industry and increase the economic returns. Furthermore, pickled cucumber products contribute to food preservation and year-round availability. Thus, cucumber shows has an important link between agriculture and food technology.

Introduction

Cucumber, also known as scientifically as *Cucumis sativus* L., is one of the most commonly cultivated and also economically important vegetable crops. It belonging to family Cucurbitaceae. It is mainly grown in tropical, subtropical and temperate regions of the world. Cucumber is commonly consumed as a salad purpose and is highly known for cooling effect, crisp texture, and low-calorie nature, making it a popular choice in health-conscious and balanced diet. It is highly valued for its refreshing taste, high moisture content, high nutritive flavour and use in both fresh consumption and processed food products, particularly for pickling and preservation.



Plate No.1: cucumber



Plate No.2 harvesting cucumber

Biological Composition of Cucumber

It is highly valuable vegetable for both nutritional consumption and food processing purposes. Fresh cucumber consists of about 95-96% water, which contributes to its cooling properties and it's hydrating, while the remaining portion contains modest protein 1%, carbohydrates 2.5% and negligible lipids content. It is a good source of vitamins and minerals. It also contains dietary fibre, mainly in the peel, which supports digestive health. The presence of natural enzymes and phytochemicals enhances its medicinal and functional food value, making cucumber for consumption and also for processing into pickles and other preserved products.

Importance of Cucumber in Food Processing and Health

1. Cucumber is popularly used in food processing industries for making of pickles, salads, juices and preserved products.
2. Pickling of cucumber helps in extending shelf life and reduces post-harvest losses.
3. It serves as an important value-added crop for farmers and entrepreneurs by increasing market opportunities and also provide additional income through processed products.

4. Cucumber contains bioactive compounds such as flavonoids and cucurbitacin that help reduce oxidative stress, inflammation and reduces chronic diseases.
5. It also contains essential vitamins such as Vit C, Vit B, Vit A and Vit K along with minerals like Potassium, magnesium, calcium that improves immunity.
6. Fermented and pickled cucumber products improve gut health and enhancing digestive benefit.

Pickle -Value-Added Product of Cucumber

A pickle is a type of food product that is created by preserving vegetables using salt, vinegar, oil and spices for improved taste and to increase the length of time they can be stored. It is often used as value-added products for food industry.

Procedure of Cucumber Pickle

1. Select healthy and fresh cucumbers for pickling.
2. Wash the cucumber well to remove the dirt and impurities.
3. Cut the cucumber into slices or small pieces as needed.
4. Mix with salt and let them sit for some time to draw out excess water.
5. Add spices, vinegar, and oil to improve taste and preservation.
6. Transfer the mixture into dry, clean and airtight container.
7. Allow the pickle to sit for few days for fermentation and flavour development.
8. Store the pickle safely and use when ready.

Conclusion

Cucumber is an important vegetable crop that have high great potential in the food processing industry. It is beneficial for human health and have rich biological composition including water, minerals, dietary fibre and antioxidants. Due to perishable nature, processing methods such as pickling play an important role in reducing post-harvest losses, extending shelf life and make value-added products. Pickled cucumber improves market structure and also enhances flavour and customer acceptance. Fresh cucumber into pickled products supports better nutrition, farmer income, food preservation and sustainable agricultural development. This makes cucumbers an important crop in both agriculture and food science.

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Nanotechnology-Driven Sustainable Agriculture: Emerging Applications, Challenges and Future Perspectives

Article ID: 74051

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Abstract

Rapid population expansion, climate change, soil degradation and dwindling natural resources create significant challenges to modern agriculture. Conventional agricultural practices have increased crop production, but excessive fertilizer and pesticide usage has polluted the environment and deteriorated soil health. In this context, nanotechnology has emerged as a possible approach to long term agricultural improvement. Due to their unique physicochemical properties, nanomaterials can improve nutrient delivery, enhance crop growth and support efficient resource utilization. Different agricultural nanomaterials are being utilized for nutrient management, crop protection, stress mitigation and precision farming. Nano enabled products such as nanofertilizers, nanopesticides, nanosensors and bioactive delivery systems have demonstrated significant potential for increasing crop output, nutrient efficiency and abiotic stress tolerance. Although nanotechnology offers several advantages, but still there are some concerns related to environmental safety, toxicity, high production costs. Limited awareness remains major challenges for its large-scale adoption. Therefore, to ensure its sustainable application further research and proper safety regulations are necessary.

Introduction

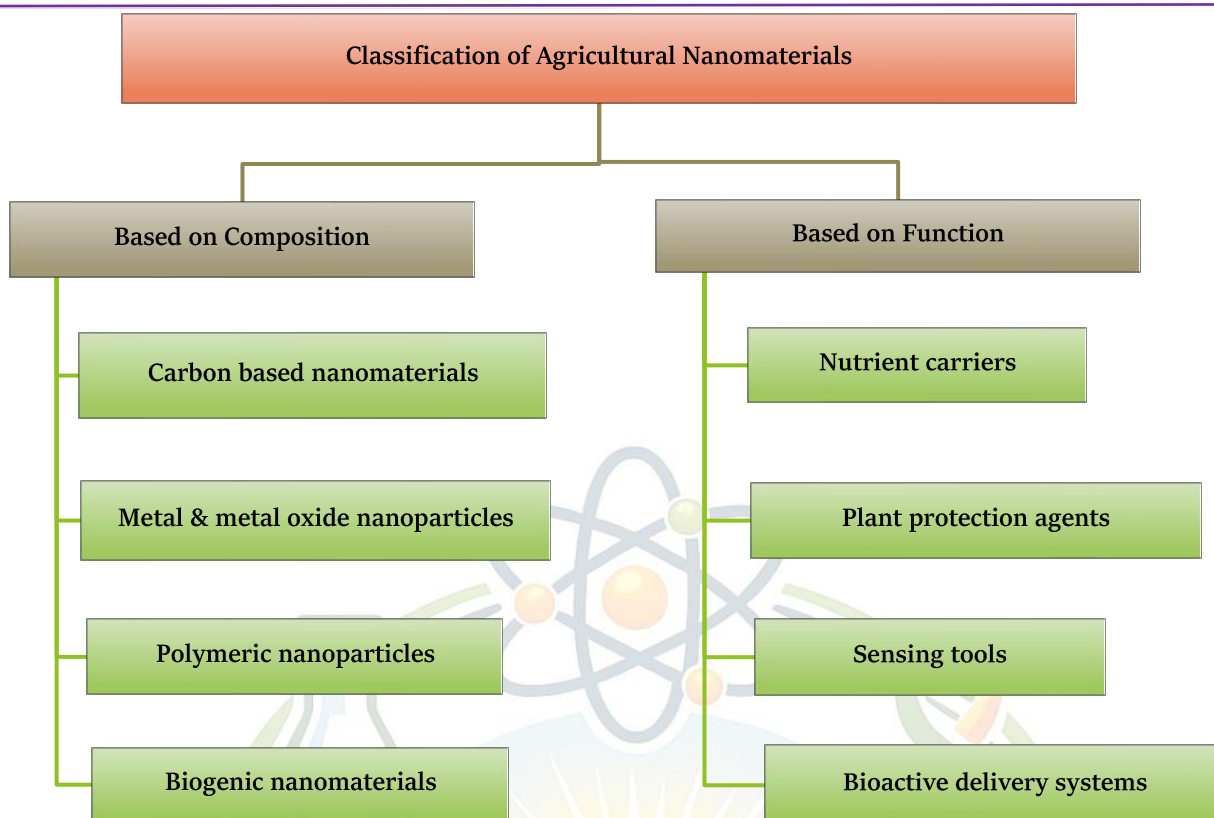
Modern agriculture is facing significant worldwide challenges due to rapid increase in population, climate changes, soil degradation, dwindling natural resources and rising food demand. Conventional agricultural practices increased crop productivity during the Green Revolution but also led to excessive use of fertilizers, pesticides and irrigation water, causing environmental pollution and soil degradation. Crops are continuously exposed to various biotic and abiotic stresses such as heat, salinity, drought, pests, diseases, and nutrient deficiency, which significantly reduce crop productivity. Thus, it is necessary to develop agricultural technologies that are efficient, sustainable and safe for the environment.

Nanotechnology has emerged as one of the most promising advanced technologies for crop improvement. The concept of nanotechnology was first proposed by Richard Feynman in 1959 and the term later was coined Norio Taniguchi in 1974. It involves the manipulation and application of materials at nanoscale level ranging from 1-100nm. At this scale, material exhibit unique physicochemical properties such a high surface area, enhanced reactivity and solubility. These distinctive characteristics make nanomaterials highly suitable for agricultural applications.

In recent years, agricultural nanotechnology has drawn a lot of attention due to its potential to assist precision farming systems, increase stress tolerance, decrease environmental contamination and improve nutrient use efficiency. Effective interactions between nanomaterials and soil, plants, and microbes can enhance agricultural productivity, plant growth and nutrient availability. Nanofertilizer provides controlled and targeted nutrient release, minimizing nutrient losses through leaching, volatilization and runoff. In similar way nanopesticides and nanoherbicides offer improved pest and disease management with lower chemical dosages and reduced toxic residues in the environment. In precision agriculture creation of nanosensors helps to monitor soil nutrient, moisture content, plant health and environmental stressors in real time. Nano enabled delivery systems are also being explored for the transfer of biomolecules such as DNA, RNA, proteins, hormones, and plant growth regulators in crop improvement programs. Nanomaterials have also demonstrated significant potential in enhancing plant tolerance to abiotic stresses by regulating antioxidant defense systems, improving photosynthesis, increasing water-use efficiency, and improve nutrient uptake. Considering its vast potential, nanotechnology has gained considerable importance in sustainable agriculture and crop improvement.

Concept and Classification of Agricultural Nanomaterials

Agricultural nanomaterials are nano sized particles specifically designed for agricultural applications such as for nutrient delivery, crop protection, stress management, and precision farming. Depending on their composition and functions, these nanomaterials are classified into different categories.



Examples and Functions of Nanomaterials

Nanomaterials	Examples	Functions
Metal & metal oxide nanoparticles	ZnO, FeO, TiO ₂ , Ag	Enhanced nutrient delivery and uptake
Carbon-based nanomaterials	CNTs, Graphene	Stress modulation, Sensing & diagnostics
Polymeric and biogenic nanoparticles	Chitosan, Lipid NPs)	Controlled release of Gene/ bioactive delivery, Eco-friendly applications
Nutrient carriers	nano-fertilizers	Improved NUE, Yield enhancement
Plant protection agents	nano-pesticides	Reduced chemical load, Targeted pest control
Sensing tools	nano-sensor	Early stress detection, Precision farming
Bioactive delivery systems	DNA/RNA, hormones	Enhanced growth, Breeding support

Role of Nanomaterial in Soil and Plant Health

1. When nanomaterials are applied to soil or plants, they interact with roots and soil microorganisms helping plants absorb nutrients more efficiently and improving overall plant health and growth.
2. Nanomaterials interact with soil minerals and organic matter affecting their stability movement and availability to plants.
3. Soil properties such as pH texture and microbial activity affect the behavior and persistence of nanomaterials in soil.
4. Plants absorb nanomaterials mainly through roots and leaves and their small size allows movement within plant tissues.
5. The interaction of nanomaterials with soil and plants can improve nutrient uptake plant growth and stress tolerance.
6. Nanomaterials may also influence rhizosphere microorganisms and nutrient cycling processes in soil.
7. The effectiveness of nanotechnology in agriculture depends on how nanomaterials behave in the soil-plant environment.

Applications of Nanotechnology in Agriculture

1. Nanotechnology based nanofertilizers are widely used in agriculture for improving nutrient management through controlled and targeted nutrient release.

2. Nanopesticides and nanoherbicides are helpful in effective pest and weed management with reduced chemical dosages and environmental contamination.
3. Nanosensors are used in precision agriculture to monitor soil nutrients moisture levels, plant health and environmental stresses in real time.
4. Nanotechnology helps plants develop tolerance against abiotic stresses by improving antioxidant and physiological activities.
5. Nanotechnology is also used in seed treatment and precision farming for improving germination crop growth and efficient use of agricultural inputs.

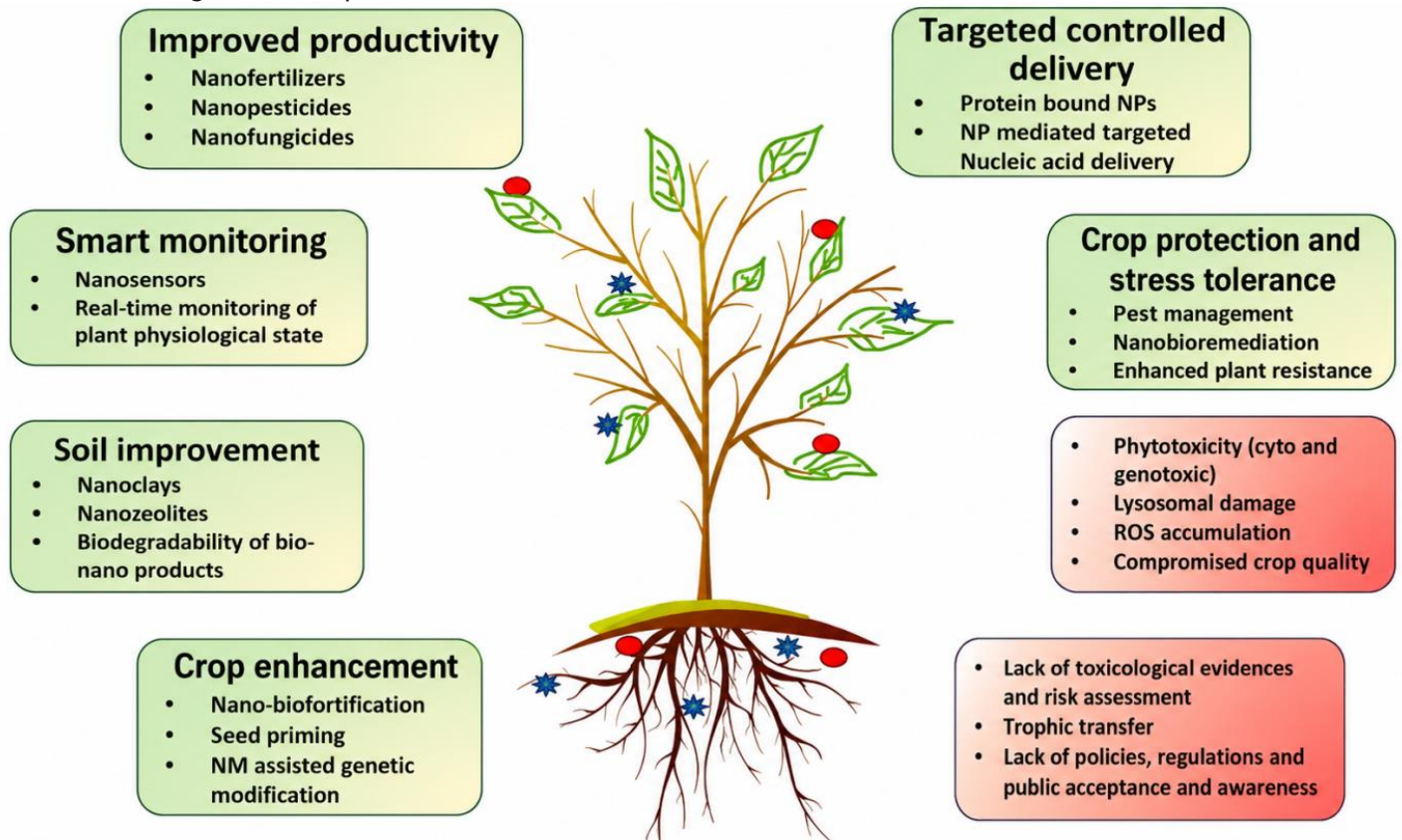


Fig. Showing Potential application of Nanotechnology in Agriculture

Benefits of Nanotechnology in Agriculture

1. Nanotechnology enhances resource efficiency and promotes sustainable agriculture.
2. It helps to prevent environmental damage caused by excessive agricultural inputs.
3. Nano-based techniques improve agricultural productivity and quality.
4. Nanotechnology enables precision farming and effective resource management.
5. It has the potential for climate-resilient and sustainable crop production.

Limitations of Nanotechnology in Agriculture

1. Excess accumulation of nanoparticles may affect soil quality and plant growth.
2. Some nanomaterials may influence beneficial soil microorganisms and nutrient cycling processes.
3. The long-term effects of nanoparticles on the environment and human health are still unclear.
4. High production costs limit the wider use of nanotechnology in agriculture.
5. Lack of awareness technical knowledge and proper safety regulations restrict the practical use of nanotechnology in farming systems.

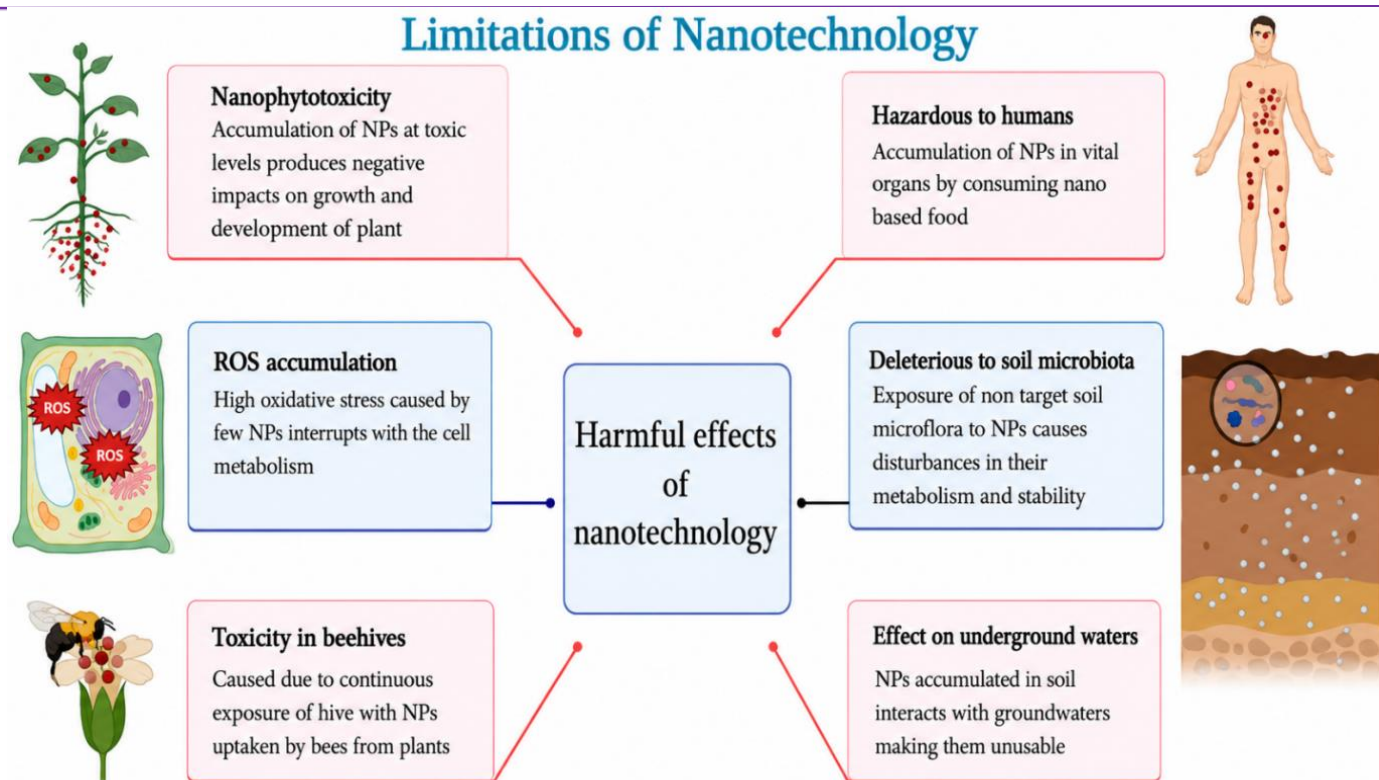


Fig. Showing Major Limitations and Harmful Effects of Nanotechnology in Agriculture

Future Prospects of Nanotechnology in Agriculture

1. Development of biodegradable and environmentally safe nanomaterials that may help to reduce the ecological risks associated with long term uses nanoparticle in agricultural.
2. Future agriculture could benefit from advanced nano-based technology such as smart nanosensors, nano enabled drones, and controlled release fertilizers.
3. Future advances in nanotechnology may help to build climate resilient crops that can tolerate drought, salinity, heat, and other environmental challenges.
4. The integration of nanotechnology with AI precision farming and smart sensing technologies has the potential to improve future agricultural monitoring and decision-making systems.
5. Continuous research and advances in agricultural nanotechnology have the potential to significantly improve food security, sustainable farming, and resource conservation in the future.

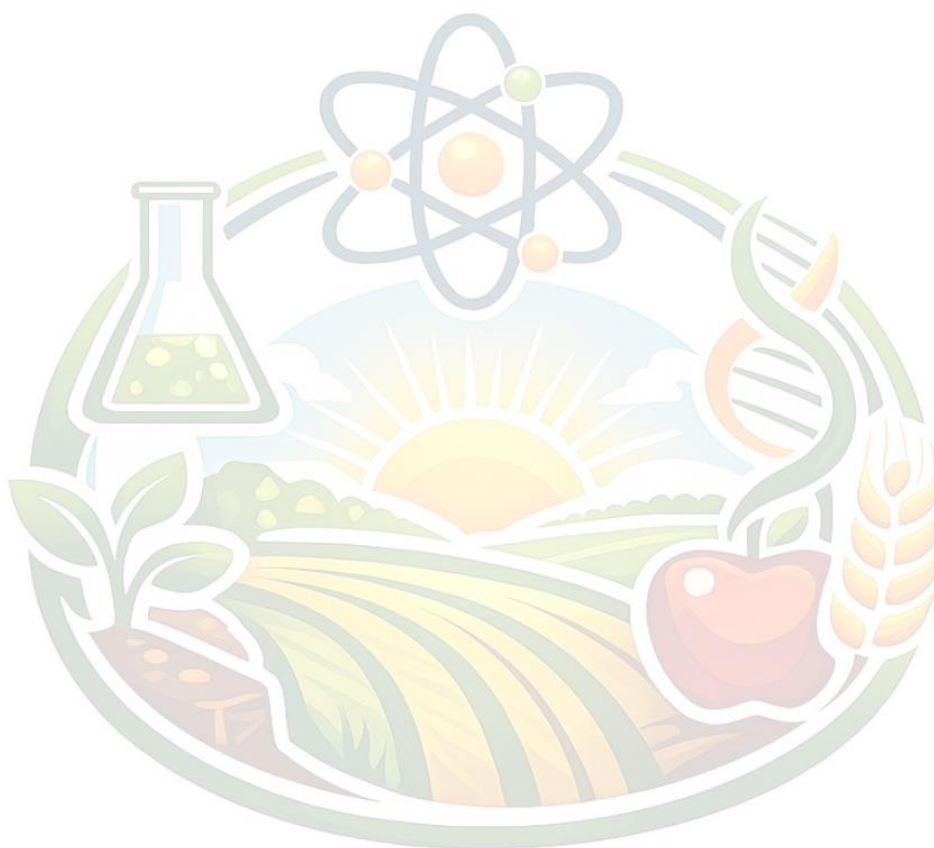
Conclusion

Nanotechnology is developing as a valuable tool for sustainable agriculture and crop enhancement. Nano based technologies have demonstrated considerable potential for increasing fertilizer management, crop yield, stress tolerance, and precision farming practices while minimizing environmental pollution caused by excessive agricultural inputs. Nanomaterials also promote efficient resource utilization and may help to create climate-resilient agricultural systems in the future. However, thorough safety assessment, environmental monitoring, and farmer awareness are necessary for the safe and sustainable use of nanotechnology in agriculture. With continuous research and advancements, nanotechnology may play a major role in ensuring future food security and sustainable agricultural development.

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Innovative Approaches in Vegetable Farming Using AI and Drone Technology

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Abstract

Vegetable cultivation plays an important role in ensuring nutritional security, income generation, and employment opportunities for farmers. However, increasing population pressure, climate variability, labor shortages, pest incidence, and inefficient resource utilization are major challenges affecting vegetable production. In recent years, advanced technologies such as Artificial Intelligence (AI) and drone technology have emerged as innovative tools for improving precision, productivity, and sustainability in agriculture. AI enables data-based decision making, disease identification, irrigation scheduling, yield prediction, and smart farm management, while drones help in crop monitoring, pesticide spraying, nutrient management, and field mapping. The integration of AI and drones in vegetable farming can significantly reduce labor costs, improve input efficiency, minimize environmental pollution, and increase crop productivity. This article highlights the role, applications, benefits, challenges, and future prospects of AI and drone technology in modern vegetable farming systems.

Introduction

Vegetables are considered protective foods due to their rich nutritional value, including vitamins, minerals, antioxidants, and dietary fiber. India is the second-largest producer of vegetables in the world; however, productivity and quality are often affected by several biotic and abiotic stresses. Traditional farming methods alone are becoming insufficient to meet the increasing food demand and quality standards of modern consumers.

The agricultural sector is currently undergoing a digital transformation with the adoption of advanced technologies such as Artificial Intelligence (AI), Internet of Things (IoT), robotics, machine learning, sensors, and drone technology. These innovations are collectively known as smart farming or precision agriculture. Smart vegetable farming focuses on the efficient utilization of resources like water, fertilizers, pesticides, and labor while maximizing productivity and profitability.

Artificial Intelligence refers to the capability of machines or computer systems to imitate human intelligence, analyze large data sets, and make intelligent decisions. Drones, also known as unmanned aerial vehicles (UAVs), are flying devices equipped with cameras, sensors, and spraying systems used for agricultural operations.

The use of AI and drones in vegetable cultivation is rapidly increasing because these technologies provide accurate information regarding crop health, nutrient status, pest infestation, irrigation requirements, and yield estimation. The adoption of these technologies can help farmers achieve sustainable vegetable production while reducing production costs and environmental impacts.

Need for Smart Vegetable Farming

Vegetable cultivation is highly intensive and requires continuous monitoring and management. Several challenges faced by vegetable growers include:

1. Increasing labor scarcity and labor costs
2. Unpredictable climatic conditions
3. Water scarcity and improper irrigation management
4. Pest and disease outbreaks
5. Excessive use of fertilizers and pesticides
6. Declining soil fertility
7. Post-harvest losses
8. Low productivity and quality.

Traditional methods often fail to provide timely and precise information for managing these challenges. Therefore, there is an urgent need for innovative and technology-based approaches to improve efficiency and sustainability in vegetable farming.

Artificial Intelligence in Vegetable Farming

Artificial Intelligence has revolutionized modern agriculture by enabling farmers to make informed and data-driven decisions. AI technologies use machine learning algorithms, image processing, sensors, and cloud computing to analyze agricultural data.

1. Disease and Pest Detection: AI-based image recognition systems can identify diseases and pests at an early stage using smartphone images or sensor data. Early detection helps farmers take timely preventive measures and reduce crop losses.

For example:

- a. Detection of tomato leaf curl virus
- b. Identification of powdery mildew in cucurbits
- c. Recognition of bacterial wilt in solanaceous vegetables.

AI systems can analyze symptoms more accurately and rapidly compared to manual observation.

2. Smart Irrigation Management: AI helps in monitoring soil moisture, temperature, humidity, and weather conditions to optimize irrigation scheduling. Smart irrigation systems reduce water wastage and improve water use efficiency.

Benefits include:

- a. Reduced water consumption
- b. Improved crop growth
- c. Prevention of over-irrigation
- d. Better nutrient uptake.

3. Yield Prediction: AI algorithms analyze climatic data, soil conditions, crop growth stages, and management practices to predict vegetable yield accurately. Yield forecasting helps farmers plan harvesting, storage, and marketing strategies.

4. Weed Management: AI-enabled robotic systems and sensors can identify weeds and selectively spray herbicides only where needed. This minimizes chemical usage and environmental pollution.

5. Nutrient Management: AI-based decision support systems help determine the exact nutrient requirement of vegetable crops based on soil analysis and crop condition. Precision nutrient management improves fertilizer efficiency and reduces input costs.

6. Weather Forecasting and Crop Advisory: AI applications provide weather forecasts, disease alerts, and crop management recommendations to farmers through mobile applications. Timely advisories help farmers protect crops from adverse climatic conditions.

Drone Technology in Vegetable Farming

Drone technology has emerged as one of the most advanced innovations in precision agriculture. Agricultural drones are equipped with cameras, GPS systems, multispectral sensors, and spraying equipment.



1. Crop Monitoring: Drones capture high-resolution images of vegetable fields and provide real-time information about crop health, plant growth, and stress conditions.

Advantages:

- a. Rapid field assessment
- b. Early stress detection
- c. Reduced monitoring time
- d. Improved farm management

2. Precision Spraying: Drones are widely used for spraying pesticides, fungicides, micronutrients, and biofertilizers. Precision spraying ensures uniform chemical application and reduces human exposure to hazardous chemicals.

Benefits:

- a. Reduction in labor requirement
- b. Uniform spraying
- c. Lower pesticide consumption
- d. Time-saving operation.



3. Nutrient Deficiency Detection Multispectral cameras mounted on drones detect nutrient deficiencies by analyzing crop reflectance patterns. Farmers can apply fertilizers only where necessary.

4. Field Mapping and Surveying Drones generate accurate field maps and topographical information useful for land preparation, irrigation planning, and crop management.

5. Plant Population Estimation: Drone imagery helps estimate plant population and identify gaps in planting. This assists farmers in improving crop stand and productivity.

6. Monitoring of Pest and Disease Spread: Drone surveillance helps detect pest and disease outbreaks before they spread widely. Timely intervention minimizes economic losses.

Integration of AI and Drones in Vegetable Farming

The combination of AI and drones offers highly efficient and intelligent farming systems. Drones collect field data through sensors and cameras, while AI analyzes the collected data and provides actionable recommendations.

Examples include:

- a. AI-based disease diagnosis using drone images
- b. Smart spraying based on crop health analysis
- c. Real-time irrigation management
- d. Automated yield estimation
- e. Precision nutrient application.

This integration improves decision-making and resource management in vegetable farming.

Benefits of AI and Drone Technology in Vegetable Farming

The adoption of AI and drones provides several advantages:

1. Increased Productivity
2. Precision farming techniques improve crop growth and yield.
3. Reduced Labor Requirement
4. Automation reduces dependency on manual labor.

5. Efficient Resource Utilization
6. Optimal use of water, fertilizers, and pesticides minimizes wastage.
7. Early Detection of Problems.
8. Timely identification of diseases and nutrient deficiencies reduces crop losses.
9. Environmental Protection
10. Reduced chemical usage decreases environmental pollution.
11. Cost Reduction
12. Efficient farm management lowers production costs.
13. Improved Crop Quality
14. Better monitoring and management enhance vegetable quality and market value.

Challenges in Adoption

1. Despite numerous advantages, the adoption of AI and drone technology faces several limitations:
2. High initial investment
3. Lack of technical knowledge among farmers
4. Limited access to digital infrastructure
5. Small land holdings
6. Maintenance and operational costs
7. Regulatory restrictions for drone usage
8. Inadequate training facilities

Government support, farmer training, and affordable technologies are essential for large-scale adoption.

Future Prospects

The future of vegetable farming lies in automation, digital technologies, and precision agriculture. AI and drones are expected to become more affordable and farmer-friendly in the coming years.

Future developments may include:

1. Fully automated vegetable farms
2. AI-powered robotic harvesting
3. Smart greenhouses
4. Internet-connected farm monitoring systems
5. Real-time crop advisory services
6. Autonomous spraying drones

These technologies will play a significant role in ensuring sustainable vegetable production and food security.

Summary

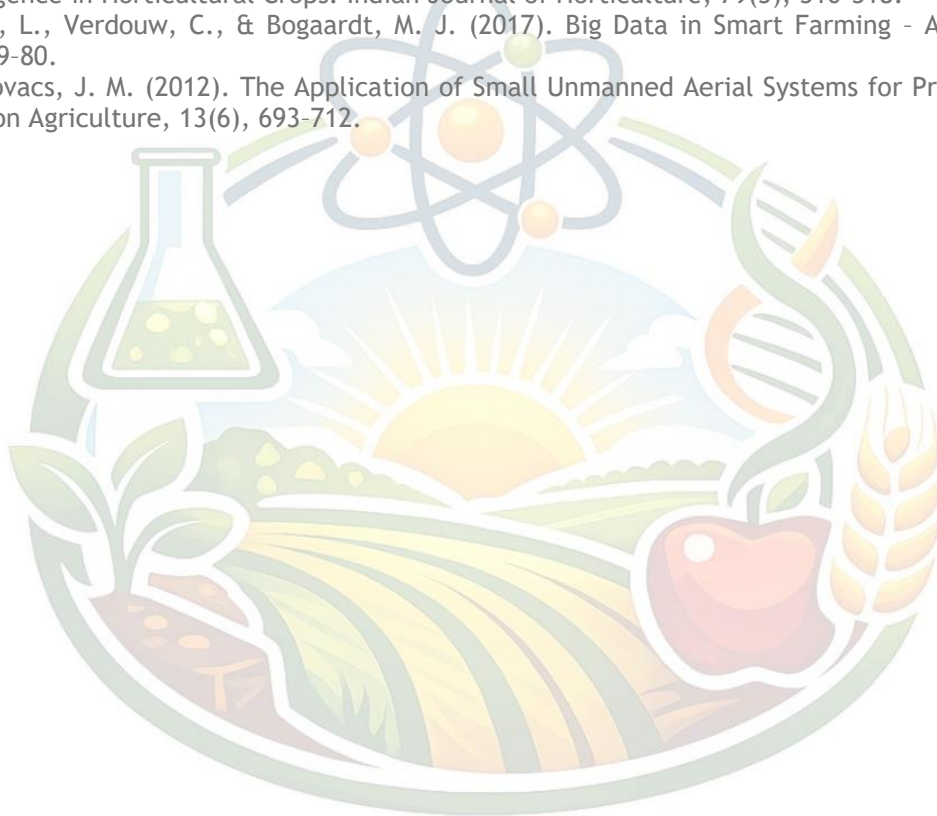
Artificial Intelligence and drone technology are transforming traditional vegetable farming into a modern, precise, and sustainable agricultural system. AI helps in intelligent decision-making, disease identification, irrigation management, and yield prediction, while drones assist in crop monitoring, spraying, and field analysis. The integration of these technologies improves productivity, reduces labor costs, and promotes efficient resource utilization. Although certain challenges such as high investment and lack of technical awareness exist, continuous technological advancements and government initiatives are expected to accelerate their adoption in the future. Smart vegetable farming through AI and drones has immense potential to revolutionize Indian agriculture and ensure sustainable vegetable production.

Conclusion

Innovative technologies such as Artificial Intelligence and drones are becoming essential components of modern vegetable farming. These technologies provide precision, efficiency, and sustainability in agricultural operations. AI-based systems enable accurate decision-making, while drones offer rapid monitoring and precision spraying capabilities. Together, they help improve productivity, reduce environmental impacts, and optimize resource utilization. The successful adoption of AI and drone technology can significantly contribute to sustainable vegetable production, higher farmer income, and enhanced food security. Therefore, awareness programs, training, government support, and affordable technological solutions are necessary to promote smart vegetable farming among farmers.

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Major Viral Diseases in Okra

Article ID: 74053

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Introduction

Okra (*Abelmoschus esculentus* L.) is one of the most important vegetable crops grown across India, valued for its nutritional importance and high market demand. However, its productivity is seriously affected by viral diseases, which have become a major constraint in recent years. Among them, **Yellow Vein Mosaic Virus (YVMV)** has long been recognized as the most destructive disease, causing yield losses ranging from 50 to 90 percent. In addition to this, **Enation Leaf Curl Virus (ELCV)** is now emerging as another serious threat in major okra growing regions. First reported in Karnataka during the early 1980s, can cause severe yield losses, especially when infection occurs at early stages of crop growth, sometimes even leading to complete crop failure. Along with these established viral diseases, **Tobacco Streak Virus (TSV)** has recently gained importance as a rapidly spreading problem, particularly in South India. Since these viruses spread efficiently through insect vectors and there is no direct cure once plants are infected, they pose a serious challenge to sustainable okra cultivation. Therefore, understanding their nature and adopting proper management practices is essential to reduce losses and improve productivity.

Yellow Vein Mosaic Virus (YVMV)

Causal Organism: Yellow Vein Mosaic Virus is caused by a begomovirus belonging to the family *Geminiviridae*. It is one of the earliest reported and most destructive viral pathogens affecting okra cultivation in India.

Symptoms: The disease is characterized by the appearance of yellowing along the veins of leaves, which later spreads to the entire leaf lamina. As the infection advances, leaves become pale yellow, reduced in size, and distorted. Infected plants show poor vigour and stunted growth. Flowering and fruiting are adversely affected, resulting in fewer, smaller, and poorly developed fibrous pods, ultimately reducing yield significantly.

Transmission: The virus is primarily transmitted by the whitefly (*Bemisia tabaci*). The insect acquires the virus from infected plants and transmits it to healthy plants during feeding. The spread of the disease is rapid under warm weather conditions, which favour the multiplication of the vector.

Enation Leaf Curl Virus (ELCV)

Causal Organism: Enation Leaf Curl Virus is caused by a begomovirus belonging to the family *Geminiviridae*. It is an emerging viral pathogen in okra and is often associated with satellite DNA components that enhance disease severity.

Symptoms: The disease is marked by the formation of small enations or outgrowths on the lower surface of leaves. As the disease progresses, leaves become thick, leathery, and curl upward. Plants exhibit twisting of stems and branches and become severely stunted. The fruits produced are small, deformed, and unsuitable for marketing, leading to heavy yield losses, especially when infection occurs at an early stage.

Transmission: The virus is transmitted by the whitefly (*Bemisia tabaci*), which acts as an efficient vector. It is not seed transmitted, but spreads rapidly through vector activity, particularly under hot and dry environmental conditions that favour whitefly multiplication.

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Tobacco Streak Virus (TSV)

Causal Organism: Tobacco Streak Virus belongs to the genus *Ilarvirus* under the family *Bromoviridae*. It is a positive-sense, single-stranded RNA virus with a tripartite genome and is known for its wide host range.

Symptoms: TSV infection initially appears as small yellow or chlorotic spots on leaves, along with mild mosaic and mottling. As the disease develops, veins may turn brown and show necrosis, and the plants become weak and stunted. A distinctive symptom is observed on the fruits, where chlorotic streaks appear, leading to deformation and loss of market value. Severe infections result in poor plant growth and low yield.

Transmission: The virus is mainly transmitted by thrips species such as *Megalurothrips*, *Frankliniella*, and *Thrips*. It can also spread through infected pollen and mechanically through plant sap during handling. Additionally, the virus survives in weed hosts like *Parthenium hysterophorus* and *Ageratum conyzoides*, which act as reservoirs.

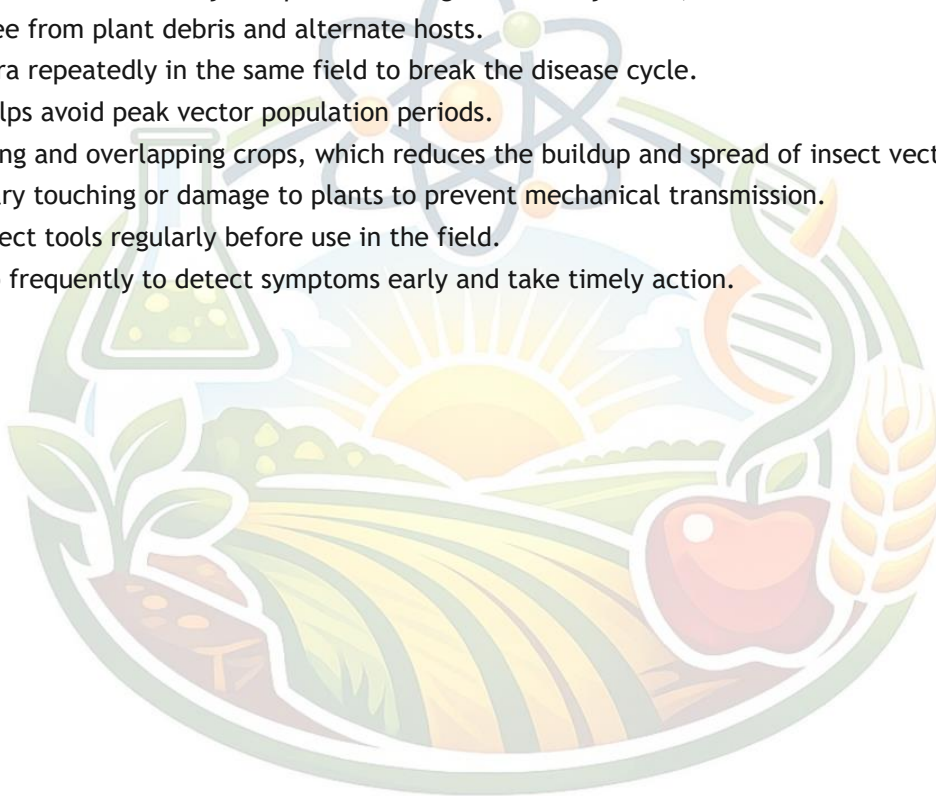
Common Management Practices for Viral Diseases of Okra (YVMV, ELCV & TSV)

Viral diseases of okra are difficult to manage because there is no cure once the plant is infected. They spread quickly through insect vectors like whiteflies and thrips and can survive in weed hosts, allowing them to persist in the field. Warm and dry conditions further increase vector populations and speed up disease spread.

Another challenge is that symptoms often appear only after significant damage has occurred. Early infection severely reduces yield and leads to poor-quality, unmarketable fruits, making these diseases a serious threat to okra production.

Since curing viral diseases is not possible, the focus must be on prevention and management. Farmers can reduce the impact of these diseases by adopting a few important practices:

1. Always use certified, virus-free seeds to prevent initial infection.
2. Uproot and destroy heavily infected plants to stop the spread.
3. Manage whiteflies and thrips using recommended insecticides.
4. Install yellow (for whiteflies) and blue (for thrips) sticky traps to monitor and reduce their population.
5. Eliminate weeds like *Parthenium hysterophorus* and *Ageratum conyzoides*, which act as virus reservoirs.
6. Keep the field free from plant debris and alternate hosts.
7. Avoid growing okra repeatedly in the same field to break the disease cycle.
8. Timely sowing helps avoid peak vector population periods.
9. Avoid overcrowding and overlapping crops, which reduces the buildup and spread of insect vectors.
10. Avoid unnecessary touching or damage to plants to prevent mechanical transmission.
11. Clean and disinfect tools regularly before use in the field.
12. Inspect the crop frequently to detect symptoms early and take timely action.

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Rugose Spiralling Whitefly in Coconut

Article ID: 74054

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Introduction

Coconut is widely known as the “tree of life” because of its immense economic and cultural importance. Every part of the coconut palm is useful, providing food, oil, fibre, timber, and income to millions of farming families across tropical regions. In India, coconut cultivation forms an important component of the agricultural economy, particularly in southern states. However, in recent years, coconut production has been increasingly threatened by the emergence of an invasive insect pest known as the Rugose Spiralling Whitefly (RSW).

What is Rugose Spiralling Whitefly?

The Rugose Spiralling Whitefly, scientifically known as *Aleurodicus rugioperculatus*, is a sap-sucking insect that has become a serious concern in coconut ecosystems. The pest was first described from Belize by Martin (2004) and later spread to Florida and several tropical countries. In India, it was first noticed in coconut plantations during 2016 in Tamil Nadu and Kerala (Sundararaj and Selvaraj, 2017). Since then, it has spread rapidly across states such as Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, and Telangana.

One of the major reasons for the successful establishment of this pest is its polyphagous nature. The insect feeds on more than 200 plant species, including banana, guava, mango, sapota, cocoa, papaya, jackfruit, curry leaf, ornamental palms, hibiscus, and several other ornamental plants (Elango *et al.*, 2019). This wide host range enables the pest to survive throughout the year and spread easily across different cropping systems.

Symptoms

The pest can be identified through several characteristic symptoms and signs. Female whiteflies lay eggs in distinct spiral patterns on the underside of leaves, which is one of the most recognizable features of infestation (Martin, 2004). The leaves often appear covered with white waxy material secreted by the insect (Fig.1).

Another important indication of infestation is the presence of sticky honeydew deposits on leaf surfaces. This honeydew supports the development of black sooty mould fungus, which forms dark patches on leaves and reduces photosynthesis (Mohan *et al.*, 2017). During severe infestations, leaves may appear blackened from a distance. Yellowing, drooping, premature drying, and shedding of leaves are also common symptoms. Heavy infestations weaken the palms and give them an unhealthy appearance.



Fig. 1. Symptoms of rugose spiralling whitefly on coconut leaf fronds (left), white waxy material secreted by the insect covering insect stages (middle), and black sooty mould on infested plants (right).

Life Cycle and Biology

The spiralling whitefly completes its life cycle in about 36-60 days depending on temperature and humidity. The insect undergoes incomplete metamorphosis with egg, crawler, nymph, pseudo-pupa, and adult stages.

1. Egg Stage: Female whiteflies lay eggs on the underside of leaves in a characteristic spiral or circular pattern, which gives the insect its name. The eggs are yellowish to creamy white and covered with a thin waxy substance for protection.

2. Crawler Stage: After hatching, the first immature stage known as the crawler emerges. This is the only active and mobile immature stage. The crawler moves around the leaf surface in search of a suitable feeding site. Once it settles, it inserts its needle-like mouthparts into the leaf tissue and begins sucking plant sap.

3. Nymphal Stage: After settling, the crawler moults into immobile nymphal stages. The nymphs are oval, flattened, and light yellow to golden in colour. As they grow, they produce dense white cottony wax and long waxy filaments on the leaf surface.

4. Pseudo-pupal Stage: The final immature stage is called the pseudo-pupa or puparium. During this stage, the insect remains inactive while transforming into the adult form.

5. Adult Stage: Adults are larger than common whiteflies, measuring about 2.5 mm in length. They possess white wings with irregular light brown markings and are covered with a waxy coating. Male adults have characteristic pincer-like structures at the tip of the abdomen (Stocks and Hodges, 2012). Both adults and nymphs feed by sucking sap from plants. During feeding, they excrete large amounts of sticky honeydew, which encourages the growth of black sooty mould fungus.

Nature of Damage

Both nymphs and adults damage the crop by sucking sap from the underside of leaves. Continuous sap feeding weakens the plant, resulting in yellowing, drying, and reduced vigour. A more serious problem associated with the pest is the production of honeydew, which promotes the growth of black sooty mould on leaf surfaces.

The mould forms a thick black coating that interferes with photosynthesis by blocking sunlight. As photosynthetic activity declines, plant growth and productivity are adversely affected (Mohan *et al.*, 2017). Honeydew also attracts ants and wasps, which protect whiteflies from natural enemies, further increasing pest survival.

Studies have shown that dwarf and hybrid coconut varieties are generally more susceptible to Rugose Spiralling Whitefly infestation compared to tall varieties. Chowghat Orange Dwarf and Malaysian Yellow Dwarf are among the highly susceptible varieties.

The increasing importance of this pest is mainly due to its invasive nature, rapid dispersal ability, and wide host range. The insect spreads easily through wind currents and the movement of infested planting materials. Heavy infestations can lead to considerable economic losses by reducing crop productivity and affecting the overall health of coconut plantations (Sundararaj and Selvaraj, 2017).

Influence of Weather on Pest Incidence

Environmental conditions greatly influence the multiplication and spread of Rugose Spiralling Whitefly. High temperatures, bright sunshine, and low humidity favour rapid population buildup. Severe infestations are commonly observed during summer months, particularly from April to May.

In contrast, rainfall reduces pest populations by washing away eggs, nymphs, and adults from leaf surfaces. Consequently, pest populations remain comparatively low during the rainy season. The tropical climate prevailing in many coconut-growing regions provides ideal conditions for the pest to establish and spread rapidly throughout the year.

Management Strategies

Effective management of Rugose Spiralling Whitefly requires an integrated approach involving cultural, mechanical, biological, botanical, and chemical methods.

1. Cultural Practices: Farmers should avoid using infested seedlings and maintain proper spacing to improve aeration within plantations. Balanced fertilizer application based on soil testing helps improve plant health and tolerance against pest attack. Severely infested leaves should be removed and destroyed to reduce pest buildup (Mohan *et al.*, 2017).

2. Surveillance and Monitoring: Regular field surveillance and monitoring are essential for early detection of the pest. The installation of yellow sticky traps helps monitor and reduce adult populations. Light traps may also help in monitoring adult activity during early morning and evening hours.

3. Mechanical Methods: Mechanical methods provide an immediate reduction in pest populations. Spraying water forcefully on the underside of leaves helps dislodge nymphs and adults. Jet water spraying also helps wash away honeydew and sooty mould deposits.

4. Biological Control: Biological control is considered the most effective and environmentally sustainable management strategy. Several natural enemies help suppress Rugose Spiralling Whitefly populations naturally. The parasitoid *Encarsia guadeloupae* is highly effective and capable of causing 60-70 percent parasitism of whitefly populations under field conditions (Mohan *et al.*, 2017). Another parasitoid, *Encarsia dispersa*, also contributes to natural control. Predators such as green lacewings (*Chrysoperla* spp.), ladybird beetles, and red ants feed on the pest and help reduce infestations. Entomopathogenic fungi such as *Isaria fumosorosea* have also demonstrated excellent control potential against the pest (Sandeep *et al.*, 2022).

5. Botanical Control: Neem oil at 0.5 percent concentration and Neem Seed Kernel Extract (NSKE) at 5% effectively suppress whitefly populations without causing serious harm to beneficial insects.

6. Chemical Control: Chemical insecticides should be used only under severe infestation conditions and with proper caution. Systemic insecticides such as Imidacloprid, Acetamiprid, Clothianidin, and Dinotefuran are commonly recommended for management. However, indiscriminate use of chemicals may suppress parasitoids and predators, leading to ecological imbalance and resurgence of the pest. Therefore, chemical control should always be considered as a last option within an Integrated Pest Management (IPM) programme.

7. Management of Sooty Mould: Management of sooty mould is equally important for restoring plant health. Spraying starch solution or maida paste mixed with soap helps loosen and remove the black fungal coating from leaf surfaces, thereby improving photosynthesis and overall plant appearance.

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The Hidden Cost of Welfare: Transaction Costs in Accessing Government Schemes among Small and Marginal Farmers in Semi-Arid India

Article ID: 74055

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Introduction

Government schemes and development programmes play a crucial role in supporting agriculture and improving rural livelihoods in India. Over the years, central and state governments have introduced numerous initiatives such as PM-KISAN, PMFBY (Pradhan Mantri Fasal Bima Yojana), Soil Health Card Scheme, PMKSY (Pradhan Mantri Krishi Sinchayee Yojana), Kisan Credit Card (KCC), Rythu Bandhu, crop insurance programmes, input subsidy schemes, and various welfare programmes targeted at farmers. These schemes aim to enhance farm income, reduce production risks, improve resource use efficiency, and strengthen food security.

However, the actual benefits received by farmers often depend not only on the availability of these schemes but also on their ability to access them. For small and marginal farmers, especially those living in the semi-arid regions of India, obtaining benefits from government programmes can involve considerable hidden costs known as **transaction costs**.

What are Transaction Costs?

Transaction costs refer to the expenses incurred while obtaining information, completing procedures, meeting eligibility requirements, and receiving benefits from government programmes. These costs are separate from the direct financial contribution required under a scheme. They include:

1. Time spent gathering information about schemes.
2. Travel expenses to government offices or banks.
3. Documentation and application costs.
4. Costs of obtaining certificates and records.
5. Opportunity cost of labour and lost wages.
6. Expenses incurred in following up with officials.
7. Delays in receiving benefits.

Although these costs may appear small individually, they can become substantial for resource-poor farmers.

Challenges in Semi-Arid Regions

Semi-arid regions, such as parts of Telangana, Karnataka, Maharashtra, Rajasthan, and Andhra Pradesh, face unique agricultural challenges. These areas experience low and erratic rainfall, frequent droughts, groundwater depletion, and limited irrigation facilities. Small and marginal farmers dominate the agricultural landscape and often depend on rainfed farming systems.

Due to scattered villages, inadequate transportation facilities, poor digital connectivity, and limited institutional support, farmers in these regions frequently encounter higher transaction costs when accessing government services.

For example, a farmer may need to travel multiple times to a Mandal office, agriculture department, bank, or insurance office to complete formalities for a crop insurance claim or subsidy application. Such repeated visits increase both monetary and non-monetary costs.

Major Sources of Transaction Costs

Information Costs: Many farmers are unaware of scheme eligibility criteria, application deadlines, or required documents. Information often reaches farmers through informal channels such as neighbours, input dealers, or local leaders. Inadequate awareness leads to additional efforts and delays in accessing benefits.

Documentation Costs: Government programmes usually require documents such as Aadhaar cards, land ownership records, bank account details, caste certificates, or tenancy proofs. Obtaining and updating these records may involve fees, travel expenses, and multiple visits to government offices.

Travel and Administrative Costs: Farmers often incur transportation expenses while visiting agriculture offices, banks, insurance centres, and revenue departments. In remote villages, public transportation may be limited, increasing the burden on beneficiaries.

Opportunity Costs: Perhaps the most overlooked component is the opportunity cost of time. Small farmers and agricultural labourers lose valuable working hours while pursuing applications and approvals. During peak agricultural seasons, these losses can significantly affect household income.

Delay Costs: Delays in receiving subsidies, insurance compensation, or credit support can reduce the effectiveness of schemes. For instance, delayed crop insurance payments may force farmers to borrow from informal lenders at high interest rates.

Impact on Small and Marginal Farmers

Transaction costs disproportionately affect small and marginal farmers because they possess fewer financial resources, lower educational levels, and limited access to institutional networks. In many cases, the hidden costs associated with obtaining benefits discourage farmers from applying for schemes altogether.

Research studies have shown that when transaction costs become too high, eligible farmers may choose not to participate in government programmes despite potential benefits. Consequently, the intended objectives of welfare interventions may not be fully achieved.

High transaction costs can also create inequalities where larger and better-connected farmers access benefits more easily than smaller farmers. This situation undermines the inclusiveness of agricultural development programmes.

Role of Digital Technologies

Recent efforts toward digitization have helped reduce certain transaction costs. Online application portals, direct benefit transfers (DBT), Aadhaar-linked payments, mobile applications, and digital land records have simplified administrative procedures.

However, digital systems can also create new challenges. Elderly farmers, women farmers, and farmers with limited digital literacy may struggle to navigate online platforms. Poor internet connectivity in remote semi-arid regions further limits the effectiveness of digital solutions.

Therefore, technology should be complemented by local support mechanisms such as village-level facilitation centres, extension workers, and farmer producer organizations (FPOs).

The Way Forward

Reducing transaction costs is essential for improving the effectiveness and inclusiveness of agricultural schemes. Policymakers can consider several measures:

1. Simplifying application procedures and documentation requirements.
2. Strengthening village-level service delivery mechanisms.
3. Expanding awareness campaigns through extension services.
4. Improving digital literacy among farmers.
5. Integrating databases across departments to reduce repeated submissions of documents.
6. Establishing single-window service centres for agricultural schemes.
7. Ensuring timely disbursement of benefits and compensation.

Conclusion

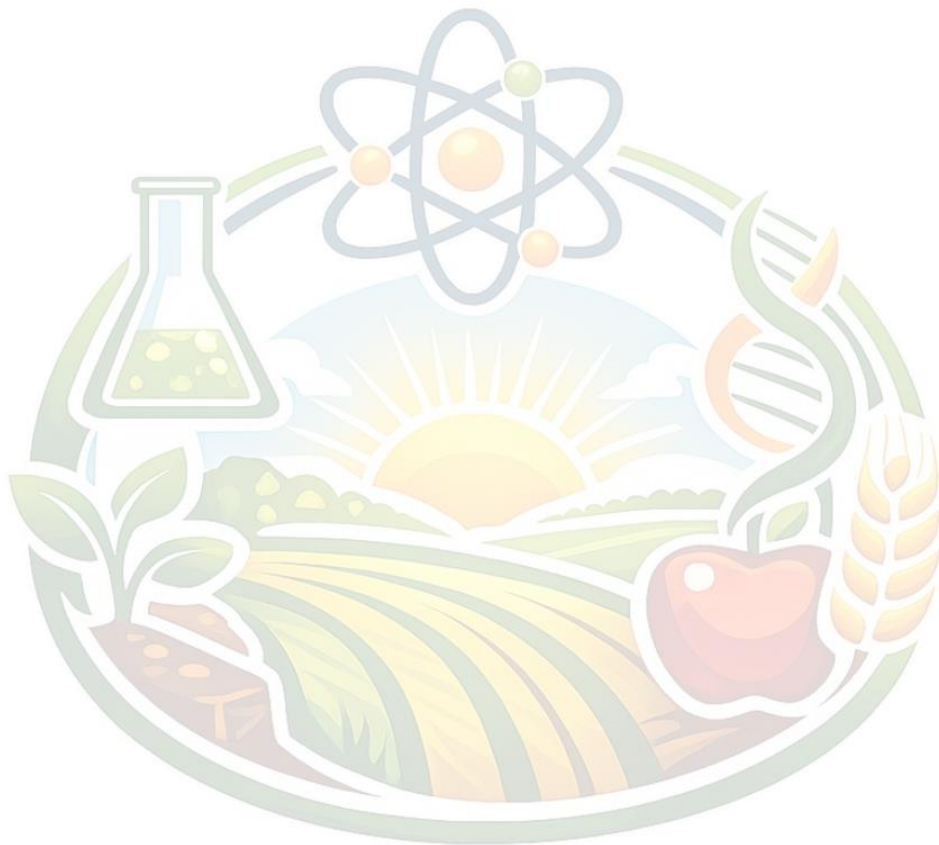
Government schemes have immense potential to improve the livelihoods of small and marginal farmers in India's semi-arid regions. However, the success of these programmes depends not only on the amount of financial assistance provided but also on the ease with which farmers can access benefits. Transaction costs represent a hidden barrier that often prevents deserving beneficiaries from fully utilizing available opportunities. Reducing these costs can enhance programme effectiveness, improve farmer welfare, and contribute to more equitable and sustainable agricultural development.

Understanding and addressing transaction costs should therefore become a key priority in the design and implementation of future agricultural policies and rural development programmes.

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Export of Honey from India

Article ID: 74056

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Importance of Honey Export

Honey export is important for farmers, beekeepers, and the national economy in several ways:

- 1. Foreign Exchange Earnings:** Exporting honey helps a country earn valuable foreign currency, strengthening the economy.
- 2. Higher Income for Beekeepers:** International markets often offer better prices than domestic markets, increasing the income of beekeepers and honey producers.
- 3. Employment Generation:** Honey production, processing, packaging, transportation, and export activities create employment opportunities in rural areas.

India's Honey Export data for Last 10 Years

The export of natural honey from India has shown a significant increase over the last decade due to rising global demand, especially from the United States, UAE, and Middle Eastern countries.

Year	Export Quantity (MT)	Export Value (USD Million)
2015-16	~38,000	~65
2016-17	~44,000	~72
2017-18	~51,000	~81
2018-19	~61,000	~108
2019-20	~59,000	~95
2020-21	~60,000	~97
2021-22	74,413	163.77
2022-23	~80,000	190.06
2023-24	~92,000	~196
2024-25	100,773	206.47

Figures for recent years are based on APEDA and DGCIS export statistics.

Major Importers of Indian Honey

1. United States
2. United Arab Emirates
3. Saudi Arabia
4. Portugal
5. Libya.

Different Types of Honey



Honey can be classified based on its floral source, production method, and geographical origin.

1. Floral Source-Based Honey:

a. Multifloral Honey:

- i. Produced from nectar of many flower species.

ii. Most common type in India.

b. Mustard Honey

- i. Obtained from mustard flowers.
- ii. Light yellow color and mild taste.

c. Litchi Honey

- i. Produced from litchi blossoms.
- ii. Sweet with a fruity aroma.

d. Eucalyptus Honey

- i. Derived from eucalyptus flowers.
- ii. Strong flavor and medicinal properties.

e. Acacia Honey

- i. Light-colored and slow to crystallize.
- ii. Considered a premium honey.

f. Sunflower Honey

- i. Produced from sunflower crops.
- ii. Golden-yellow color and mild flavor.

g. Neem Honey

- i. Collected from neem blossoms.
- ii. Known for antibacterial properties.

h. Ajwain Honey

- i. Produced from ajwain flowers.
- ii. Popular for digestive benefits.

i. Jamun Honey

- i. Obtained from jamun flowers.
- ii. Often preferred by health-conscious consumers.

j. Coriander Honey

- i. Produced from coriander flowers.
- ii. Distinctive aroma and taste.

2. Based on Production Method

a. Raw Honey:

- i. Unprocessed and unheated.
- ii. Retains natural enzymes and nutrients.

b. Processed Honey: Filtered and pasteurized for commercial sale.

c. Organic Honey: Produced according to organic farming standards.

d. Wild Forest Honey: Collected from bees in natural forests. Rich in natural flavors and minerals.

3. Specialty Honey:

a. Comb Honey - Sold with the honeycomb intact.

b. Creamed Honey - Processed to give a smooth, spreadable texture.

c. Manuka Honey - Produced mainly in New Zealand from Manuka flowers; highly valued for medicinal uses.

d. Sidr Honey - Premium honey produced in Yemen and nearby regions.

Major Honey Types Produced in India

These varieties differ in color, aroma, taste, nutritional composition, and export potential.

Multifloral Honey	Mustard Honey	Litchi Honey	Eucalyptus Honey	Ajwain Honey
Neem Honey	Sunflower Honey	Forest Honey	Jamun Honey	

Most Demanded Honey Types in Local Market and Export Market

Honey demand differs between domestic consumers and international buyers based on taste, health benefits, price, and quality standards.

Sr no	Honey Type	Local Market Demand	Export Market Demand
1	Multifloral Honey	Very High	Very High
2	Mustard Honey	High	Very High
3	Litchi Honey	High	High
4	Eucalyptus Honey	High	High
5	Jamun Honey	High	Medium to High
6	Forest Honey	Medium	High
7	Acacia Honey	Medium	Very High
8	Organic Honey	Growing	Very High
9	Ajwain Honey	Medium	Niche Demand

10	Neem Honey	Medium	Niche Demand

Most Demanded Honey in Export Markets

1. Multifloral Honey:

- The largest export category from India.
- Preferred because of large-scale availability and competitive pricing.
- Major shipments go to the United States, United Arab Emirates, and Saudi Arabia.

2. Mustard Honey:

- Strong demand in European markets.
- Light color and mild taste make it suitable for international consumers.

3. Acacia Honey:

- Premium export variety.
- Commands higher prices because of its clarity and slow crystallization.

4. Litchi Honey: Popular in premium segments of the United States and Middle East markets due to its fruity aroma.

5. Organic and Forest Honey:

- Rapidly growing demand among health-conscious consumers worldwide.
- Often sold at premium prices.

Top Export-Oriented Honey Types from India

Multifloral Honey	Mustard Honey	Acacia Honey	Litchi Honey	Eucalyptus Honey
Forest Honey	Organic Honey	Sunflower Honey	Jamun Honey	Himalayan Wild Flora Honey

Conclusion

For the local Indian market, Multifloral Honey, Jamun Honey, and Eucalyptus Honey have the highest demand. For exports, Multifloral Honey, Mustard Honey, Acacia Honey, Litchi Honey, and Organic Honey are the most demanded varieties because of their quality, flavor, and international consumer preferences.



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Food Waste Oilseed and Nut Waste Valorisation

Article ID: 74057

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Summary of Article

The rapidly growing global agri-food sector generates enormous quantity of processing waste that introducing significant challenges such as economic and environmental disposal. Among these, oilseed press-cakes, hulls, and nut processing waste generates large amount of by-products.

These underutilized biomass/ residues are rich in component such as proteins, dietary fibers, bioactive compounds, and lignocellulosic materials that can be converted into valuable resources using biotechnological interventions. Applications such as microbial fermentation, enzymatic processing, solid-state fermentation, and anaerobic digestion can be used to convert huge biomass into value-added products.

The process of valorization using biotechnological approaches convert waste into value added products like enzymes, antioxidants, biofuels, biofertilizers, and protein concentrates. This valorisation not only reduces pollution and landfill burden but also supports sustainable development and circular bioeconomy concepts.

Despite of challenges like feedstock variability and process scalability, adaptation of biotechnological tools offers significant economic and environmental benefits using biowaste.

Introduction

Oilseed and nut processing industries generate a significant amount of solid by-products at different stages of oil extraction and nut handling. These residues include press cakes / oilseed meals, shells, hulls, skins, and filter fines, which are produced after mechanical pressing, solvent extraction, and dehulling processes. Instead of being mere waste, these by-products possess high nutritional and biochemical value.

Press cakes are known to contain 30-50% protein, substantial amounts of structural carbohydrates (cellulose, hemicellulose), residual oil, dietary fibre, micronutrients, and various bioactive compounds such as phenolics, flavonoids, terpenes, tocopherols (vitamin-E), and essential amino acids.

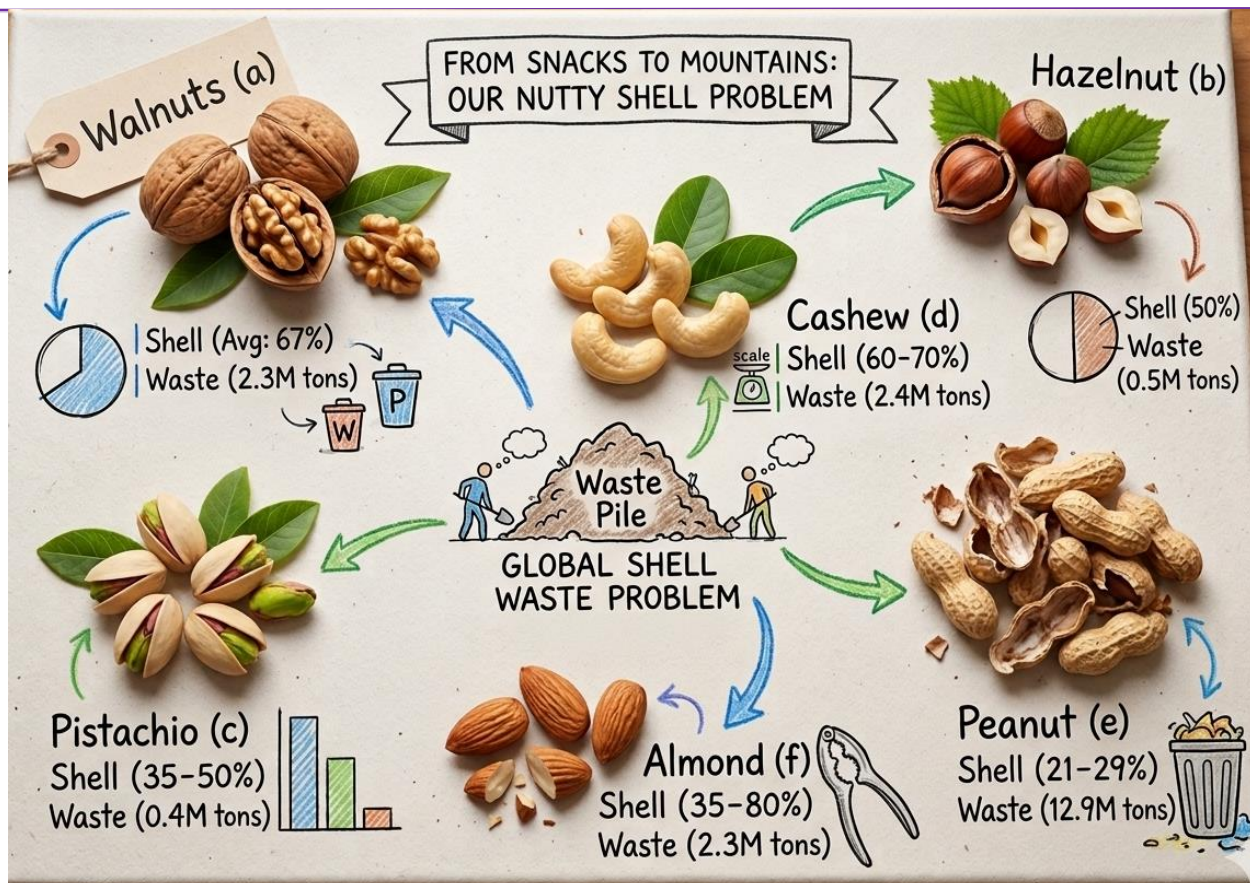
Nut shells and husks are rich in lignocellulosic material, which makes them excellent sources for the production of biofuels, biochar, and bio-composites. Due to their natural composition and biochemical richness, these residues are now considered valuable feedstocks for biotechnological valorization rather than waste meant for disposal. Through advanced biotechnology and green processing techniques such as solid-state fermentation, enzymatic hydrolysis, anaerobic digestion, and aqueous enzymatic extraction, these wastes can be transformed into a wide range of value-added and commercially important products—including functional proteins, industrial enzymes, antioxidants, organic acids, dietary supplements, biodegradable polymers, and even renewable energy like biogas and bioethanol.

Utilizing oilseed and nut waste not only minimizes environmental pollution caused by landfilling or burning, but it also aligns with the modern concept of a circular bio-economy, where every by-product is reused efficiently within the production system.

Effective utilization reduces waste-management expenses for industries, lowers carbon emissions, and creates economic opportunities by generating new product streams. Thus, valorizing these agricultural residues is an essential and sustainable approach to achieve zero-waste agro-processing and long-term environmental and economic benefit.

Types of Waste

- 1. Press cakes/meals (oilseed cakes):** Residues after mechanical/solvent extraction of soybean, rapeseed/mustard, sesame, groundnut, sunflower etc.
- 2. Shells/hulls/skins:** Nut shells and hulls high in bioactive compounds (example: cashew nut shell liquid).
- 3. Fine fractions:** Suitable for fermentation or extraction.



Biotechnological Approaches for Valorization

- 1. Microbial Fermentation** - This technique utilizes selected bacterial, yeast, or fungal strains to convert residual sugars, oils, and proteins in oilseed/nut waste into value-added metabolites such as enzymes, organic acids (citric, lactic), and bioactive peptides.
- 2. Enzymatic Processing** - It uses different commercial or microbially produced enzymes such as proteases, cellulases, and lipases to hydrolyze complex macromolecules in the waste matrix, releasing bioactive peptides, fermentable sugars, and free fatty acids/phenolics.
- 3. Solvent or Green Extraction** - Extraction methods recover bioactive oils, phenolics, and specialty chemicals using advanced techniques such as supercritical CO₂ extraction, ultrasound- or microwave-assisted extraction, and bio-based solvents (ethanol, limonene).
- 4. Solid-State Fermentation (SSF)** - SSF uses fungal or bacterial cultures grown directly on the moist solid waste substrate (low water activity), closely mimicking the natural habitat of many industrial enzyme-producing microbes. SSF is particularly suited to lignocellulosic and shell-based residues, yielding cellulases, xylanases, and tannases while simultaneously upgrading the substrate's nutritional profile for animal feed.
- 5. Anaerobic Digestion / Composting** - Converts the organic fraction of residues into biogas (methane-rich) through microbial consortia under anaerobic conditions, while composting (aerobic) stabilizes the residual biomass into a nutrient-rich digestate/compost.

Value-Added Products from Waste

1. Bioactive extracts and specialty chemicals (CNSL, antioxidants).
2. Protein concentrates and peptides for feed/food.
3. Industrial enzymes from SSF.
4. Bioenergy (biogas), biofertilizer (digestate).

Challenges and Future Perspectives

- 1. Variability of feedstock** - composition of oilseed/nut waste fluctuates with species, geography, season, and processing method, making standardized process design difficult.
- 2. Presence of anti-nutritional factors** - tannins, phytates, and oxalates can hinder protein digestibility and bioactivity, requiring additional detoxification or processing steps before food/feed use.

3. Process economics and scale-up challenges - many green extraction and enzymatic technologies remain capital-intensive at industrial scale, and yields demonstrated at lab scale do not always translate efficiently to pilot or commercial operations.

4. Regulatory and safety challenges - novel extracts and fermentation-derived ingredients often require extensive safety assessment and regulatory approval before market entry, particularly for food, feed, and pharmaceutical use.

Conclusion

Oilseed and nut wastes represent a substantial and currently underutilized bioresource. Microbial and solid-state fermentation, enzymatic processing, green extraction, and anaerobic digestion, these residues can be systematically transformed into functional extracts, proteins, enzymes, and bioenergy. As feedstock variability, anti-nutritional factors, and scale-up barriers are progressively addressed through improved bioprocess engineering and supportive regulatory frameworks, oilseed and nut waste valorization is well positioned to become a key pillar of sustainable, circular bioeconomy models worldwide.

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Oil Palm in Rayalaseema Region: A High-Income Crop for Edible Oil Security and Sustainable Farming

Article ID: 74058

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India is one of the largest consumers of edible oils in the world, yet a major share of its requirement is met through imports. To reduce this dependence and strengthen domestic production, oil palm has emerged as a strategic crop under the National Mission on Edible Oils-Oil Palm (NMEO-OP). Among Indian states, Andhra Pradesh has become the leading contributor to oil palm cultivation and crude palm oil production, creating a strong foundation for expansion into suitable irrigated regions such as Rayalaseema.

Oil palm is globally recognized as the highest oil-yielding crop per unit area. Compared to traditional oilseed crops like ground nut, sunflower, soybean, and sesame, it produces several times more edible oil from the same land area. Native to West Africa, oil palm is now widely cultivated in tropical regions, with Indonesia and Malaysia leading global production. In India, its commercial expansion has been supported by government policy, private sector participation, and assured market linkages.

Andhra Pradesh: India's Oil Palm Hub

Andhra Pradesh holds a dominant position in India's oil palm sector, contributing nearly half of the total cultivated area and a major share of crude palm oil production. The success of the crop in coastal districts has encouraged its gradual expansion into irrigated tracts of Rayalaseema. With improving irrigation infrastructure, micro-irrigation adoption, and government support, oil palm is emerging as a viable long-term commercial crop for farmers in drought-prone regions.

Suitability for Rayalaseema Conditions

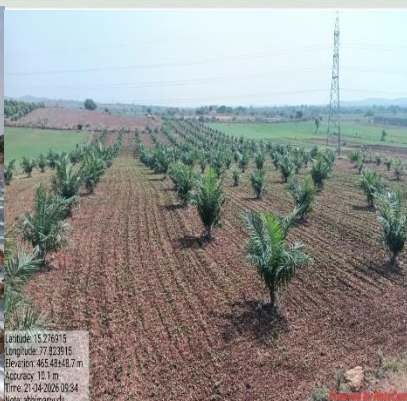
Although oil palm is traditionally suited to high rainfall regions, it can be successfully cultivated in Rayalaseema under assured irrigation. The crop requires deep, well-drained soils and continuous moisture supply, which can be efficiently managed through drip irrigation systems. Water-saving practices such as mulching, farm ponds, rainwater harvesting, and cover cropping are essential to sustain productivity in semi-arid conditions.

Importance of Intercropping (First 4 Years Income Support)

A major advantage of oil palm cultivation is the opportunity for intercropping during the initial 3-4 years, when palm canopies are not fully developed. This allows farmers to generate regular income before the main crop enters its yielding phase.

Suitable intercrops include groundnut, greengram, blackgram, cowpea, vegetables (tomato, chilli, brinjal, okra, cabbage), onion, garlic, turmeric, ginger, banana, fodder crops, and flower crops (Crossandra and Marigold). Legume intercrops improve soil fertility through nitrogen fixation, while vegetable and spice crops provide high market returns.

Depending on crop selection and management, farmers can earn approximately ₹40,000 to ₹1,50,000 per hectare annually from intercrops. This income significantly reduces financial stress during plantation establishment and improves overall farm profitability. Thus, intercropping acts as a “bridge income system” until oil palm begins commercial production.





Different Intercrops In Oil palm

Scientific Cultivation Practices

Successful oil palm cultivation depends on proper planning and scientific management. Recommended spacing is 9 m × 9 m × 9 m in a triangular system, accommodating about 143 palms per hectare. Quality planting material, timely field preparation, and proper pit filling are critical for plantation establishment.

Oil palm is a nutrient-demanding crop requiring balanced application of nitrogen, phosphorus, potassium, magnesium, and micronutrients. Integration of organic manures with chemical fertilizers improves soil health and long-term productivity. Soil testing and leaf analysis help in precise nutrient management.

Weed control is essential during early growth stages. Mulching, cover crops, and basin management help suppress weeds and conserve soil moisture while improving soil structure.

Water Management: Key to Success in Rayalaseema

Oil palm requires continuous water supply for optimum growth. Drip irrigation is essential in Rayalaseema to ensure efficient water use. Depending on age, water requirement ranges from 100 litres per palm per day in young plantations to over 300 litres in mature palms. Efficient irrigation scheduling, along with moisture conservation practices, ensures stable productivity even under semi-arid conditions.

Pest and Disease Management

Major pests include rhinoceros beetle and red palm weevil, which damage young and mature palms by attacking growing points and trunk tissues. Integrated pest management involving field sanitation, pheromone traps, and regular monitoring is essential for control.

Important diseases include basal stem rot and bud rot. These can be minimized through proper drainage, use of healthy planting material, and removal of infected palms. Early detection and preventive management are crucial for long-term plantation health.



Rhinoceros beetle



Red palm weevil

Harvesting and Yield Potential

Oil palm begins yielding from the third to fourth year, with commercial production starting from the fifth year onwards. Harvesting is done every 10-15 days by cutting fresh fruit bunches at the correct maturity stage. Timely harvesting is essential to maintain oil quality and maximize returns.

Under good management practices, yield levels of 25-35 tonnes of fresh fruit bunches per hectare per year can be achieved, making oil palm one of the most productive commercial crops in agriculture.

Processing and Value Addition

Harvested fresh fruit bunches are transported quickly to processing mills to extract crude palm oil and palm kernel oil. Delayed processing reduces oil quality, making timely transport critical.

Palm oil is widely used in cooking oils, bakery products, processed foods, confectionery, soaps, detergents, cosmetics, pharmaceuticals, and biodiesel production. By-products such as empty fruit bunches and palm kernel cake are used for composting, organic manure production, and animal feed, supporting circular agriculture.

Government Support and Schemes

The Government of India promotes oil palm under NMEO-OP with support for planting material, plantation establishment, and micro-irrigation systems. The Government of Andhra Pradesh further strengthens the sector through subsidies, technical guidance, extension services, and assured market linkages.

Farmers also benefit from training programmes, field demonstrations, and price support mechanisms linked to oil recovery, making oil palm a secure long-term investment.

Industry Participation and Market Linkage

A strong network of oil palm companies supports cultivation and ensures assured procurement of fresh fruit bunches. Major players include Navabharat Limited, Godrej Agrovet Limited, 3F Oil Palm Private Limited, Patanjali Foods Limited, Ruchi Soya (now part of Patanjali Foods), APOILFED, Asian Oil Palm Limited, Liv Palm Resources Private Limited, and other approved processors operating across Andhra Pradesh.

These companies provide planting material, extension services, field support, procurement systems, and processing infrastructure, ensuring farmers have a reliable market and technical backup throughout the crop lifecycle.

Conclusion: A Transformative Crop for Rayalaseema

Oil palm represents a long-term, high-income agricultural opportunity for irrigated areas of Rayalaseema. With proper water management, scientific cultivation practices, and strong institutional support, farmers can achieve sustainable productivity and stable income for nearly 25-30 years.

The combination of intercrop income during the initial years and assured returns from oil palm in later stages makes this crop economically attractive and resilient. Supported by government schemes and industry partnerships, oil palm has the potential to transform the agricultural landscape of Rayalaseema and contribute significantly to India's edible oil self-reliance.

Key Message

Oil palm offers a unique blend of high productivity, assured market, government support, and long-term income security making it one of the most promising crops for the future of Rayalaseema farming.

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Participatory Plant Breeding (PPB)

Article ID: 74059

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Introduction

Participatory Plant Breeding (PPB) is an approach to crop improvement that actively involves farmers and other stakeholders in the plant breeding process. Unlike conventional plant breeding, which is largely researcher-driven and conducted at research stations, PPB integrates farmers' knowledge, preferences, and local conditions into breeding decisions. This approach enhances the relevance, adoption, and impact of newly developed varieties, especially in diverse, marginal, and resource-poor environments. PPB emerged as a response to the limitations of centralized breeding programs, which often failed to address the needs of smallholder farmers, particularly in developing countries.

Concept and Definition

Participatory Plant Breeding can be defined as: A collaborative breeding approach in which plant breeders, farmers, and other stakeholders jointly participate in the selection, evaluation, and development of crop varieties adapted to specific environments and user needs.

Key elements of PPB include:

- Decentralized selection
- Farmer participation in decision-making
- On-farm testing
- Integration of scientific and indigenous knowledge.

Rationale for Participatory Plant Breeding

1. Limitations of Conventional Plant Breeding:

- Conducted mainly under controlled research station conditions
- Limited representation of diverse agro-ecological zones
- Poor adoption of varieties due to mismatch with farmers' needs
- Neglect of traits like taste, cooking quality, fodder value, and cultural preferences.

2. Need for PPB:

- High genotype × environment (G×E) interaction
- Diverse farming systems and stress-prone environments
- Climate change and unpredictable growing conditions
- Need for farmer empowerment and local seed systems.

Objectives of Participatory Plant Breeding

The major objectives of PPB are:

- To develop crop varieties well-adapted to local agro-ecological conditions
- To incorporate farmer-preferred traits into breeding programs
- To enhance genetic diversity in farmers' fields
- To improve adoption rate of new varieties
- To strengthen farmer capacity and empowerment
- To promote sustainable and resilient farming systems.

Principles of Participatory Plant Breeding

PPB is guided by the following principles:

- 1. Participation:** Farmers actively participate rather than serve as passive recipients
- 2. Decentralization:** Breeding activities are conducted on farmers' fields
- 3. Collaboration:** Scientists and farmers work as equal partners
- 4. Diversity-oriented selection:** Focus on multiple traits and adaptation
- 5. Transparency:** Shared decision-making and information exchange.

Types of Participatory Plant Breeding

1. Participatory Variety Selection (PVS):

- Farmers evaluate and select from advanced breeding lines or released varieties
- Selection based on yield, taste, maturity, stress tolerance, etc.
- Faster and simpler than full PPB.

2. Participatory Plant Breeding (PPB) Proper:

- Farmers involved from early generations
- Joint selection during segregation
- Greater farmer influence on genetic makeup

3. Functional PPB:

- Breeders handle crossing and early selection
- Farmers select in later generations under real field conditions.

Methodology of Participatory Plant Breeding

1. Selection of Crop and Area:

- Crops important for local food security
- Regions with high environmental variability or marginal conditions

2. Stakeholder Identification:

- Farmers (men and women)
- Breeders and agronomists
- Extension workers
- NGOs and seed producers

3. Parent Selection and Crossing:

- Parents chosen jointly by breeders and farmers
- Inclusion of local landraces and elite lines

4. On-Farm Trials:

- Conducted in farmers' fields
- Managed by farmers with minimal intervention
- Replicated across locations

5. Farmer Evaluation and Selection:

- Visual scoring, ranking, and preference analysis
- Traits evaluated: yield, maturity, taste, grain color, lodging, pest resistance

6. Data Collection and Analysis:

- Combination of qualitative (farmer perception) and quantitative data
- Statistical analysis of yield and stability

7. Seed Dissemination:

- Farmer-to-farmer seed exchange
- Community seed banks
- Local seed enterprises

Role of Farmers in PPB

Farmers play multiple roles:

- Identifying breeding objectives
- Selecting parents and lines
- Managing trials
- Evaluating varieties
- Conserving and multiplying seed

Their indigenous knowledge contributes to:

- Understanding local stress factors
- Trait prioritization
- Traditional selection criteria

Advantages of Participatory Plant Breeding

- Higher adoption rate of varieties
- Better adaptation to local conditions
- Reduced breeding time

4. Cost-effective testing
5. Empowerment of farming communities
6. Conservation of agrobiodiversity
7. Gender inclusiveness.

Limitations and Challenges of PPB

1. Difficulty in maintaining experimental precision
2. Variation in farmers' selection criteria
3. Need for strong coordination
4. Limited scalability
5. Intellectual property and ownership issues
6. Requirement of long-term commitment.

PPB and Climate Change

PPB plays a vital role in climate-resilient agriculture by:

1. Selecting for stress tolerance under real conditions
2. Promoting locally adapted varieties
3. Enhancing genetic diversity
4. Supporting rapid adaptation to changing climates.

PPB in Different Crops

PPB has been successfully applied in:

1. Cereals: rice, wheat, maize
2. Pulses: chickpea, lentil
3. Millets: sorghum, pearl millet
4. Root and tuber crops
5. Horticultural crops.

Integration of PPB with Modern Breeding Tools

PPB can be combined with:

1. Marker-assisted selection (MAS)
2. Genomic selection
3. GIS-based environment characterization
4. Digital data collection tools

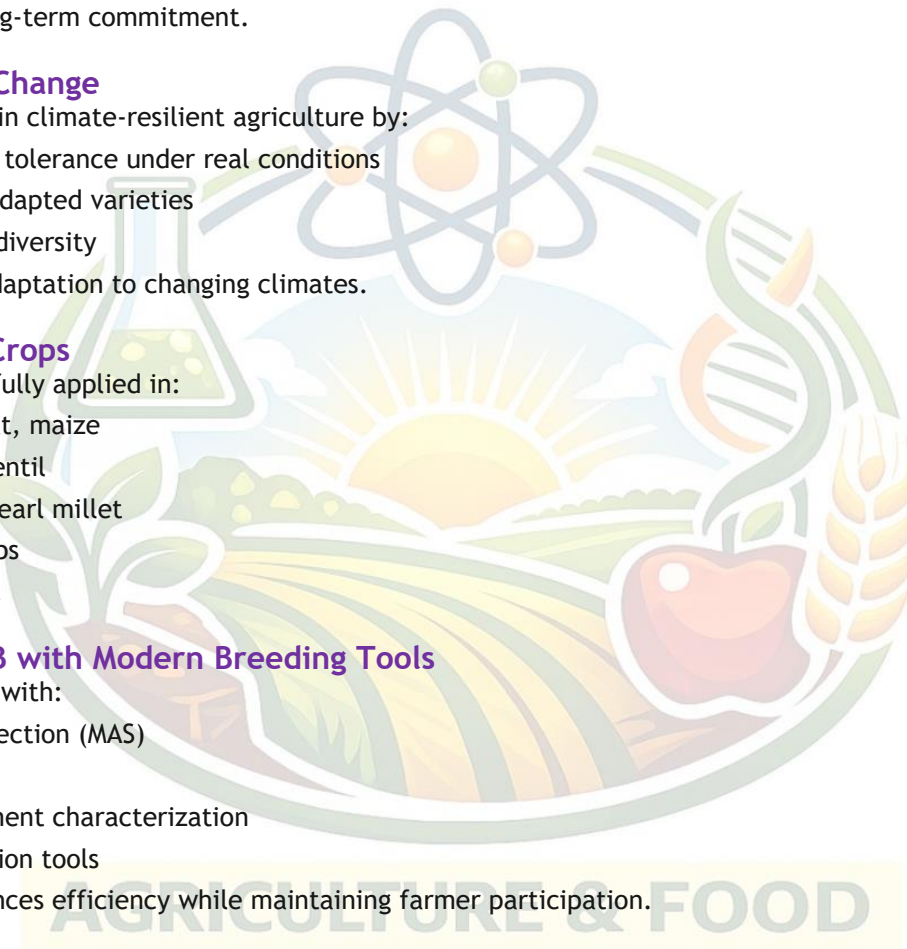
This integration enhances efficiency while maintaining farmer participation.

Case Studies

1. **Rice PPB in South Asia:** Improved adoption and yield stability
2. **Barley PPB in drylands:** Enhanced drought tolerance
3. **Maize PPB in Africa:** Increased farmer income and food security.

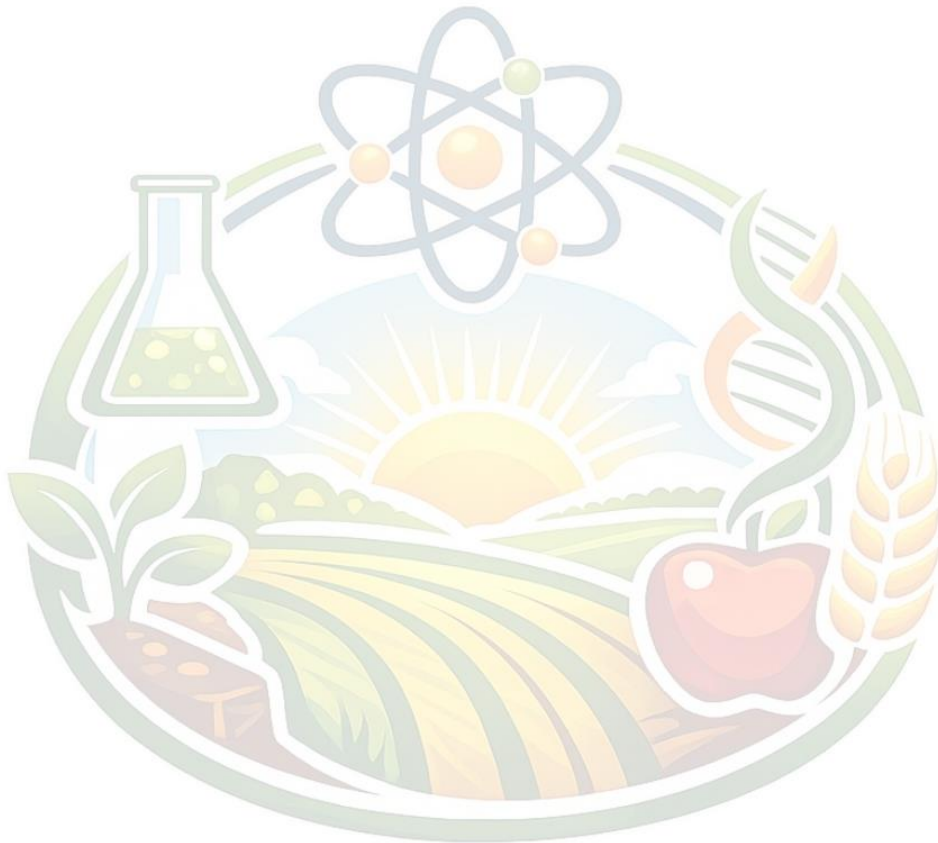
Future Prospects of Participatory Plant Breeding

1. Expansion to climate-smart agriculture
2. Integration with digital platforms
3. Policy support for decentralized breeding
4. Strengthening local seed systems
5. Greater inclusion of women and youth



Conclusion

Participatory Plant Breeding represents a paradigm shift from centralized, breeder-driven programs to inclusive, farmer-centered crop improvement. By combining scientific breeding techniques with farmers' experiential knowledge, PPB enhances adaptability, sustainability, and food security. It is particularly relevant in the face of climate change and the need for resilient agricultural systems.

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Clonal Multiplication Techniques in Tapioca

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Tapioca (*Manihot esculanta*)

Manihot esculenta, sometimes known as tapioca or cassava or yuca (among other regional names), is a woody shrub that is native to South America and is found in Brazil. It belongs to family Euphorbiaceae and having chromosome number $2n=2X=36$.

Botany

Flowering does not occur in all the varieties. Flowers are born on terminal panicle. It is monoecious plant male flowers at tip of the inflorescence and female at bottom. Anthers are small, one ovary is located on 10 lobed granular disc. It has three locules, each locule having single ovate. Stigma has three lobes united to form a single style. Female flowers opened first (Protogynous) followed by male flowers. Pollinating agent are insects. Maturation period is 3-5 months. Matured fruits are capsule, globular and it has three locules each containing single seed. Seed is oval in shape or ellipsoidal 1 to 1.5 cm length. Seeds are brittle with gray coloured marks. It has caruncle tissue over micropylar region that helps water absorption.

Varieties

C-3, CO-1, CO-2 (Seed tapioca), CO-3, Mulluvadi, H- 165, Sree Vishaham (H 1687), Sree Sehaya (H 2304), H-97, H-165, H-226, Sree Jaya, Sree Vijaya, Nidhi, M- 4, Sree Sahya, Sree Prabha, Sree Annam, Sree Apoorva, Sree Athulya, Sree Prakash, Sree Prakash, Sree Vijaya, Sree jaya, YTP1, YTP2, CO4, CO5, and MVD-1.

Season: Throughout the year under irrigation. April is best for rainfed crop.

Isolation: Fields of other varieties and fields of same variety not conforming to varietal purity, the isolation distance for foundation-5m and for certified seed-5m.

Seed and sowing: Seed rate 17,700 setts/ha at a spacing 75 x 75 cm. Setts should be 15 cm length with 8-10 nodes and should be collected from middle portion of the stem.

Vegetative Propagation

Sett Preparation: Stem collected from the previous crops are generally used to raise new crop. Stem cuttings or stakes or setts are directly planted in the field. In some places cuttings are planted in a close spaced nursery. Stems are collected from the middle portion of stem are ideal for planting.

Stems having a thickness of 2-3 cm are ideal for planting. The length of stake is related to the depth of planting. 20 cm long stakes are optimum size for planting.

Sett treatment: The setts should be dipped in 0.1% Bavistin for 15 min and then it should be dipped in phosphate slurry 2 hours before planting. The phosphate slurry will be prepared with super phosphate, soil and water @ 1:1:2 ratio by weight. 75 kg super phosphate is enough to treat the setts required for one ha. The setts should be dipped up to 5 cm i.e., portion which goes into the soil.

Tissue Culture Techniques Followed in Tapioca

1. Shoot Multiplication:

a. **Clonal Propagation** - This method ensures that cassava plants remain genetically identical to the parent plant, preventing genetic variations.

b. **Use of Nodal Segments and Axillary Buds** - Explants from these parts of the plant are most commonly used for shoot induction and multiplication.

c. **Hormonal Control** - Cytokinins, particularly benzylaminopurine (BAP), are used alone or in combination with naphthaleneacetic acid (NAA) to stimulate shoot proliferation.

d. **Murashige and Skoog (MS) Medium** - This nutrient-rich medium, sometimes supplemented with sucrose and polyvinyl pyrrolidone (PVP), is ideal for cassava shoot growth.

e. High Multiplication Rate - A single nodal explant can produce multiple shoots, significantly improving the multiplication ratio compared to conventional propagation.

2. Somatic Embryogenesis:

a. Embryo Formation from Somatic Cells-Unlike shoot multiplication, this technique allows cassava to regenerate from single somatic cells rather than pre-existing buds.

b. Auxin-Induced Callus Formation-High concentrations of auxins like picloram, 2,4-D, or dicamba induce callus formation, from which somatic embryos develop.

c. Stages of Development-Somatic embryogenesis involves induction, proliferation, maturation, and plant regeneration, similar to zygotic embryo formation.

d. Genotypic Dependency-Different cassava varieties respond differently to somatic embryogenesis, requiring optimization for each genotype.

e. Limited Large-Scale Application-Despite its potential for mass multiplication, the low regeneration frequency and risk of genetic variation limit its commercial use.

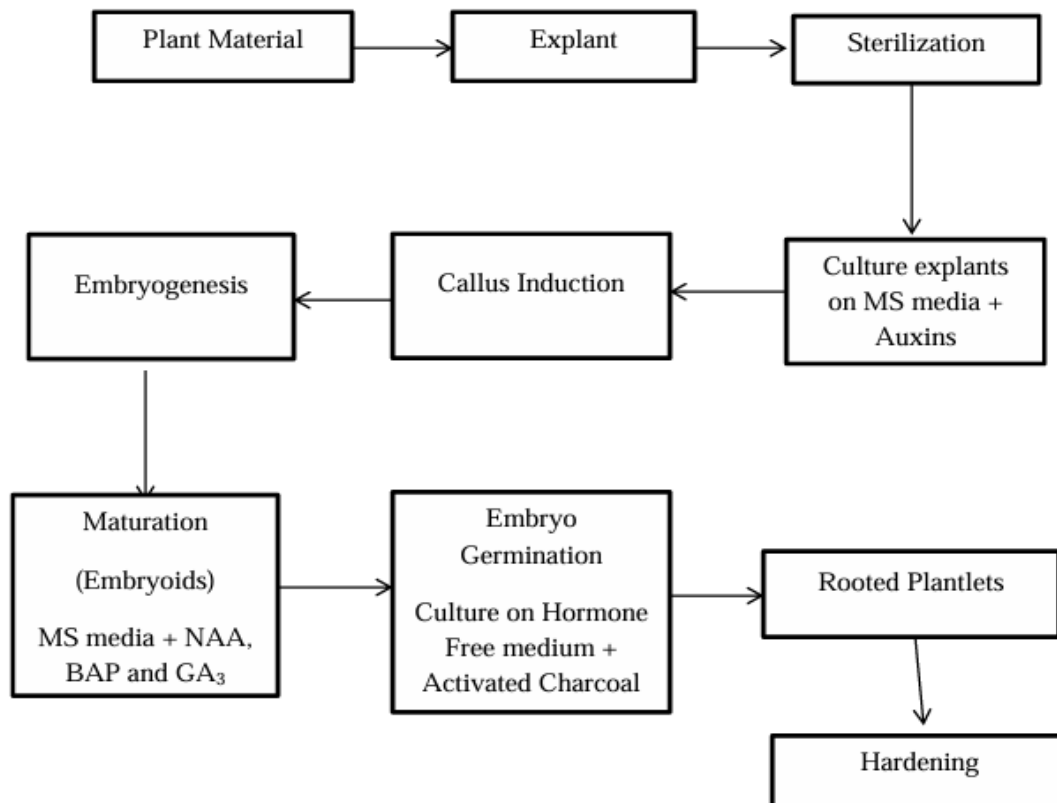


Figure 1. Flow diagram illustrating production of primary somatic embryo on cassava

3. Adventitious Shoot Proliferation:

a. Direct Organogenesis-Shoots form directly from explants, bypassing the callus stage, which helps maintain genetic stability.

b. High Cytokinin-to-Auxin Ratio-Cassava explants require a high concentration of BAP, kinetin, or thidiazuron (TDZ), often combined with low levels of auxins like NAA.

c. Multiple Shoot Formation-Depending on the hormonal balance, a single explant can develop numerous shoots, enhancing propagation efficiency.

d. Genotypic Variation-The success of this method varies among cassava clones, requiring specific hormonal adjustments for optimal results.

e. Commercially Feasible-Compared to somatic embryogenesis, this technique is more efficient for commercial-scale propagation due to its higher shoot formation rates.

4. In Vitro Rooting:

a. Transition from Shoots to Whole Plants-Once shoots are well-developed, they must form roots before being transferred to soil.

b. Auxin-Driven Root Induction-Indole-3-butyric acid (IBA), indole-3-acetic acid (IAA), and NAA are commonly used to stimulate root development.

c. Medium Optimization-Rooting efficiency depends on the balance between auxins and cytokinins, with low or no cytokinins promoting root elongation.

d. Variable Rooting Success-Some cassava clones root easily, while others require higher auxin concentrations or prolonged exposure for proper root initiation.

e. Improved Survival Rates-Well-rooted plantlets have a higher chance of surviving acclimatization and adapting to soil conditions.

5. Acclimatization of Plantlets:

a. Gradual Transition to Ex Vitro Conditions-In vitro plantlets need to adjust to external humidity, temperature, and light before being planted in the field.

b. Use of Controlled Environments-Initial hardening is done in greenhouses or shaded areas with high humidity to prevent plant desiccation.

c. Substrate Selection-A mixture of peat moss, sand, soil, and compost provides proper aeration and nutrients for successful root adaptation.

d. Survival Rate Optimization-Studies have shown that survival rates reach 85-100% when plantlets are hardened in well-draining media with controlled watering.

e. Final Field Transfer-Once plantlets develop strong roots and leaves, they are gradually exposed to field conditions, ensuring successful establishment.

Method of Planting

1. Raising nursery and transplanting.
2. Direct planting.

Nursery Technology

In this method, stakes are planted in the nursery at a very close spacing of 4.5 x 4.5 cm with irrigation for about 3 weeks prior for the regular planting time in the main field.

Advantage

1. Setts expressing symptoms of mosaic disease can be discarded in the nursery itself to reduce the incidence of mosaic in the main field.
2. In areas where the crop is raised under irrigation this technique can save water.
3. This technique will reduce the percentage of failure in the main field.

Direct Planting

Different methods of planting of stakes, such as vertical planting (at 45° angle) and horizontal planting showed that vertical planting resulted in more tuber yield.

Methods of Planting

Three different systems are adopted for cassava planting, such as flat, mound and ridge. Both the ridge and mound systems facilitate easy weeding and also harvesting. Under irrigated cropping, the ridge system is commonly adopted. Another method known as 'pit followed by mounds' was found to be superior to other methods.

Advantages

1. Setts expressing symptoms of mosaic disease can be discarded in the nursery itself to reduce the incidence of mosaic in the main field.
2. Rapid multiplication
3. This technique will reduce the percentage of failure in the main field.
4. Multiplication ratio is higher in minisett compared with traditional sett.

Minisett Technique

Studies conducted at the Central Tuber Crops Research Institute during 2002 to 2008, have evolved a farmer friendly technique called "Minisett Technique"

1. Multiplication ratio of cassava 1:10 only.
2. Proved that multiplication ratio in cassava could be significantly enhanced to 1:60 from the traditional 1:10.
3. Raising two node minisetts in nursery and transplanting at a spacing of 45x45 cm.
4. Revealed successfully address the twin problems of low multiplication ratio and CMD.
5. Enhancing productivity and production from a unit area of land significantly over the traditional method. (40 t/ha).

Depth of Planting

Shallow planting facilitates production of more number of roots when the soil is sufficiently loose and friable, stakes can be planted to a depth of 5 to 10 cm. Deeper planting result in swelling of the mother stem and reduction on root size and yield.

Fertilizer:

Compost: 12.5 t/ha

Basal: 30:60:85 kg NPK/ha

Top dressing: 30: 75 kg NK/ha on 40-60 days after sowing.

Harvest and Storage: Optimum harvest time ranges between 7 to 12 months after planting. The storage capacity of cassava planting material depends on the variety; some varieties tolerate prolonged storage, whereas others do not. Stems should be cut as long as possible, because, overtime, increasingly larger portion of their extremes, especially the apical, deteriorate and need to be cut off. The middle part thus diminishes. Stems should be stored vertically, not horizontally to reduce loss of planting material and control weight loss in usable stakes. Treating stem with insecticide fungicide solution can help prevent seed deterioration under poor storage conditions. Cassava stems should be moved to the storage site as soon as possible after harvest. Exposure to sun reduces the seed storage capacity.

Effects of Methods and Duration Storage on Cassava Stake

The storage duration of planting material should not exceed 30 days with placing outdoors covered with hemp sacks and placing under the shade of a tree were superior to have fast and higher germination and survival percentage.

True Seed

The seeds are sown in ridges. Seed treatment with KNO₃ 0.5% and GA₃ 100 ppm reduces the initial dormancy. The seed matures 60 days after anthesis and harvesting is done with change of colour from green to yellow. During crop growth yellowing of leaves may take place due to Iron deficiency. Spraying of 0.15% ferrous sulphate 3-4 times at weekly intervals to the deficient symptom. The seeds can be processed using 12/64' round perforated metal sieve. The seeds can be stored up to 1 year under ambient storage condition.

Plant Protection

Pests

Mites: spraying with dicofol 18.5 EC 2.5 ml/lit during 3rd and 5th month.

White fly (*Bemisia tabaci*) Integrated pest management practices:

- Remove alternate weed hosts viz., *Abutilon indicum*.
- Installation of yellow sticky traps at 12 Nos/ha.
- Use of nitrogen judiciously.
- Avoiding excessive irrigation.
- Spraying of neem oil 3 % or fish oil rosin soap 25 g/lit or methyl demeton 25 EC 2 ml/lit. While using neem oil teepol or sandovit should be added at 1 ml/lit for better contact with foliage. Apply methyl demeton in the early stage and phosalone in the late stages of crop growth.

Spiralling whitefly:

- Growing resistant genotypes.
- Installation of sticky cum light traps between 4 to 6 am to attract the adult.
- Spray of dichlorvos 76 WSC @ 1 ml/lit or triazophos 40 EC 2 ml/lit.

Diseases:

Cercospora Leaf spot: Spraying of Mancozeb at 2 g/lit twice at 15 days interval.

Tuber rot: Water stagnation should be avoided. Spot drenching with Copper oxychloride 2.5 g/lit.

Iron deficiency: Spraying 3 to 4 times ferrous sulphate 2.5 g/lit on the appearance of deficiency symptom at weekly intervals. Equal quantity of lime should be added for neutralizing the solution.

Field Inspection - minimum of four inspections

- first about 60 days,
- second about 120 days and
- Third about 180 days after planting
- Fourth prior to cutting of planting stakes to verify isolation, Off-types and other relevant factor.

Field Standards

Isolation distance: Seed fields shall maintain minimum isolation distance for foundation seed and certified seed as given in Table:

<i>Contaminants</i>	<i>Minimum distance (Meters)</i>	
	<i>Foundation</i>	<i>Certified</i>
1	2	3
Fields of other varieties	5	5
Fields of the same variety not conforming to varietal purity requirement for certification	5	5

B. Specific requirements

<i>Factor</i>	<i>Maximum permitted (%)*</i>	
	<i>Foundation</i>	<i>Certified</i>
1	2	3
*Off-types	0.10	0.20
Plants showing symptoms of mosaic	0.10	0.50
Plants infested with scale insects	None	None

*Standards for Off-types shall be met at final inspection and for mosaic and plants infested with scale insects at each inspection.

Note: All off-types, diseased plants and plants infested with scale insects should be rouged out along with tubers.

Seed Standards

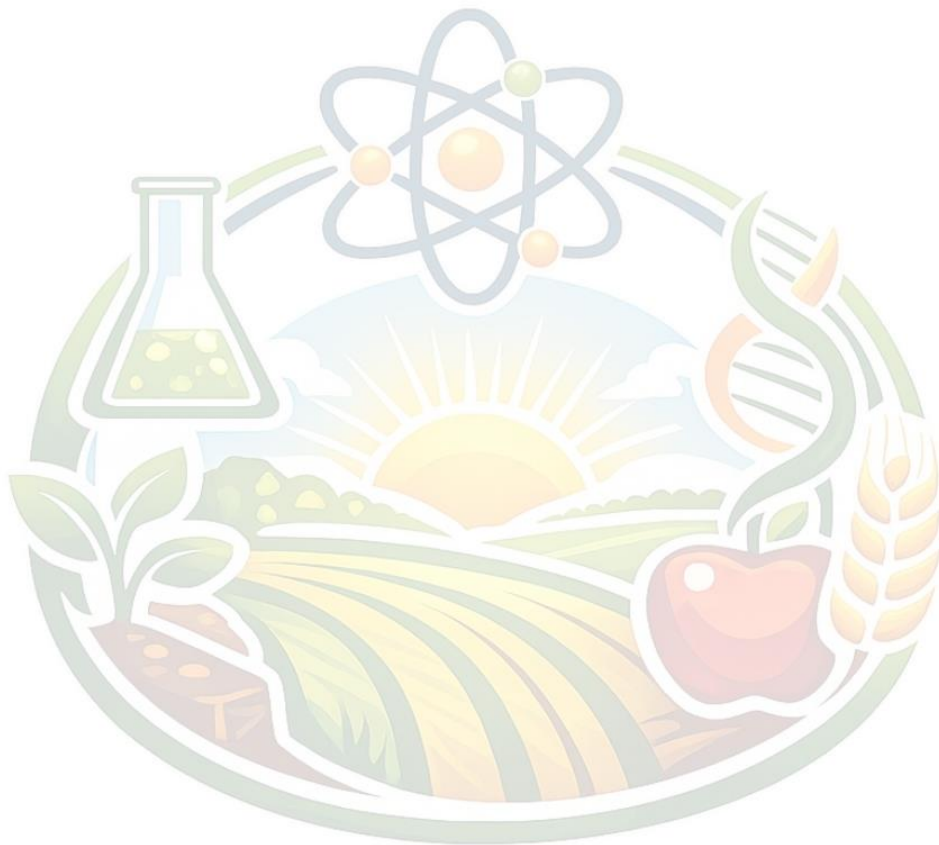
1. Age of the crop: 7 to 12 months.
2. Diameter of the stem: 1.5 to 2.5 cm (planting stake)
3. Approximate length of the stem: 20 cm (planting stake)
4. Approximate number of nodes: 5 in the planting stake.
5. Presence of latex at the cut end of the planting stake is the indication of good quality planting material.

B. Maximum tolerance limit of planting stakes showing visible symptoms of infestation caused by scale insect will be as follows:

<i>Factor</i>	<i>Maximum tolerance limit</i>	
	<i>Foundation</i>	<i>Certified</i>
Planting stakes infested with scale insects	None	None

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Seed Production in Cucurbitaceous Vegetables

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Cucurbitaceae vegetables commonly called as “Cucurbits”. They are used for making salad (Cucumber), cooking (all Gourds), pickles (Gherkin), dessert fruit (Muskmelon, Watermelon), preserved (Ash gourd). They occupies largest area in India and in Tropical countries (as a group). They are the largest group of summer vegetables. Cucurbits seeds has high oil and protein contents (methionine). Cucurbits contains 117 genera and 825 species in World and in India-36 genera and 100 species were available. All cucurbits belong to the same family cucurbitaceae but genera will be different. The cultural requirements of all crops in this group are more or less similar.

Table-1: Major Cucurbitaceae vegetables are as follows:

Crop	Botanical name	Chromosome no.	Origin
Bitter gourd	<i>Momordica charantia</i>	2n = 22	Tropical Asia
Bottle gourd	<i>Lagenaria siceraria</i>	2n = 22	India
Ridge gourd	<i>Luffa acutangula</i>	2n = 26	India
Snake gourd	<i>Trichosanthes anguina</i>	2n = 22	India
Ash gourd	<i>Benincasa hispida</i>	2n = 24	Japan
Cucumber	<i>Cucumis sativus</i>	2n = 14	India
Pumpkin	<i>Cucurbita moschata</i>	2n = 40	Tropical America
Watermelon	<i>Citrullus vulgaris</i>	2n = 22	Tropical America
Muskmelon	<i>Cucumis melo</i>	2n = 24	Tropical America
Summer squash	<i>Cucurbita pepo</i>	2n = 40	America(Mexico)
Winter squash	<i>Cucurbita maxima</i>	2n = 40	America(Mexico)

Plant General Characters

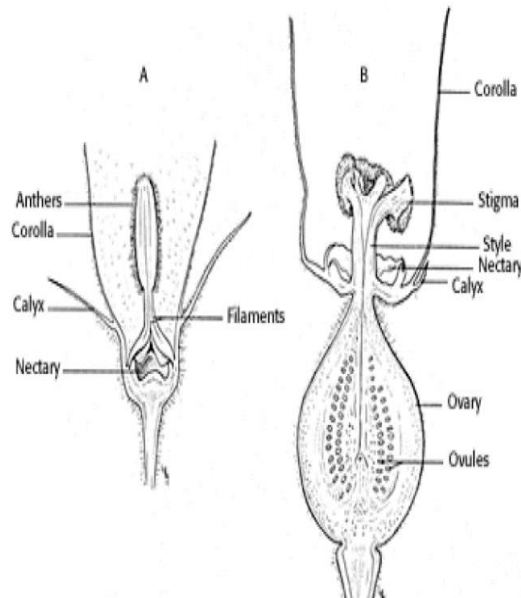
- Habit:** Mostly annual or perennial herbs. They are mostly tendril climbers.
- Roots:** Tap root system.
- Stem:** Herbaceous. Stem is very solitary. It has tendrils.
- Leaves:** Petiolate; Leaves are alternate; simple; exstipulate; palmately reticulate venation. Some leaves bear tendrils in their axils.
- Inflorescence:** The flowers are solitary but some have Racemose or cymose clusters.
- Flower:** Pedicellate; ebracteate; actinomorphic; Regular; complete or incomplete; unisexual or hermaphrodite; plant may be monoecious or dioecious; epigynous;
- Calyx:** 5 sepals; united
- Corolla:** 5 petals; united at base or free; yellow or white.
- Stamens in male flowers:** 3 to 5 stamens; united by various degree; anther are very long. Stamens are borne on calyx tube.
- Carpels in female flowers:** 3 fused carpel; syncarpous; inferior ovary; Parietal placentation.
- Fruits:** Fleshy berry
- Seed:** Non-endospermic seed.

Seed Structure

Type of cotyledon	:	Dicot seeds
Storage tissue	:	Cotyledons
Endosperm presence	:	Absent
Type of germination	:	Epigeal germination
Embryo	:	Straight embryo (Flattened seeds with thick margins)

Pollination

Cucurbits are highly cross-pollinated and pollination is done by honeybees and bumble bees. Flowers are born in axils of leaves and are solitary or in racemose clusters. Pollination takes place early in morning between 6-8 am in cucumber, pumpkin, muskmelon and watermelon. Pollination is altered in the day when temperature is high in bottle gourd and ridge gourd. In snake gourd and pointed gourd, anthesis takes place during night and pollination early in the morning. In pumpkin, pollen production is more while in muskmelon, pollen production is scanty and pollen grains are sticky due to oily film surrounding them. Extent of cross pollination in cucurbits is 60-80%. They are entomophilous and bees, beetles and moths cause pollination. Majority of cucurbits start flowering 30-45 days after sowing and it follows a definite sequence. An alternate sequence of male and female flowers follows upto fruit set. The first 4-6 flowering nodes bear male flowers.



Sex Modification

Majority of cucurbits are monoecious and sex ratio (male: female) ranges from 25-30:1 to 15:1. Sex ratio is influenced by environmental factors. High N content in the soil, long days and high temperature favour maleness. Besides environmental factors, endogenous levels of auxins, gibberellins, ethylene and abscisic acid also determine sex ratio and sequence of flowering. A primordium can form either a female or a male flower and it can be manipulated by addition or deletion of auxins. Endogenous application of plant growth regulators can alter sex form, if applied at 2-4 leaf stage. High ethylene level induces female sex and is suggested to increase female flowers in cucumber, musk melon, summer squash and pumpkin. In cucumber, maleic hydrazide (50-100 ppm) GA 3 (5-10 ppm), Ethrel (150-200 ppm), TIBA (25-50 ppm), boron (3 ppm) also induce female flowers. Gibberellins promote maleness and are antagonistic to the action of ethylene and abscisic acid. In fact, gynoeceous line of cucumber is maintained by inducing male flowers through spray of GA 3 (1500-2000 ppm). Silver nitrate (300-400 ppm) also induces maleness.

Cucurbit Sex Forms

Sex forms	Cucurbits
Monoecious (♂ and ♀)	Cucumber, Musk melon, Pumpkin, Summer squash, Winter squash, Water melon, Sponge gourd, Round melon, Bottle gourd, Bitter gourd.
Gynoeceous (♀)	Cucumber, Bitter gourd, Musk melon, Watermelon, Ridge gourd
Androeceous (♂)	Cucumber, Musk melon
Dioecious (♂ and ♀ in separate plant)	Pointed gourd, Ivy gourd.
Andromonoecious (♂ and ♀ in same plant)	Muskmelon, Water melon, Cucumber
Gynomonoecious (♀ and ♂ in same plant)	Cucumber, Musk melon, Ridge gourd
Trimonoecious (♂, ♀ and ♂ in same plant)	Cucumber
Hermaphrodite (♂)	Ridge gourd (Satputia)

Fig-1. Sex forms in cucurbits

Seed Production Technologies

Land Requirements: There are no land requirements as to previous crop, but the land should be free of volunteer plants. Generally the soil should be well drained and aerated.

Season: The main season for cucurbits seed production is June - July and January-February. But in Watermelon and Muskmelon, they are grown in February - March.

Spacing: 45 x 45 x 45 cm at 2.5 x 2 m, sowing of three seeds per pit at 2cm depth & micropylar end facing upward is favorable for better field emergence.

Table-2:- Seed Rate of Major Cucurbitaceae Vegetables:

Crop	Seed rate(kg/ha)
Bitter gourd	1.8
Bottle gourd	3.0
Ridge gourd	2.5
Snake gourd	1.5
Ash gourd	1.5
Cucumber	2 to 5
Pumpkin	1
Watermelon	2.5 to 5
Muskmelon	3 to 4
Squash	5

Pre-Soaking Treatment

Sowing pre-germinated seeds in order to maintain optimum field population. The seeds are soaked in water for 24 hours. Then place the seeds in moistened sand and cover the seeds with sand and left for 3 days. Maintain the sand in wet condition. After 3 days the seeds with protruding radicle are separated and used for sowing. It is done to remove the hard and ill filled seeds.



Fig-2. Pre-soaking treatments followed in Cucurbitaceae Vegetables

Soaking in butter milk is also reported to promote germination. Seeds should be soaked in a solution of cow's urine (1 part cow's urine + 5 parts of water) for 30 minutes prior to the sowing. This will inhibit the seed borne diseases. Treat the seeds with Trichoderma viride @ 4 gms/kg of seeds.

Isolation Requirements

For pure seed production and isolation distance all around seed field is necessary to separate it from fields of other varieties, fields of the same variety not conforming to varietal purity requirements for certification, from wild cucurbit species.

Class	Minimum distance (meters)
Foundation	1000
Certified	500

Sowing

Direct seeding: On raised beds, sow one to two seeds per hole at a depth of 2-3 cm. When planted in warm soil, seedlings will emerge in a week or less. Thinning to one seedling when they have two true leaves.

Nursery raising: Sow seeds in trays having 50 cells using a coco-peat that has good water-holding capacity and good drainage. Sowing one seeds per cell. Water the seedlings thoroughly every morning to maintain a moisture. The seedlings are sprayed with commercially available supplemental nutrient mixtures of NPK (19:19:19) @ 1-2 g per lit of water at 2-3 days intervals to maintain healthy growth. Seedlings are ready for transplanting 10-12 days after sowing.

Transplanting: The ideal transplant is a seedling with 2-3 true leaves. Transplanting should be done in the late afternoon.

Fertiliser requirement: Farm yard manure or compost is applied @ 10 tonnes/acre (25 tonnes/ha) before last ploughing and incorporated into the soil. In each pit, farm yard manure or compost @ 1 kg mixed with 100 gms of neem cake is applied as a basal manure. One month after sowing apply 500 gms of vermicompost per plant as top dressing. 100 g of the mixture of NPK@ (6:12:12) per pit as basal and 10 g N/pit at 30 days after sowing.

Foliar application: Maleic hydrazide @ 400 ppm at 2 leaves stage and 4 leaves stage enhances the seed yield and quality or application of ethrel @ 100 to 200 ppm at weekly intervals from 4th leaf stage for four times. During the course of fruit development apply urea @ 12 kg / ha, super phosphate 4 kg /ha, potash 2 kg /ha and micronutrients 400 g/ha.

Weed management: Weeding is most important during all the growth stages of the crop. The field should be maintained clean by frequent hand weeding. Periodical removal of objectionable weeds should be done.

Irrigation management: Irrigated the crop before dibbling the seeds. First irrigation is done before sowing. Subsequent irrigation should be done once a week. Irrigation during flowering and fruit setting stages are very crucial.

Main field maintenance: Each plant has to be provided with stacking 20-25 days after sowing for training the vines over the pandal. Training operation has to be carried out daily until the fruiting stage.

Types of Training

1. Single stem training (60 x 45 cm)
2. Umbrella system (60 x 60 cm)
3. V-system (60 x 60 cm)

Plant Protection

Pests: Beetles, fruit flies and caterpillars: Spray malathion 50 EC 1ml/lit or dimethoate 30 EC 1ml/lit or methyl demeton 25 EC 1ml/lit or fenthion 1000 EC 1ml/lit. Avoid copper and sulphur dust since these chemicals cause injury to the plants.

Red pumpkin beetle(Pumpkin, Cucumber): Spray 5% Malathion dust.

Diseases:

Powdery mildew: Spray Dinocap 1ml/lit or Carbendazim 0.5 g/lit.

Downy mildew: Spray Mancozeb or Chlorothalonil 2 g/lit twice at 10 days interval.

Yellow vein mosaic virus (Pumpkin): Spray Monocrotophos @ 2ml/l

Roguing

Roguing should be done from early vegetative stage to flowering and fruiting stage. All the offtypes and diseased plants should be rogued off periodically. The off-types are identified based on the morphological characteristics like plant type, leaf shape, flower colour, fruit shape etc. Removal of the off-types during fruit setting stage is helpful in preventing further genetic contamination.

Field Inspection

A minimum of three field inspections should be done from vegetative to fruit maturity stage by the Seed Certification Officer. The first inspection is conducted during vegetative stage before flowering followed by the second one at flowering and fruiting stage. The final inspection should be scheduled during fruit maturity stage to determine the true characteristics of the fruits.

Field Standards

	Foundation seeds	Certified seeds
Isolation distance	1000 m	500 m
Off-types	0.10%	0.20%

Harvesting

Harvesting is done once the fruits are physiologically mature. The physiological maturity of the fruits is identified by colour change and seed coat become hard and produce rattling sounds.

Seed Extraction Process

Bitter gourd: Fruits are cut longitudinally and seeds are removed along with mucilaginous substances and seeds are washed with water.

Bottle gourd: For seed extraction, fruits are cut opened at one end and seeds are separated out. Separated seeds are pre-cleaned to remove unfilled seeds.

Ridge gourd: Fruits are cut opened at distal end and seeds are separated. They are pre-cleaned manually to remove white and pale yellow coloured unfilled seeds.

Snake gourd: Fruits are cut longitudinally and seeds are extracted. Immature seeds can be removed by water floatation techniques.

Cucumber: Fruit are cut into two halves and seeds are scooped out. Seeds can also be extracted by mechanical extractor.

Pumpkin: Fruits are cut into two halves and seeds are scooped out.

Acid method: Add 25 ml HCl/5kg pulp. After 25mins, seeds are washed out and extracted

Watermelon: Fruit is macerated and transferred to the screen and washed with running water. Seeds are retained in sieve while remaining is washed away in water.

Muskmelon: Fruit is cut into two halves and central portion is scooped out. It is kept for fermentation for 24hrs. After seeds are washed with water and seeds are separated.

Squash: Cut the fruit and scoop out the seeds. They are washed in water and seeds are separated.

Ash gourd: Fruits are cut longitudinally and they are soaked in conc. HCl for 30mins (1:6 parts of HCl and water). Immature seeds are thus removed.

Drying and Storage

The extracted seeds should be washed and dried thoroughly before storage because of the hard seed coat in bitter gourd seeds. Before storage the moisture content of the seeds should be 7%. Under cool and dry condition the well dried seeds can be stored up to five years with good germination capacity.

Grading: Graded by BSS 4 x 4 sieve. Use 16/64" round perforated metal sieve.

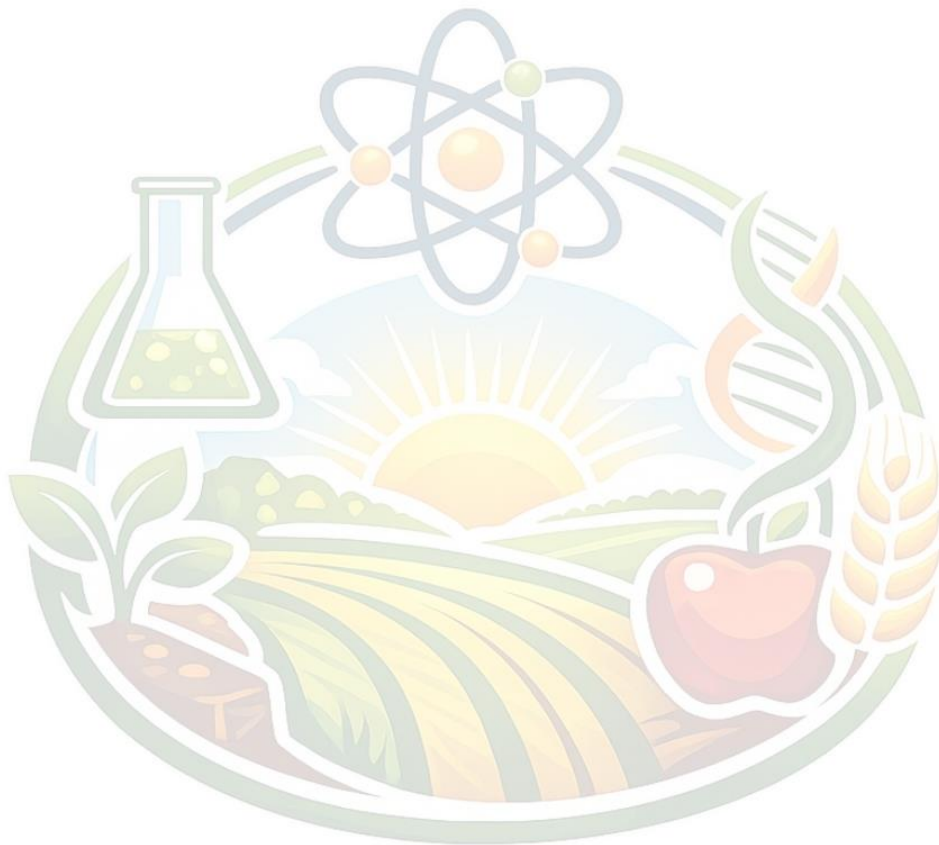
Seed standards:

Factor	Standards for each class	
	Foundation	Certified
Pure seed (minimum)	98.0%	98.0%
Inert matter (maximum)	2.0%	2.0%
Other crop seeds (maximum)	None	None
Weed seeds (maximum)	None	None
Other distinguishable varieties (maximum)	5/kg	10/kg
Germination (minimum)	60%	60%
Moisture (maximum)	7.0%	7.0%
For vapour-proof containers (maximum)	6.0%	6.0%

Seed yield: 200-300 kg of seed yield/ha

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Genomic Selection and AI-Assisted Vegetable Breeding

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Abstract

Vegetable crops play a critical role in global food and nutritional security by providing essential vitamins, minerals, antioxidants, and dietary fiber. However, increasing population pressure, climate change, emerging pests and diseases, shrinking arable land, and changing consumer preferences demand accelerated development of superior vegetable cultivars. Conventional breeding approaches, although successful, are often time-consuming and labor-intensive due to the complex inheritance of economically important traits. The advent of genomic technologies has revolutionized plant breeding by enabling genome-wide marker-assisted selection and genomic prediction. Genomic selection (GS), which uses genome-wide molecular markers to predict breeding values, has emerged as a powerful approach for improving complex quantitative traits. Simultaneously, artificial intelligence (AI), machine learning, deep learning, computer vision, and big-data analytics are transforming breeding pipelines by enhancing phenotyping, prediction accuracy, decision-making, and breeding efficiency. The integration of genomic selection with AI-assisted breeding platforms offers unprecedented opportunities to accelerate genetic gain, reduce breeding cycle duration, improve prediction precision, and develop climate-resilient, high-yielding, and nutritionally enhanced vegetable varieties. This review discusses the principles, methodologies, applications, achievements, challenges, and future prospects of genomic selection and AI-assisted vegetable breeding, highlighting their transformative role in modern horticultural crop improvement.

Introduction

Vegetables constitute an indispensable component of human diets and agricultural systems worldwide. They contribute significantly to food security, nutritional health, income generation, and rural livelihoods. Global demand for vegetables continues to increase due to rapid population growth, urbanization, rising incomes, and greater awareness of healthy diets. Simultaneously, vegetable production faces unprecedented challenges arising from climate variability, water scarcity, soil degradation, emerging pests and pathogens, and increasing demand for sustainable agricultural practices. Traditional vegetable breeding has achieved remarkable success in developing improved cultivars with enhanced yield, quality, disease resistance, and stress tolerance. Nevertheless, conventional breeding methods often require multiple generations of selection and extensive field evaluations before a superior variety can be released. The process becomes even more difficult when dealing with complex quantitative traits such as yield, nutritional quality, drought tolerance, heat tolerance, shelf life, and disease resistance, which are controlled by numerous genes and influenced by environmental interactions.

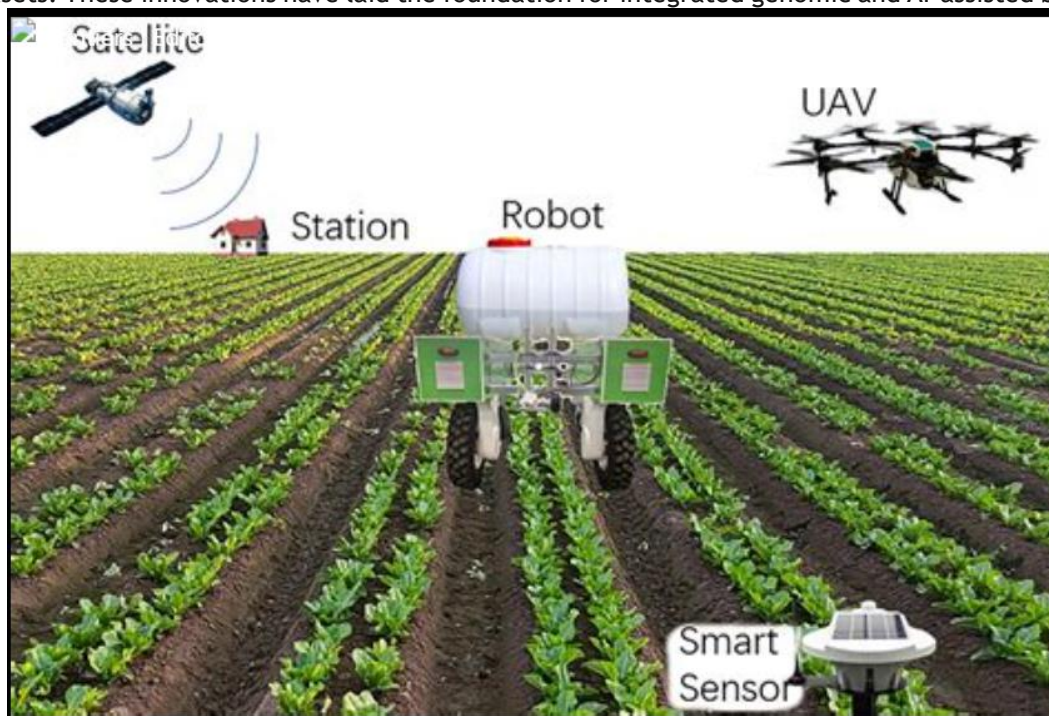
Recent advances in genomics, bioinformatics, artificial intelligence, and computational biology are reshaping plant breeding paradigms. The availability of high-throughput sequencing technologies, genome-wide molecular markers, phenomics platforms, and advanced computational algorithms has enabled breeders to utilize genomic information more effectively. Genomic selection, first proposed by Meuwissen et al. (2001), has emerged as a revolutionary breeding strategy that predicts the genetic merit of individuals using genome-wide markers. Parallel developments in AI and machine learning have introduced sophisticated tools for analyzing large-scale genomic, phenotypic, environmental, and management datasets. AI-assisted breeding systems can identify hidden patterns, predict trait performance, optimize parental selection, automate phenotyping, and improve breeding decisions. Together, genomic selection and AI are creating a new era of precision vegetable breeding characterized by faster genetic gains, enhanced prediction accuracy, and more efficient resource utilization.

Evolution of Vegetable Breeding Technologies

The history of vegetable breeding reflects the gradual progression from phenotype-based selection to data-driven precision breeding. Early breeding efforts relied primarily on visual selection and empirical knowledge. The rediscovery of Mendelian genetics facilitated the development of systematic breeding programs based on inheritance principles. The molecular era introduced marker-assisted selection (MAS), enabling breeders to track specific genes and quantitative

trait loci (QTLs). While MAS proved effective for simple traits controlled by major genes, its effectiveness was limited for complex traits governed by numerous minor-effect loci.

The emergence of next-generation sequencing technologies dramatically reduced genotyping costs and generated vast amounts of genomic information. These developments led to genomic selection, which utilizes all available marker information simultaneously rather than focusing on individual loci. This approach captures both major and minor genetic effects, making it particularly suitable for quantitative traits. Simultaneously, advances in AI, machine learning, robotics, remote sensing, drones, imaging technologies, and high-performance computing have enabled the collection and analysis of massive datasets. These innovations have laid the foundation for integrated genomic and AI-assisted breeding systems.



Principles of Genomic Selection

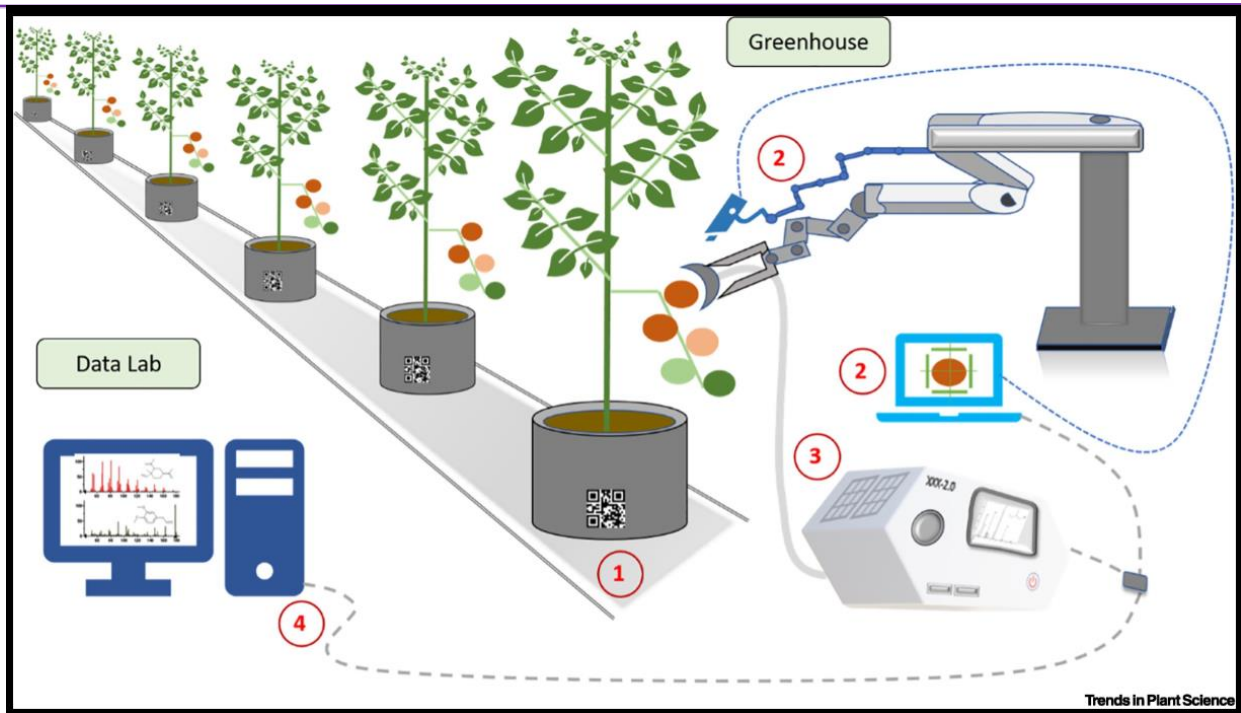
Genomic selection is a breeding methodology that predicts the breeding value of an individual using genome-wide marker data. Unlike marker-assisted selection, which targets a limited number of markers associated with major genes, genomic selection incorporates thousands of markers distributed across the entire genome. The fundamental principle involves developing a training population consisting of individuals that have both genotypic and phenotypic information. Statistical models are used to establish relationships between marker profiles and observed trait performance. Once the prediction model is developed, it can estimate genomic estimated breeding values (GEBVs) for untested individuals using only their genomic information.

The genomic selection process generally involves genotyping, phenotyping, model training, genomic prediction, and selection of superior individuals. Because phenotypic evaluation is not required for every generation, breeding cycles can be shortened significantly, leading to increased rates of genetic gain. According to Meuwissen et al. (2001), genomic selection enables simultaneous estimation of effects from thousands of markers, providing a more comprehensive representation of the genetic architecture underlying complex traits.

Components of Genomic Selection Programs

A successful genomic selection program depends upon several critical components. The training population serves as the foundation of genomic prediction. It should represent the genetic diversity and breeding objectives of the target population. Larger and more diverse training populations generally improve prediction accuracy. High-density molecular markers are essential for capturing genome-wide genetic variation. Single nucleotide polymorphisms (SNPs) have become the marker system of choice due to their abundance, stability, and cost-effectiveness.

Accurate phenotyping remains crucial despite advances in genomic prediction. High-quality phenotypic data enhance model reliability and improve prediction performance. Statistical prediction models are used to estimate genomic breeding values. Common models include genomic best linear unbiased prediction (GBLUP), ridge regression BLUP, Bayesian models, random forest algorithms, support vector machines, and deep learning approaches. Validation populations are necessary to evaluate model performance and estimate prediction accuracy before implementation in breeding programs.



Statistical Models Used in Genomic Selection

Several statistical approaches have been developed for genomic prediction. Genomic Best Linear Unbiased Prediction (GBLUP) is among the most widely used methods due to its simplicity and computational efficiency. It assumes equal variance across marker effects and performs well for many quantitative traits. Bayesian methods such as BayesA, BayesB, BayesC π , and Bayesian LASSO allow variable marker effects and are particularly useful when traits are influenced by a combination of major and minor genes.

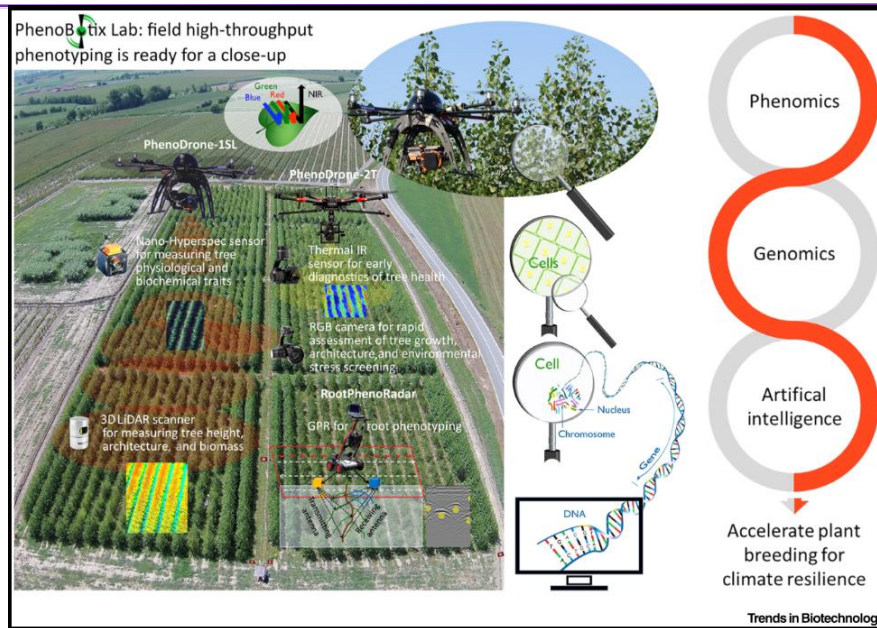
Machine learning algorithms including Random Forests, Support Vector Machines, Gradient Boosting Machines, and Artificial Neural Networks provide flexible frameworks capable of capturing nonlinear relationships and complex interactions. Deep learning approaches have gained increasing attention because of their ability to process high-dimensional genomic datasets and identify intricate genotype-phenotype relationships.

Applications of Genomic Selection in Vegetable Crops

Genomic selection is increasingly being applied in major vegetable crops. In tomato, genomic selection has been utilized for yield improvement, fruit quality, disease resistance, shelf life, and abiotic stress tolerance. Prediction models have demonstrated considerable accuracy for fruit weight, soluble solids content, and resistance traits. In pepper, genomic prediction has been employed for improving fruit quality, capsaicin content, disease resistance, and stress adaptation. Cucumber breeding programs have explored genomic selection for yield, fruit morphology, disease resistance, and environmental adaptation. In carrot, genomic selection has facilitated the improvement of root quality, nutritional content, and disease resistance. Onion breeding programs are beginning to adopt genomic prediction approaches to accelerate selection for bulb yield, storage quality, and disease resistance. Brassica vegetables such as cabbage, cauliflower, broccoli, and kale are increasingly benefiting from genomic selection strategies aimed at improving productivity, quality, and resilience under changing climatic conditions. Leafy vegetables including spinach and lettuce are also emerging targets for genomic selection due to the increasing demand for nutrient-rich and climate-resilient cultivars.

Artificial Intelligence in Vegetable Breeding

Artificial intelligence refers to computational systems capable of performing tasks that traditionally require human intelligence. In vegetable breeding, AI technologies encompass machine learning, deep learning, computer vision, robotics, natural language processing, and advanced predictive analytics. AI systems excel at identifying patterns within large and complex datasets that are often beyond human analytical capacity. These capabilities make AI particularly valuable in modern breeding programs where massive volumes of genomic, phenotypic, environmental, and management data are generated. The integration of AI into breeding workflows enables data-driven decision-making, improved prediction accuracy, automated phenotyping, optimized resource allocation, and accelerated cultivar development.



Machine Learning Approaches in Vegetable Breeding

Machine learning algorithms have become increasingly important for analysing breeding datasets. Supervised learning algorithms use labelled datasets to predict target traits. These methods are widely used for genomic prediction, disease diagnosis, yield forecasting, and stress response assessment. Unsupervised learning techniques identify hidden patterns and clusters within datasets, facilitating germplasm characterization and population structure analysis. Reinforcement learning approaches are emerging tools for optimizing breeding decisions and resource management. Random Forest algorithms are particularly useful for trait prediction and feature selection. Support Vector Machines effectively classify disease symptoms and stress responses. Neural networks can model highly complex biological relationships and improve predictive performance.

AI-Assisted High-Throughput Phenotyping

Phenotyping has traditionally been the most labour-intensive and expensive component of breeding programs. AI-assisted high-throughput phenotyping is transforming this bottleneck. Modern phenotyping platforms employ drones, unmanned aerial vehicles, ground robots, hyperspectral imaging, thermal imaging, LiDAR systems, and computer vision technologies to collect large-scale plant data. Deep learning algorithms analyse images to quantify plant height, canopy architecture, fruit size, colour, disease symptoms, biomass accumulation, flowering behaviour, and stress responses. In tomato breeding, computer vision systems can automatically assess fruit shape, colour uniformity, cracking, and disease symptoms. In lettuce and spinach, AI-based image analysis enables rapid evaluation of biomass and growth rates. In cucumber and pepper, automated phenotyping systems facilitate early selection of superior genotypes. According to Singh et al. (2016), high-throughput phenotyping integrated with advanced analytics significantly enhances breeding efficiency and precision.

Integration of Genomic Selection and AI

The convergence of genomic selection and artificial intelligence represents one of the most significant developments in modern plant breeding. AI enhances genomic prediction by identifying nonlinear relationships among markers, genes, and traits. Deep learning models can process large genomic datasets and capture complex genetic interactions that traditional statistical models may overlook. Integration allows simultaneous utilization of genomic, transcriptomic, metabolomic, phenomic, environmental, and management data. Such multi-dimensional analyses improve prediction accuracy and provide deeper insights into trait architecture. AI-driven genomic selection platforms can optimize parental selection, predict hybrid performance, identify superior breeding lines, and guide resource allocation. These capabilities significantly accelerate breeding progress and improve selection efficiency.

Multi-Omics and AI-Driven Breeding

The emergence of multi-omics technologies has generated unprecedented biological information. Genomics provides information about DNA sequences and genetic variation. Transcriptomics reveals gene expression patterns. Proteomics examines protein abundance and function. Metabolomics characterizes biochemical pathways and metabolic profiles. Phenomics captures observable plant characteristics. AI algorithms integrate these diverse datasets to uncover complex biological networks and identify key determinants of agronomic traits. Such integrated analyses facilitate the discovery

of novel biomarkers, candidate genes, and regulatory pathways associated with yield, quality, stress tolerance, and disease resistance.

Digital Breeding Platforms and Decision Support Systems

Modern vegetable breeding increasingly relies on digital breeding platforms that integrate genomic, phenotypic, environmental, and management data into unified decision-support systems. Cloud computing, big-data analytics, and AI-powered software enable real-time data processing and collaborative breeding activities across multiple locations. Decision-support systems assist breeders in selecting parents, designing crosses, predicting performance, managing trials, and optimizing breeding strategies. Digital breeding platforms reduce human error, improve efficiency, and facilitate evidence-based decision-making.

Applications for Climate-Resilient Vegetable Breeding

Climate change presents major challenges for vegetable production through increased temperatures, drought, flooding, salinity, and emerging pest pressures. Genomic selection and AI technologies are valuable tools for developing climate-resilient vegetable cultivars. Prediction models can identify genotypes with superior adaptation to stress conditions. AI algorithms can analyse genotype-by-environment interactions and predict performance under future climate scenarios. These technologies support breeding efforts aimed at improving heat tolerance in tomato and pepper, drought tolerance in cucumber, salinity tolerance in onion, and disease resistance across numerous vegetable species.

Nutritional Quality Improvement Through AI and Genomics

Consumers increasingly demand vegetables with enhanced nutritional quality. Genomic selection facilitates improvement of traits such as vitamin content, mineral accumulation, antioxidants, carotenoids, flavonoids, and other health-promoting compounds. AI-assisted prediction models help identify genotypes with superior nutritional profiles while maintaining agronomic performance. Examples include biofortified tomatoes with increased lycopene content, carrots with enhanced carotenoid levels, and leafy vegetables with improved micronutrient concentrations.

Economic Benefits of Genomic Selection and AI-Assisted Breeding

The adoption of genomic selection and AI technologies can generate substantial economic benefits. Reduced breeding cycle duration accelerates cultivar release and increases genetic gain per unit time. Improved prediction accuracy decreases the need for extensive field testing and reduces operational costs. Automation minimizes labour requirements and enhances resource efficiency. Earlier identification of superior genotypes increases breeding success rates. Collectively, these advantages improve return on investment and strengthen the competitiveness of breeding programs.

Challenges and Limitations

Despite remarkable progress, several challenges remain. High initial investments in genotyping, phenotyping infrastructure, computational resources, and skilled personnel may limit adoption in developing countries. Prediction accuracy can be influenced by population structure, training population size, marker density, and environmental variability. Data management remains a significant challenge due to the enormous volumes of genomic and phenotypic information generated. AI models often function as "black boxes," making biological interpretation difficult. Ethical considerations regarding data ownership, privacy, and equitable technology access must also be addressed. Furthermore, successful implementation requires interdisciplinary expertise spanning genetics, breeding, statistics, computer science, artificial intelligence, and bioinformatics.

Future Perspectives

The future of vegetable breeding will increasingly depend upon integrated digital breeding ecosystems. Advances in genome sequencing, pangenomics, gene editing, speed breeding, phenomics, and AI are expected to further accelerate genetic improvement. Digital twins of crop plants, autonomous breeding systems, explainable AI, quantum computing, and real-time predictive analytics may revolutionize breeding workflows in the coming decades.

Integration of genomic selection with CRISPR-based genome editing could enable precise manipulation of target genes while maintaining favourable genomic backgrounds. The development of affordable genotyping technologies and open-source AI platforms will facilitate wider adoption, particularly in developing countries where vegetable production plays a critical role in food and nutritional security.

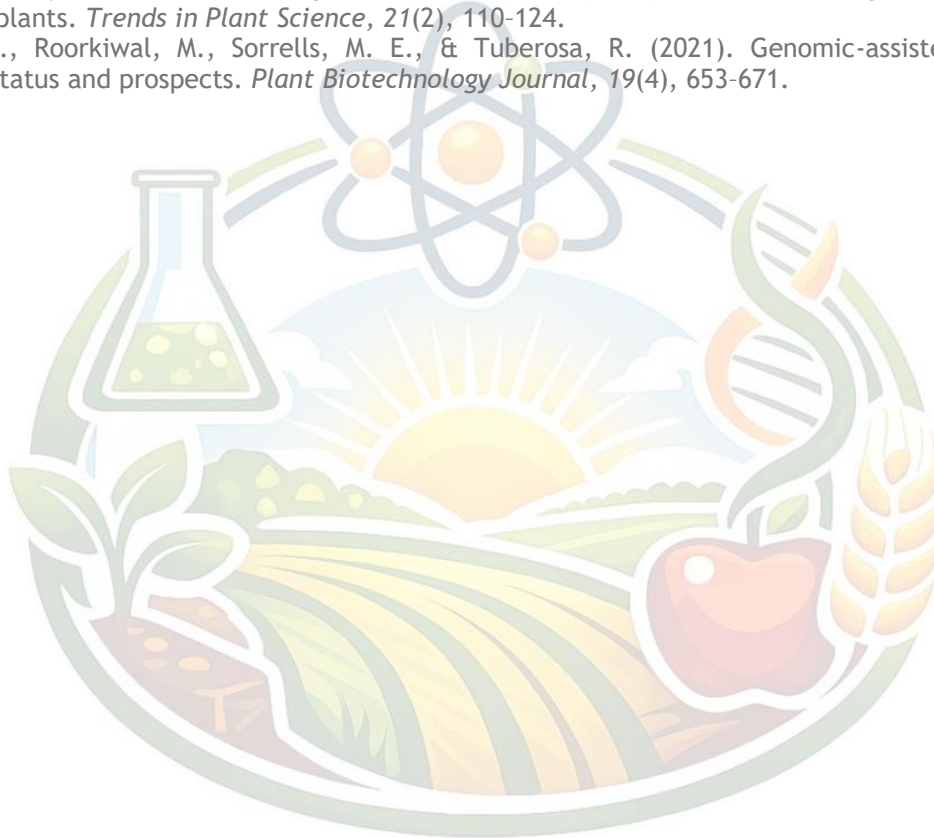
Conclusion

Genomic selection and AI-assisted breeding represent transformative technologies for the future of vegetable crop improvement. By combining genome-wide marker information with advanced computational intelligence, these approaches overcome many limitations of conventional breeding and marker-assisted selection. Genomic selection enables rapid and accurate prediction of breeding values for complex traits, while AI enhances data analysis, phenotyping, decision-making, and prediction accuracy. Their integration supports accelerated development of high-

yielding, nutritionally enriched, climate-resilient, and disease-resistant vegetable cultivars. Although challenges related to infrastructure, data management, and expertise remain, ongoing advances in genomics, artificial intelligence, and digital agriculture are expected to further enhance breeding efficiency and sustainability. The convergence of these technologies will play a central role in ensuring future vegetable productivity, nutritional security, and agricultural resilience under changing global conditions.

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Seafood Marination

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Fish and fishery products play a vital role in global food security and human nutrition. Fish is an excellent source of high-quality protein containing all essential amino acids required for growth and maintenance of the human body (FAO, 2024). Fish remains one of the most perishable food commodities because of its high moisture content, neutral pH, and the presence of spoilage microorganisms. Consequently, effective preservation techniques are required to maintain quality, reduce post-harvest losses, and ensure consumer safety (Ghaly et al., 2010). Among the various preservation methods, marination has emerged as a simple and effective technique for improving the flavor, texture, and storage stability of fish products. Marination involves treating fish with ingredients such as salt, organic acids, spices, and herbs, which not only enhance sensory properties but may also inhibit the growth of spoilage microorganisms (Gokoglu, 2019). In recent years, consumer preference for natural preservatives has increased, leading to greater interest in the use of ingredients such as turmeric, black pepper, and citrus juices in seafood processing. These natural ingredients are valued for their flavor-enhancing properties as well as their potential antioxidant and antimicrobial activities.

Traditional Marination Method

Marinades are solutions, including sugar, spices, oil, acids (from vinegar, fruit juice, wine) and they are used to improve tenderness, juiciness, flavour and aroma and to extend shelf life of meat, poultry, seafood and vegetables (Cadun et al., 2005). The methods of preparation of various types of traditional Fish marinades have been described by several authors. Pickling is generally done with vinegar (5-7) and treatment time varies according to the product (Poligne & Collignan, 2000). The seafood like squid, surimi, mussel, shrimp, sea snail, and cuttlefish and octopus are also used for marination (Hecer, 2011; Ozogul et al., 2008).

Marination by Using Flavour Enhancer

Marinades are semi preserves; acid, usually acetic acid and salt are added to the fish to retard the action of bacteria and enzymes, resulting in a product with a characteristic flavour and an extended but limited shelf life (McLay, 1972). Different vegetable additives and sauces including garlic, pasteurized hot pepper sauce, marinated green olive with a toothpick are used in marinated anchovy where vegetable additives and sauces had no pathogenic effect on microorganisms that might endanger towards public health (Sen & Temelli, 2003). Sauce plays as an important flavour enhancer in the marinated product. Different types of sauce like tomato sauce, pomegranate sauce and olive lemon juice sauce are used in the marinated product (Topuz et al., 2014). The sauce contains many preservatives like spices, salt, condiments, sugar with the addition of garlic powder and some stabilizer where the sugar act as a cryo-protectant. So it has the effect to make the product safe with extended shelf life in refrigerated storage. Different types of oil like sunflower oil, cornoil, essential oil and vegetable oil are also used in marination (Baygar et al., 2012; Yi et al., 2013; Yildiz, 2016).

Marination by using plant extract: In addition, synthetic antioxidants have limited applications because of their low water solubility (Bekhit et al., 2003). There is, therefore, a growing interest in the identification of new, natural antioxidants that would serve as alternatives to the synthetic compounds. The use of these synthetic antioxidants, however, has begun to be restricted because of their toxicity and carcinogenicity (Vareltzis et al., 1997; Serdaroglu & Felekoglu, 2005). Therefore, a growing interest in the identification of new, natural antioxidants that would serve as alternatives to the synthetic compounds. The antioxidant properties of plants are related to their phenolic contents (Ashton, 2002). Meat is treated with different types of biological marinades, such as kefir, yogurt, butter (Latoch et al., 2019; Latoch, 2020), turmeric, torch ginger, lemongrass, curry leaves (Iqbal et al., 2016), karuk juice (Ozturk and Sengun, 2019), chili, pepper, garlic, and ginger (Gamage et al., 2017).

Nutritional quality of marinated product: Marinated fish products are considered valuable dietary components because they contain significant amounts of essential amino acids, including aspartic acid, glutamic acid, and lysine, which together account for nearly 31% of the total amino acid content. Certain amino acids such as glutamic acid, aspartic acid, alanine, and glycine play a major role in enhancing the flavour and taste of the product, contributing to the distinctive sensory characteristics of marinated fish. Additionally, marinated fish are rich in omega-3 long-chain polyunsaturated fatty acids, particularly eicosapentaenoic acid (EPA; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-3). The presence of these beneficial fatty acids may help reduce the risk of age-related and cardiovascular disease (Behera et al., 2020).

Problems in marinated product: There are some limitations in marinated products like gaseous spoilage manifested by bulging of the lids of jars, slime formation, and off-odour changes occurring during the storage period (Björkroth, 2005;

Lyhs et al., 2001). This gaseous spoilage type in marinated fish products is associated with acetic acid tolerance organisms, and *Leuconostoc gelidum* and *Leuconostoc gasicomitatum* strains dominated both in spoiled marinated herring and marinade ingredient samples, as these species are heterofermentative – producing CO₂ from glucose and dextran from sucrose (Björkroth et al., 2003). Heterofermentative lactic acid bacteria produce significant amounts of undesirable catabolites such as CO₂ gas, ethanol, acetic acid, butanoic acid, and acetoin, with consequent off-odours and visual effects such as ropy slime formation and meat discolouration. (Taylor & Francis) (Iulietto et al., 2015). The abundant growth of slime-producing strains of *Lactobacillus* spp. and *Leuconostoc* spp. causes spoilage of marinated meat products even at cold storage temperatures of 4°C, with bacterial concentration exceeding 10⁵ CFU/mL after prolonged storage (Comi et al., 2020). Therefore, before adding vegetables and spices to the marinade, they should be sterilized or stored in cold storage to eliminate the micro-organisms.

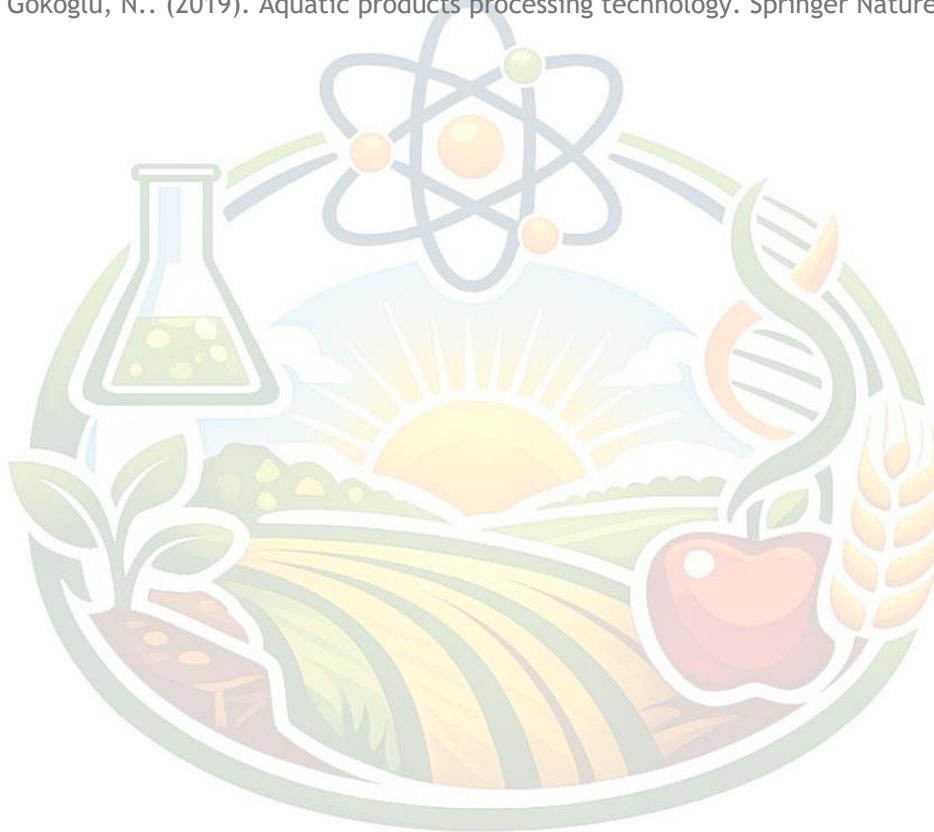
Conclusion

Marinades which is a traditional preservation method has a great reputation and public interest for typical taste, texture and flavour properties. Limited information exists about marinated seafood products. Fish preservation by marination technology is an untouched area in India. So standardize procedure should be applied in the valorisation food industry by extending the shelf life.

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Duck and Fish Integrated Farming

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Abstract

Duck-cum-fish farming is an eco-friendly and profitable integrated farming system where duck rearing and fish culture are carried out together in the same pond ecosystem. This method makes efficient use of natural resources by recycling duck droppings as organic manure, which improves pond fertility and promotes the growth of natural fish food like plankton. At the same time, ducks benefit from the pond by feeding on insects, weeds, snails, and leftover feed, reducing additional feeding costs. This integrated system helps farmers save on fertilizers and fish feed while increasing fish production, egg yield, and duck meat output. It is especially suitable for small and marginal farmers because it requires less investment and provides multiple income sources. Besides improving farm productivity, duck-cum-fish farming also supports sustainable agriculture by reducing waste and maintaining environmental balance. With proper pond management, breed selection, and health care, this system can be a practical solution for improving rural livelihoods and ensuring food security.

Introduction

Integrated farming is a sustainable agricultural approach where various farm enterprises (e.g., crops, livestock, aquaculture) are combined to improve resource utilization, minimize waste, and enhance overall productivity and profitability. Chinese people have a tradition of eating Such eggs and processing them into salted or preserved eggs. Duck raising required less equipment. Ducks mature earlier and produce more number eggs of large size. Ducks live in groups, feed on natural feeds through grazing. On an integrated fish farming, grow out pond can be used to raise egg-laying ducks. Ducks are considered as omnivorous as they feed on by-products of both crops and animal feeds. Though duck and goose are considered as water fowl, duck manure has higher nitrogen contents, which doubles that of goose manure, and the phosphate contents are nearly twice that of goose manure.

Duck-cum-Fish farming is an economically viable and technologically simple system. Land area (embankment, dykes) of a pond is used for constructing duck pens, as it harbours insects, worms, etc. it acts as a feeding ground for ducks.



Benefits of IFS

1. Enhanced resource utilization and nutrient recycling.
2. Waste generated from one component serves as input for another (e.g., duck droppings fertilize fish pond).
3. Diversified income sources, reducing risk for farmers.
4. Increased productivity per unit area.
5. Improved soil fertility & water quality.
6. Reduced reliance on external inputs (fertilizers, feed)



Fish-Cum-Duck Farming: The Synergy

Rearing ducks on or around fish ponds, where their activities and droppings benefit the fish culture, and the pond provides a suitable environment for the ducks. This creates a mutually beneficial relationship. Ducks' swimming and dabbling activities in the pond agitate the water, increasing dissolved oxygen levels. Duck droppings directly fertilize the pond water, providing essential nutrients (nitrogen, phosphorus, potassium, organic matter) for the growth of natural food organisms (phytoplankton and zooplankton) which serve as feed for fish.

Ducks feed on aquatic weeds, insects, snails, and their larvae, helping to control unwanted organisms and potential disease vectors. Ducks consume spilled fish feed and other organic matter, further recycling nutrients.

Site Selection for Pond

Non-rocky, level or gently sloping land should be selected for pond construction. Soil should be highly water-retentive, heavy clay or clayey loam is ideal. Soil pH should be near neutral (6.5-7.5). Water source should be dependable, year-round water supply (e.g., borewell, canal, perennial stream) to maintain water depth (1.5-3.0m). Water quality should be non-polluted (pH 7.0-8.5, DO 5-7 mg/L, Temp 20-30°C). The pond must be constructed in a location such that it should be easily accessible for management and marketing of produce. Site which is selected for pond should not be prone to flooding.

Duck Housing

The duck house should be constructed on the pond embankment, preferably directly over a part of the pond, or with a slatted floor over the water to allow direct dropping of excreta into the pond. This minimizes nutrient loss. The duck house must be spacious with adequate accommodation such that it should be cool in summer, warm during winter, with sufficient sunlight and should provide protection from rain. House should provide protection from natural enemies such as jackals, fox, dog, cat, snake, crows etc. Ducks must be reared in open-water, centralized system, floating house, house constructed on pond dykes. Floor space of 0.3-0.5 sq.m. per bird must be provided. Duck house should provide a secure night shelter to protect ducks from predators and for egg collection.



Pond Preparation and Management

Dewater the pond to remove excess silt and unwanted fish/predators. Raking the pond bottom to release nutrients from the soil. Apply lime (CaO or CaCO_3) to adjust pH, disinfect the pond, and improve soil and water quality. While duck droppings provide continuous fertilization, a basal dose of organic manure (e.g., cow dung) can be applied if needed, especially before introducing ducks. Maintain optimal water depth and monitor water quality parameters (pH, DO, temperature) regularly.

Area of nursery pond ranges from 100-500 sq. m. and the depth of water should be in between 1-1.5m. This pond covers 5% of total productive area of the fish farm. Area of rearing pond varies between 500-1000 sq.m. and the depth of water ranges from 1.5-2.0 m. This type of pond covers 15% area of the total productive area of the fish farm. Area of the stocking pond varies between 1000-20000 sq.m and the depth of water ranges from 2-2.5 m. This type of pond covers 60-70% area of the total productive area of the fish farm.

Liming and Fertilization

A pond with water to a depth of 2-2.5m. to maintain a desire 2-2.5m water depth inlet and outlet may be constructed at the pond dyke with measures to prevent the entry of unwanted organisms and also to prevent the escape of cultured fishes. Then water pH is measured and based on the pH value liming is done as follows. After 7-10 days of liming fertilization pond water is done. Cow dung@ 670 kg/bigha/year is applied as organic fertilizer. Inorganic fertilizer- urea @ 13 kg/bigha/year, single super phosphate @ 3kg/ bigha/year and murate of potash 212 kg/bigha/year is applied after 7-15 days of application of organic fertilizer. 1/3rd of the required amount of lime and fertilizer is applied initially to the pond, and then the rest amounts is divided equally into 11 installments and are applied to the pond at monthly regular interval. Then by seeing the pond productivity after 7-15 days of application of inorganic fertilizer, fish seed is released to the pond water.

Control of Water Seepage

Water seepage can be controlled by using bentonite or using plastic sheet. Since bentonite is not easily available in all places and its high value in the market, therefore, a layer (15 cm thick) of muddy clay soil may be used. Sometime a layer of cow dung and muddy soil mixture has shown promising result like that of bentonite.

Removal of Aquatic Weeds

Unwanted aquatic weds are needed to be removed form fish pond as it reduces the pond productivity. These unwanted aquatic weeds could be remove- manually, mechanically, chemically, and biologically. Grass carp. Tilapia, etc, are good biological agents.

Duck Husbandry

For the selection of ducks, we have to consider two things such as sturdiness and egg laying capacity. The selected duck breed should be able to withstand the weather conditions of the open pond in all seasons as ducks spend most of their time in pond water. Ducks should have high egg-laying capacity in order to earn income. Duck breed should be hardy, prolific egg layers that are good foragers are preferred. Common Breeds which are selected for duck farming are Indian runner, Khaki campbell, white pekin. Egg laying capacity of Indian runner is 150 eggs/year and khaki campbell is 180-200 eggs/year. Typically, ducks should be stocked in 100-300 per hectare of pond area. 15-20-day old ducklings should be introduced after proper acclimation. Improved breed of Indian runners are more suitable in view of its hardness. Manure from 450-500 ducks can fertilise 1 ha of water area.

Feeding

Ducks are excellent foragers and can obtain a significant portion of their diet (up to 60%) from the pond (insects, snails, larvae, aquatic weeds). Supplementary feeding (e.g., rice bran, kitchen waste, commercial duck feed) can be provided, especially during non-foraging hours or for higher production. Feed at a rate of 100g/bird/day. Ducks during day-time feed on natural food such as insects, worms, tadpoles, molluscs, soft aquatic weeds. Feeding during first 3 weeks is vital for future growth of duck. Feed with 17% of protein with high energy will be excellent for proper growth of Duckling. Feed with 15%of protein is good enough for layers. Ducks are voracious feeders, hence artificial feed of standard or superior quality of poultry feed mixed with rice bran in 1:2 ratio by weight at 100 g feed/bird/day should be given. Pelleted feed is considered better as ducks find it difficult to swallow dry mash.



Khaki Campbell



Indian runner

Health Management

Ducks are generally hardy, but vaccination against common duck diseases like duck plague and duck cholera is crucial. Monitor for signs of illness and isolate sick birds. Ducks are susceptible to aflatoxin which is a feed contaminant. Duck plague, virus hepatitis and cholera may cause heavy losses to duck population. Infected duck shows following indications such as: restlessness, water discharge from eye and nose, bird sound, decreased in daily feed consumption.

Prevention and Treatment of Common Diseases

Duck pest and Fowl cholera are the most important infectious diseases of egg laying duck. To treat fowl cholera, each egg-laying duck is injected intramuscularly with 50,000 IU of streptomycin at an interval of 4 hours for 3 consecutive times, then followed by oral ingestion of 0.2 gms of sulafadimethoxinum daily for 3 consecutive days. Sterilization, isolation and deep bury of carcass should be taken to prevent the spreading of the disease.

Egg Laying

Ducks usually start laying eggs from 5-7 months of age. Collect eggs daily from the night shelter. Usually, ducks start egg laying when they reach 24-week-old and continue to lay for 2 years but Khaki campbell which is prolific layer starts to lay eggs when it reach 3 months (12-14 weeks) old and continue to lay for 2-3 years. Ducks lay eggs during night, hence facilities such as straws or hay or providing in duck housing for egg laying. Khaki campbell produces 180-200 eggs/year while other breeds produce 150 eggs/year.

Use of Duck Dropping as Manure

Duck droppings contain 25% of organic and 20% of inorganic substances which are rich in Carbon, nitrogen, phosphorus, potassium, calcium etc. Ducks act as a living manuring machine. A duck voids on an average 125-150 gm droppings/day and thus 200-300 ducks would void on an average 10000-15000 kg of droppings/year which is sufficient to manure 1 ha water area under composite fish culture. Duck dropping has high manuring value. Duck dropping contains carbon, nitrogen, phosphorus which can stimulate growth of natural food organisms.

Fish Husbandry

Polyculture of compatible fish species with different feeding habits is highly recommended to utilize all trophic levels in the pond and maximize nutrient uptake from duck droppings.

Surface Feeders such as Catla (naturally feeds on zooplankton), Silver Carp (feeds on phytoplankton - benefits directly from duck droppings) are selected. Column Feeders such as Rohu (feeds on zooplankton, detritus) are selected. Bottom Feeders: Mrigal (detritivore), Common Carp (omnivorous, can stir bottom, consuming decaying organic matter) must be selected. Weed Feeders such as Grass Carp (consumes aquatic macrophytes, which ducks also help control). Typically, 5,000-7,500 fish fingerlings are stocked per hectare, depending on pond productivity and management. Advanced fingerlings (5-10 cm) must be stocked to minimize predation by ducks, although ducks generally prefer smaller organisms. Stocking Ratio: A common ratio for polyculture is:

Catla: 20-30%, Silver Carp: 20-30%, Rohu: 20-25%, Mrigal: 15-20% & Grass Carp: 5-10% (if aquatic weeds are prevalent). Generally, due to the continuous fertilization by ducks, the need for supplementary fish feed is significantly reduced or eliminated. However, grass carp may require some aquatic vegetation if natural growth is insufficient.

Management Practices

Daily morning ducks should be released into pond and eggs must be collected from the duck house. At daytime, ducks must forage in the pond. Daily evening the ducks are confined to their night shelter and supplementary feed must be provided. Regular monitoring of water quality parameters such as DO, pH, temperature and fish health, duck health should be done.

Harvesting

Ducks can be reared for 12-18 months for egg production, after which they can be sold for meat. Partial harvesting of fish can be done after 6-8 months of culture and the final harvesting can be done after 10-12 months, depending on growth rates. Yield from fish is 3000-4000 kg/ha/yr.

Economic Viability and Benefits

Integrated duck-cum-fish farming generates income from fish, duck eggs and duck meat. In this system, significant savings on fish feed (upto 60%) and fertilizers can be done due to natural manuring by ducks. When compared to traditional fish farming, integrated duck-cum-fish farming has high fish yield along with substantial egg and meat production from ducks. High benefit-cost ratio (often 3500-6000) is being observed, making it a highly profitable venture for farmers, especially small-scale and rural farmers. Duck-Cum-fish farming is an environmentally friendly due to

efficient waste recycling and reduced chemical inputs. This farming system provides a diverse range of protein-rich food for the farming family.

Challenges and Considerations

Setting up the pond and duck housing requires an initial investment. While generally robust, proper health management for both fish and ducks is crucial to prevent disease outbreaks.

Protection of ducks from predators (foxes, stray dogs, birds of prey) is essential. Ensuring proper market access for fish, eggs, and duck meat. Requires a basic understanding of both aquaculture and duck rearing. Overstocking of ducks can lead to excessive fertilization and potential water quality issues (e.g., algal blooms, oxygen depletion), requiring careful management.

Economics of Duck-cum-Fish Farming System

Expenditure analysis for 0.133 ha(1 bigha)		
Sl. no	Commodity/item	Cost involved (Rs.)
1	Pond preparation	3000.00
2	Yearlings (n=800)	8000.00
3	Poultry housing	2000.00
4	Chara Chambelli ducklings (n=40)	3200.00
5	Duck feed	9000.00
6	Labour cost	10,000.00
7	Miscellaneous	5000.00
Total cost involved		40200.00
Outcome statement		
1	Fish (560 Kg)@ Rs 100.00 per kg	56000.00
2	Eggs (5760nos)@ 180 eggs/bird for 32 no.s female duck@ Rs. 5.00 per egg	28800.00
3	Duck 40nos @ Rs. 200.00 per duck	8000.00
Total outcome per demonstration (0.133 ha)		92800.00

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Pelleted Fertilizer

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Granulation/ Pelletisation/ Agglomeration is the process of particle size enlargement and most commonly refers to the upgrading of material fines into larger particles, such as pellets or granules. In addition to material fines, agglomeration is also useful for sludge-like materials, such as manure or FGD sludge, to transform them into a more usable, more easily handled form.

Pelleted Form of Fertilizers

Nutri-rich organic fertilizer pellets offer the most natural source of essential nutrients to promote vigorous plant growth, bountiful yields and brilliant flowering. Derived from dried poultry waste, these fertilizer pellets are formulated with a broad spectrum of nutrients that slowly release as a plant needs them.

Fertiliser products such as **Nutri-Rich**, are convenient if you want to provide nutrients slowly and over a long time. These are particularly good for heavy feeder crops like corn and tomatoes. To apply a pelleted fertilizer, just sprinkle it around each plant at the quantity directed on the packaging. You may only need to reapply once mid-season.

There are many types of agglomeration, all offering their own unique advantages and disadvantages, but in general, they can all offer certain benefits.

Benefits of Agglomeration/ Granulation/ Pelletisation

1. Significant dust reduction
2. Improved handling convenience
3. More complete utilization of raw materials, conversion of waste to a marketable product, reduced transportation and handling costs.
4. Improved product characteristics and appearance, reduce caking and lump formation.

Types of Agglomeration/ Granulation/ Pelletisation

While there are many agglomeration techniques available, they generally fall under one of two main categories: pressure agglomeration, or non-pressure agglomeration (ex: tumble growth agglomeration). Pressure agglomeration technologies use mechanical compression to shape a material into a desired form. Very little, if any, moisture is needed. Non-pressure agglomeration technologies use a tumbling process to “grow” material into a spherical pellet form. A liquid binder is often used to assist in the agglomeration process.

Pressure Agglomeration

Briquetting: Typically a dry process, briquetting uses pressure to form pillow-shaped briquettes from material fines.

Compaction: Also typically a dry process, compaction presses material fines into a sheet-like form, which is then broken up into jagged granules.

Non-Pressure Agglomeration

Pelletizing: A wet process whereby material fines are rolled into uniform pellets with the help of a binding agent.

Micro Pelletizing: Also a wet process, in which material fines are mixed with a binder to form small agglomerates, or prepare the material for pelletizing.

Conditioning: A process which often refers to the mixing of material fins with a binding agent in order to reduce dust and transform the material into a more usable form.

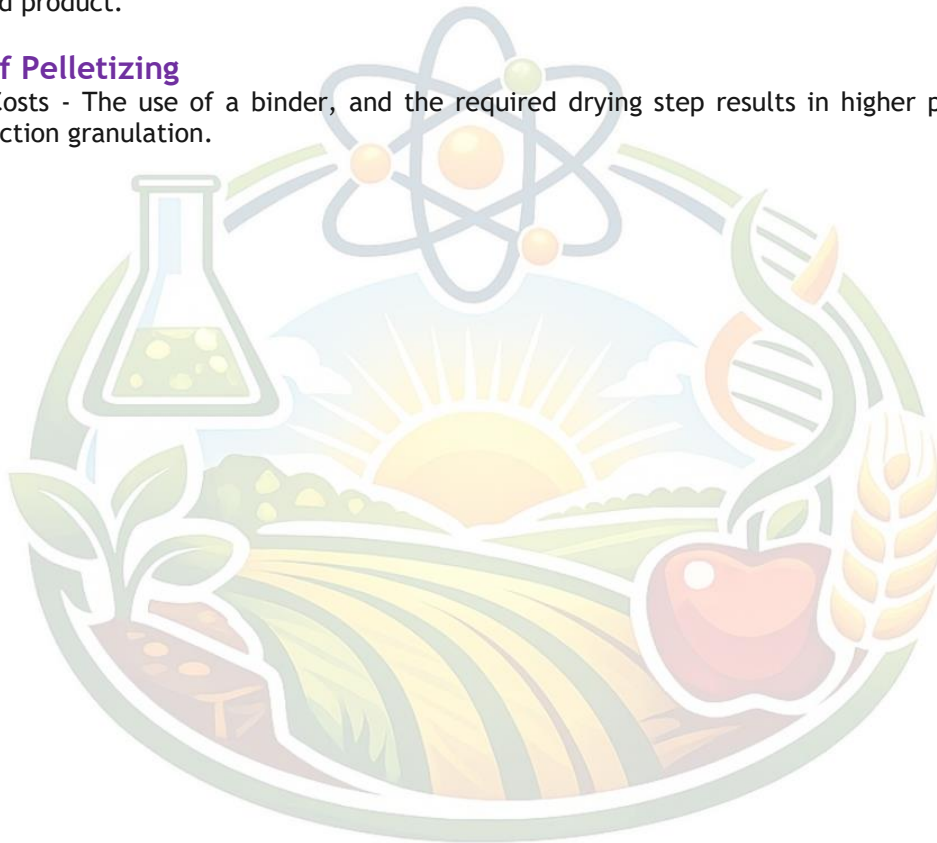
Industry Example: Agglomerated agricultural wastes (such as manure or compost) are easier to transport, store, and apply than unprocessed materials. Other improved characteristics include custom formulations, and opportunity for storing.

Advantages of Pelletizing

- 1. Faster nutrient delivery:** Because pellets are not created through pressure, they are less dense than their compaction granule counterparts. The less dense pellets created in pelletizing can withstand handling, but can still quickly break down upon application, an ideal characteristic for soil amendments, fertilizers, and other applications that benefit from fast material breakdown.
- 2. Less dust and fines:** Compared to compaction granules, pellets produce less fines. Since pellets are round, there are no edges to break off and create dust.
- 3. Binders can serve as beneficial additives:** Pelletization offers the opportunity to control formulation, through the addition of specially formulated binders, in order to create optimum pellet characteristics.
- 4. Lower capital costs:** The pelletizing method often requires a lower capital investment than compaction granulation.
- 5. A premium product is produced:** The round, smooth pellets produced in the pelletizing process are considered a premium product. Additionally, the pelletizing process offers the opportunity to include additives to further customize and enhance the end product.

Disadvantages of Pelletizing

Higher Processing Costs - The use of a binder, and the required drying step results in higher processing costs when compared to compaction granulation.



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Organic Farming and Climate Change Mitigation

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Climate change and variability are a considerable threat to agricultural communities, particularly in India. This threat includes the likely increase of temperature, extreme weather conditions, increased water stress and drought, and desertification. Farmers need tools to help them adapt to these new conditions. Organic farming is one such option which has both climate change mitigation and adaptation potential particularly in rainfed agriculture. It emphasizes recycling techniques and low external input and high output strategies. It is based on enhancing soil fertility and diversity at all levels and makes soils less susceptible to erosion. Emissions of nitrous oxide (N₂O) are directly linked to the concentration of easily available mineral nitrogen in soils. High emission rates are detected directly after fertilization and are highly variable. In a study by Petersen et al. (2005), lower emission rates for organic compared to conventional farming were found for five European countries. The use of organic amendments in organic farming not only supply nutrients but also have the potential to contribute to soil carbon sequestration. In a study at Hyderabad, organic production system being on par with integrated production system improved the easily oxidizable, oxidizable and weakly oxidizable organic C fractions at different soil depths compared to control. The C sequestration rate ranged from 0.21 to 0.85 t C/ha/yr in organic production systems compared to negligible rate (0.01-0.04 t C/ha/yr) in the plots under control. Organic agriculture systems have a strong potential for building resilient food systems in the face of uncertainties, through farm diversification and building soil fertility with organic matter. Several mechanisms may increase drought tolerance of organic cropping systems. Soil organic matter has positive effects on the water-capturing capacity of the soil. Numerous studies have shown soil organic carbon to be higher in organically managed systems (Gopinath et al., 2023). As a result, organically managed soils have high water holding capacity. In India, most of the organic cotton farmers stated that the capacity of their soils to absorb and retain water was increased after conversion to organic management. Many farmers also said that they need less rounds of irrigation and the crops can sustain longer periods of drought.

Constraints in Scaling Up of Organic Farming

Besides the well-known limitation of the availability of FYM and other organic forms of nutrients in desired quantities, water availability also is an important constraint for adoption of organic farming, particularly in arid and dry semi-arid tropics. Absence of surplus rainwater for harvesting and long periods of low soil moisture can limit the overall biomass production for recycling, green leaf manuring and on-farm composting. Application of 5-10 t FYM/ha is required in most crops to produce on par yields with recommended chemical fertilizers. Such level of in-puts use can only be possible in limited areas for specific crops. However, biomass production during the off-season through a legume cover cropping and its incorporation in the soil can be another strategy to overcome the limitation of organic matter availability in high rainfall regions. Since the overall biomass production is linked to rainfall, using crop biomass either by composting or through recycling should be a major strategy in relatively high rainfall receiving areas in moist semi-arid and dry subhumid regions (750 - 1200 mm) while the dry semi-arid and arid areas (300 - 750 mm) may depend on use of FYM as the principal source, since livestock is a strong component in these regions. Considering the low organic matter and fertility status of Indian soils, the yield decline during conversion period could be sharp in the absence of external inputs. In view of the limited biomass and organic resources available for use in rainfed areas, organic production either for domestic or export markets should be encouraged in highly selected areas and commodities. This strategy alone can sustain the production and marketing of organic food on long-term basis.

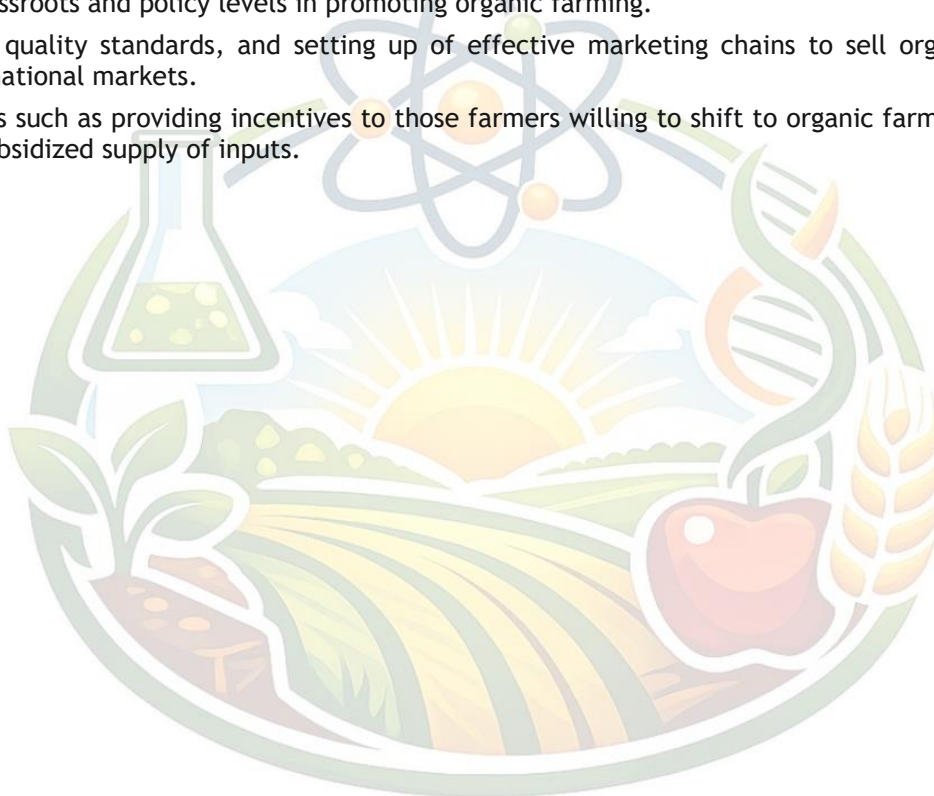
Way Forward

India is bestowed with a lot of potential to produce all varieties of organic products due to its various agro-climatic regions and traditional knowledge. Due to low input demand, rainfed areas are potential hotspots to produce organic products (Gopinath et al., 2019). It is evident from research findings that many crops respond better to organic management particularly after an initial conversion period of 2-3 years in rainfed areas. Organic farming can significantly contribute to improving the livelihoods of small holders as it generates higher incomes and involves less risk. As the export potential is increasing, overcoming the hurdles in rainfed areas, developing cost effective production systems, and adequate scientific research will help India emerge as a good exporter of organic products and increase farm net revenues.

Some of the thrust areas to promote organic farming in rainfed areas are:

1. Delineation of the potential areas/ zones like hill and tribal areas, for rainfed organic farming by identifying contiguous blocks of areas with little or no chemical input use and where productivity can be enhanced by using permitted inputs to enable group certification to farmers.

2. Carry out a country wide survey/ inventorisation of areas in arid, semi-arid and dry sub humid regions about the level of chemical input use, and productivity in selected commodities which have potential to fetch price premiums in international markets.
3. Survey, documentation and critical evaluation of indigenous technological knowledge on organic farming.
4. Inter-disciplinary and location-specific research for development of package of practices for organic farming and integrated organic farming systems. Organic production packages will be more location-specific than inorganic package of practices as the input use depends largely on locally available resources.
5. Development of cost effective technology for on-farm organic manure production as well as large scale production of compost from domestic, agricultural, and industrial wastes.
6. Generation of adequate scientific information on the yield, quality, economics and post-harvest aspects of various crops under different management levels and agro-climatic conditions.
7. Assess the climate change adaptation and mitigation potential of rainfed organic farming systems
8. Extension machinery including State departments, NGOs, and other private organizations should develop intensive partnerships, at grassroots and policy levels in promoting organic farming.
9. Development of quality standards, and setting up of effective marketing chains to sell organic produce in both domestic and international markets.
10. Policy initiatives such as providing incentives to those farmers willing to shift to organic farming, providing market information, and subsidized supply of inputs.



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DNA Insecticides: A New Frontier in Sustainable Pest Management

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Abstract

Modern agriculture faces a difficult challenge: increasing food production while reducing dependence on conventional chemical pesticides. The widespread use of insecticides has contributed to resistance development, environmental contamination, pesticide residues, and concerns regarding non target effects. In this context, DNA insecticides have emerged as a novel biotechnology based approach to insect pest management. These molecules utilize short insect specific DNA fragments that interfere with essential cellular processes in target pests. Recent studies have demonstrated promising results against several insect species, including the gypsy moth (*Lymantria dispar*), while exhibiting minimal effects on non target organisms. This article explores the scientific basis of DNA insecticides, highlights key research findings, discusses their advantages and limitations, and examines their potential role in sustainable agriculture.

Introduction: Why Agriculture Needs New Weapons

Insect pests are responsible for substantial losses in agricultural production worldwide. Chemical insecticides have been indispensable tools for pest management; however, their extensive use has resulted in several problems, including insecticide resistance, environmental pollution, pesticide residues, and adverse effects on beneficial organisms. As agriculture moves towards sustainability, there is an urgent need for innovative pest management strategies that are effective, selective, and environmentally safe.

The ideal insecticide of the future would combine high efficacy with exceptional specificity, targeting pest insects while sparing beneficial organisms and the surrounding environment. DNA insecticides represent one of the most promising developments in this direction.

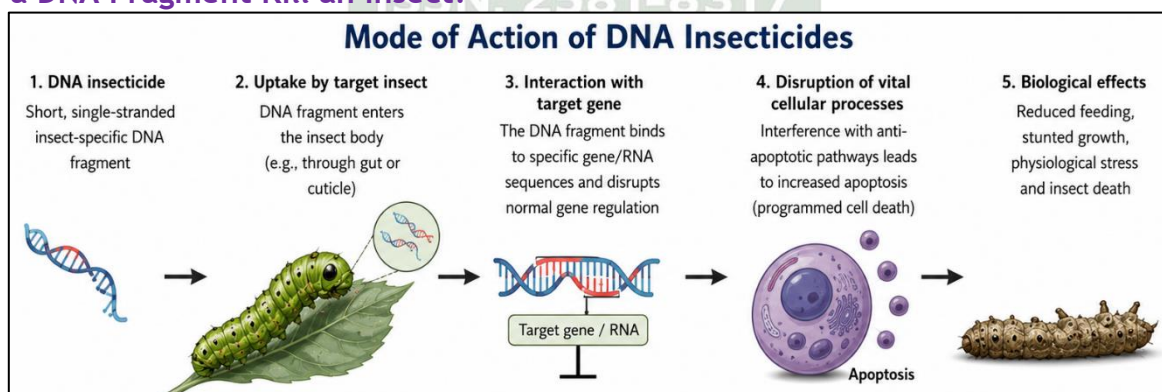
What are DNA Insecticides?

DNA insecticides are short single stranded DNA (ssDNA) fragments derived from viral genes that possess insecticidal activity and can be applied topically. The concept was pioneered by Volodymyr V. Oberemok in 2008, who described them as “intellectual insecticides that think before they act” (Oberemok and Skorokhod, 2014).

The development of DNA insecticides originated from studies on baculoviruses, a group of naturally occurring viruses that infect insects. Baculoviruses possess genes known as inhibitors of apoptosis proteins (IAPs), which help infected cells avoid premature death. Scientists discovered that short DNA fragments derived from these viral genes could interfere with similar cellular pathways in susceptible insects.

Unlike conventional insecticides that typically affect the nervous system or metabolic pathways, DNA insecticides function at the molecular level by interacting with specific genetic sequences. Their mode of action resembles mechanisms employed in RNA interference (RNAi) and antisense oligonucleotide technologies, but they offer several unique advantages, including simple design and topical application.

How can a DNA Fragment Kill an Insect?



Every insect depends on a complex network of genes that regulate growth, development, reproduction, and survival. One critical process is apoptosis, commonly known as programmed cell death. Under normal conditions, apoptosis removes damaged or unnecessary cells and maintains cellular balance. However, insects possess anti-apoptotic mechanisms that prevent excessive cell death.

DNA insecticides are designed to interfere with these protective mechanisms. When a specific DNA fragment enters a target insect, it disrupts the expression of genes involved in cellular protection. As apoptosis increases, tissues begin to deteriorate, feeding declines, growth slows, and mortality eventually occurs. This highly targeted mechanism distinguishes DNA insecticides from conventional chemical pesticides.

The Gypsy Moth: A Test Bed for DNA Insecticides

The gypsy moth (*Lymantria dispar*) is one of the world's most destructive forest pests, capable of defoliating vast areas of woodland. In a landmark study, researchers tested short DNA fragments derived from the IAP-3 gene of the gypsy moth nucleopolyhedrovirus (Oberemok *et al.*, 2016). Two regions of the gene were examined: the BIR domain and the RING domain.

Caterpillars treated with the RING domain fragment experienced mortality rates of $42.5 \pm 23.2\%$, compared with only $7.5 \pm 1.8\%$ in untreated controls. In addition to increased mortality, treated caterpillars showed reduced biomass and impaired development.

Even more intriguing was the observation that surviving females produced eggs with altered expression of genes associated with apoptosis and cellular regulation. These findings suggest that DNA insecticides may produce effects extending beyond the treated generation.

Do DNA Insecticides Harm Non-Target Insects?

While efficacy against target pests is important, any new insecticide must also demonstrate safety toward non target organisms.

To evaluate the specificity of DNA insecticides, researchers tested the same DNA fragments on the tobacco hornworm (*Manduca sexta*) and the common fruit fly (*Drosophila melanogaster*) (Oberemok and Nyadar, 2015).

The results demonstrated mortality levels of approximately 10%, similar to untreated controls. These findings indicate that DNA insecticides can discriminate between target and non target species, a property that could significantly reduce ecological risks.

Nature's Own DNA Based Defence

Recent research has revealed that plants naturally release extracellular DNA (exDNA) on their surfaces. This extracellular DNA forms microscopic protective layers on leaves, stems, and roots.

Scientists have suggested that these DNA layers may play a role in plant defence against insects and pathogens. Research involving *Pittosporum tobira* revealed that concentrated extracellular DNA caused $98.14 \pm 2.5\%$ mortality in larvae of the soft scale insect *Coccus hesperidum* (Oberemok *et al.*, 2022). Such discoveries indicate that DNA based defence mechanisms may already exist in nature and could inspire future pest management innovations.

Why Should Farmers Care?

DNA insecticides offer several potential advantages that align closely with the goals of sustainable agriculture:

1. Highly species specific targeting
2. Reduced effects on beneficial insects
3. Biodegradable and environmentally friendly
4. Potential tool against insecticide resistance
5. Compatibility with Integrated Pest Management (IPM)
6. Reduced pesticide residues in agricultural systems

If successfully commercialized, DNA insecticides could complement existing pest management strategies and contribute to more sustainable crop protection programmes.

Challenges Before Commercial Adoption

Despite their promise, DNA insecticides remain largely experimental. Several challenges must be addressed before large scale agricultural use becomes feasible.

Researchers must improve field stability, develop efficient delivery systems, reduce production costs, and satisfy regulatory requirements. Furthermore, most evidence currently comes from laboratory studies, and extensive field evaluations will be required before commercial deployment becomes possible. The long term ecological implications of large scale DNA insecticide use also require careful investigation.

Conclusion

DNA insecticides represent a radical departure from conventional pest management approaches. By using carefully designed genetic sequences to interfere with essential biological processes, they offer the possibility of highly selective and environmentally friendly insect control. Although significant scientific and regulatory challenges remain, current research demonstrates that the future of pest management may increasingly be written in the language of DNA rather than traditional chemical formulas.

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Insecticide Contaminated Honeydew: The Hidden Threat to Pollinators and Natural Enemies

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Abstract

Honeydew, the sugar rich excretion of sap feeding insects such as aphids, whiteflies, mealybugs and scale insects, serves as an important food source for many beneficial insects including pollinators, predators and parasitoids. Recent studies have revealed an unexpected ecological concern: systemic insecticides can contaminate honeydew and expose beneficial insects to toxic residues. Unlike nectar, honeydew is abundant across seasons and crops, making it a major carbohydrate source in agricultural ecosystems. Research has demonstrated that insecticides such as imidacloprid, thiamethoxam, flonicamid and pymetrozine can reach honeydew through treated plants and sap-feeding insects. Beneficial insects consuming contaminated honeydew suffer increased mortality, reduced longevity and impaired biological control efficiency. This overlooked route of exposure highlights the need to reconsider pesticide risk assessment and promote safer pest management practices.

Nature's Sweet Resource

When aphids, mealybugs, whiteflies and other sap feeding insects feed on plant phloem, they ingest large quantities of sugary sap. Since the sap contains far more sugar than these insects require, the excess is excreted as a sticky liquid known as honeydew. For decades, honeydew was considered merely a nuisance because it promotes the growth of sooty mould on plant surfaces. However, ecologists now recognize honeydew as one of the most important energy sources available to beneficial insects. Bees, hoverflies, lacewings, ladybird beetles, predatory bugs, parasitic wasps and even ants regularly feed on honeydew.

In many cropping systems, honeydew is available throughout the growing season, often when floral nectar is scarce. More than 80% of honeydew dry matter consists of carbohydrates, including glucose, fructose, sucrose and several complex sugars. It also contains amino acids and micronutrients that support insect survival and reproduction.

When Sweet Turns Toxic!

Modern agriculture relies heavily on systemic insecticides. These compounds are absorbed by plants and transported through their vascular tissues, protecting crops against sap feeding pests. Scientists recently discovered that these insecticides do not remain confined within plant tissues. Instead, they can enter the bodies of honeydew-producing insects and eventually appear in the honeydew they excrete.

As a result, beneficial insects may unknowingly consume insecticides while feeding on what appears to be a natural food source. This exposure pathway remained largely unnoticed because pesticide risk assessments traditionally focused on nectar, pollen and direct spray exposure.

How Does Honeydew Become Contaminated?

Researchers have identified three major pathways (Calvo-Agudo *et al.*, 2019):

- 1. Direct contamination:** Honeydew already present on plants may be directly sprayed with insecticides.
- 2. Through honeydew-producing insects:** Sap-feeding insects may absorb insecticides during spraying and subsequently excrete contaminated honeydew.
- 3. Through treated plants:** Systemic insecticides move throughout plant tissues. Aphids, mealybugs and scale insects feeding on treated plants ingest these compounds and later excrete them in their honeydew.

Among these pathways, contamination through treated plants is considered the most important because it can persist long after pesticide application.

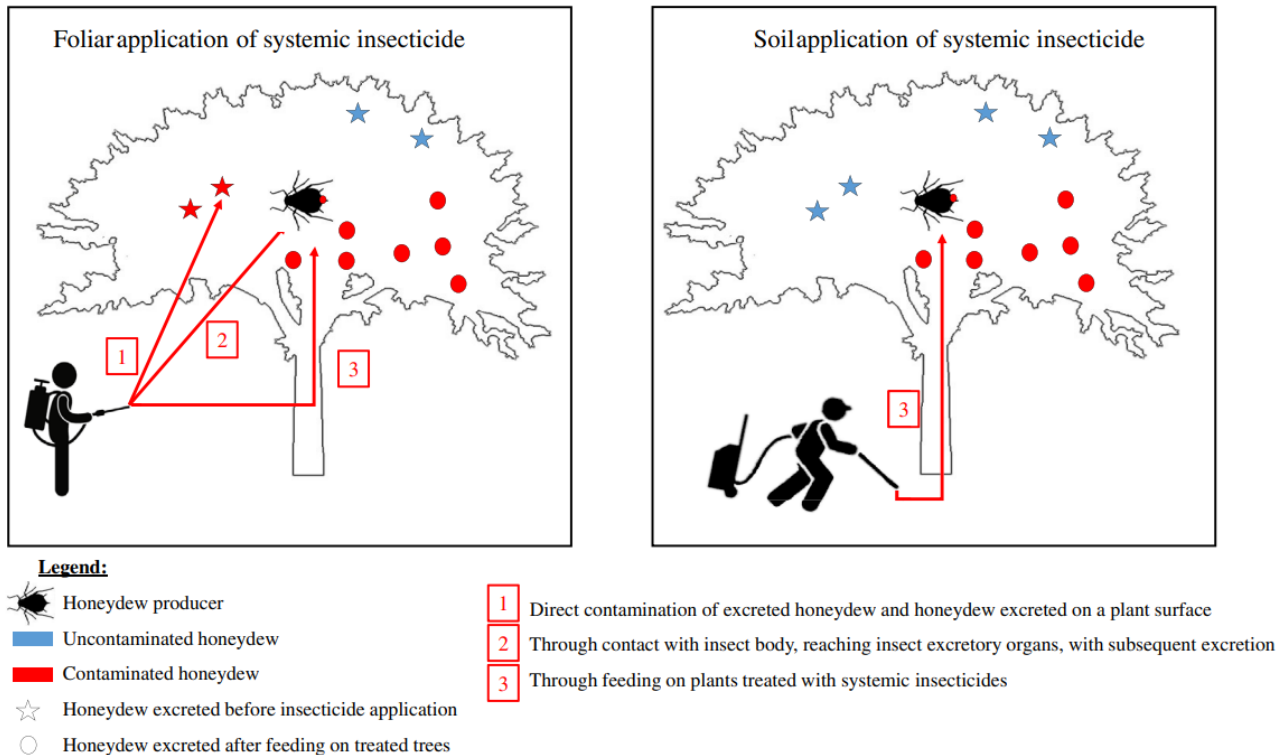


Fig. 1. Pathways by which honeydew can be contaminated with insecticides

Following the Trail of Contaminated Honeydew

Pine Scales and Imidacloprid: A study conducted on striped pine scale insects feeding on insecticide treated pine trees provided the first direct evidence that systemic insecticides can be excreted through honeydew (Quesada *et al.*, 2020).

Researchers detected both imidacloprid and spirotetramat in honeydew collected from treated trees. Imidacloprid was detected only four days after application, demonstrating that insecticides can move rapidly from soil to plant tissues, into sap feeding insects and finally into honeydew. The study confirmed that contaminated honeydew can serve as a previously overlooked reservoir of pesticide residues in the environment.

Soybean Aphids and Seed Treated Crops: Neonicotinoid coated seeds are widely used in soybean cultivation. Researchers investigated whether residues from seed treatments could reach honeydew produced by soybean aphids (Calvo *et al.*, 2021). The results were alarming. Honeydew collected from aphids feeding on treated soybean plants contained elevated concentrations of clothianidin, a metabolite of thiamethoxam. Beneficial insects that consumed this honeydew suffered significant reductions in longevity. Female predatory midges lived only 7-10 days compared with 14 days when feeding on uncontaminated honeydew. Similarly, parasitoid wasps showed reduced lifespan after consuming contaminated honeydew. These findings demonstrated that pesticide exposure can occur even without direct contact with treated plants.

Citrus Mealybugs and IPM-Compatible Insecticides: Flonicamid and pymetrozine are often considered relatively safer insecticides and are commonly recommended in Integrated Pest Management (IPM) programs.

However, research in citrus orchards showed that honeydew produced by mealybugs feeding on treated trees contained measurable amounts of both insecticides (Calvo *et al.*, 2020). When hoverflies consumed contaminated honeydew, mortality increased dramatically. More than half of the hoverflies died after feeding on honeydew containing flonicamid residues. In contrast, parasitoid wasps were less affected, indicating that susceptibility differs among beneficial insect groups. These findings highlight that even insecticides regarded as IPM-compatible may pose hidden ecological risks through indirect exposure pathways.

Why Should Farmers Care?

Beneficial insects provide essential ecosystem services worth billions of dollars globally. Pollinators enhance crop productivity, while predators and parasitoids naturally suppress pest populations.

When these beneficial organisms decline, farmers may face:

1. Reduced pollination efficiency.
2. Increased pest outbreaks.

3. Greater dependence on chemical pesticides.
4. Higher production costs.
5. Reduced sustainability of pest management programs.

Because honeydew is abundant in crops such as soybean, cotton, cereals, brassicas and citrus, contamination can influence a wide range of agricultural systems.

Implications for Integrated Pest Management

The discovery of contaminated honeydew challenges traditional approaches to pesticide risk assessment. Future IPM strategies should emphasize:

1. Judicious use of systemic insecticides.
2. Selection of compounds with lower persistence.
3. Avoidance of unnecessary prophylactic seed treatments.
4. Conservation of beneficial insect habitats.
5. Inclusion of honeydew exposure pathways in environmental risk assessments.

Conclusion

Honeydew is far more than a sugary waste product. It serves as a vital food source connecting herbivores, predators, parasitoids and pollinators within complex food webs. Scientific evidence now shows that systemic insecticides can contaminate honeydew and expose beneficial insects to toxic residues. This hidden route of exposure may contribute to declines in pollinators and natural enemies, ultimately affecting agricultural sustainability. Recognizing honeydew as a pathway of pesticide exposure is essential for developing safer and more ecologically sound pest management strategies.

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Behavioral Resistance in Insects: The Overlooked Dimension of Insecticide Resistance

Article ID: 74069

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Abstract

For decades, insecticide resistance has been viewed primarily as a physiological phenomenon in which insects survive toxic compounds through detoxification, target site modifications, or reduced penetration. However, insects possess another powerful strategy that often goes unnoticed which is simply avoiding insecticides altogether. This phenomenon, known as behavioral resistance, enables insects to escape exposure by altering their feeding, resting, host seeking, or foraging behavior. From house flies avoiding DDT treated surfaces to German cockroaches rejecting glucose containing toxic baits and mosquitoes shifting their biting habits to evade insecticide treated nets, behavioral resistance has emerged as an important but often overlooked challenge in pest management. Understanding how insects modify their behavior in response to insecticidal selection pressure is becoming increasingly important for the development of sustainable pest-management strategies.

Introduction: The Resistance We Often Miss

When an insecticide fails, the usual explanation is that insects have become resistant. Most people imagine insects developing biochemical weapons that detoxify insecticides or genetic mutations that render toxins ineffective. But what if insects survive without ever touching the insecticide?

Imagine a pest population that learns to rest on untreated surfaces, avoid toxic food baits, feed at different times of the day, or shift to locations where insecticides are absent. Such insects may remain fully susceptible to the insecticide itself, yet control programs fail because exposure never occurs. This phenomenon is known as **behavioral resistance**, one of the most fascinating and underappreciated forms of insect adaptation.

More Than Just Survival

Unlike physiological resistance, where insects survive after exposure, behavioral resistance reduces the likelihood of exposure in the first place. Behavioral resistance is defined as an evolved response to the selective pressures exerted by a toxicant or formulation that enhances the ability of a population to avoid the lethal effects of that toxicant or formulation and exhibit different behavior typical for that insect taxon (Hubbard and Murillo, 2024). In simple terms, insects change what they do, where they go, or what they eat to avoid danger (Fig. 1).

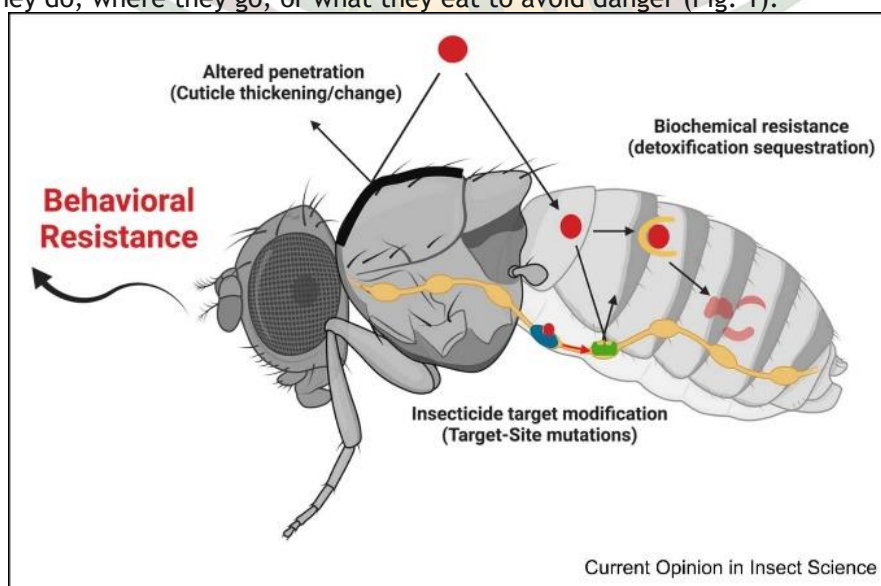


Fig. 1 Mechanisms of Insecticide resistance

This strategy can be remarkably effective because an insect does not need to detoxify a poison if it never encounters it.

The First Clues: House Flies and DDT

The story of behavioral resistance began soon after the introduction of DDT, one of the most celebrated insecticides in history. During the late 1940s, farmers and livestock owners reported that DDT treatments were no longer providing satisfactory control of house flies. At first, many suspected poor quality insecticide formulations. However, researchers discovered something unexpected. House flies were increasingly resting on untreated floors, feed troughs, and equipment instead of on DDT treated walls and ceilings. The insecticide had not lost its toxicity. Instead, the flies had altered their behavior (King and Gahan, 1949).

This phenomenon became known as **excito-repellency**, where insects avoid treated surfaces because of irritant or repellent effects. The observation represented one of the earliest documented examples of behavioral resistance.

When Mosquitoes Changed their Schedule

Mosquito control programs have relied heavily on Indoor Residual Spraying (IRS) and Insecticide Treated Nets (ITNs). These interventions were highly successful because many malaria vectors preferred feeding indoors during the night. But mosquitoes did not remain passive.

Studies from Africa, Asia, and the Pacific region revealed remarkable behavioral shifts (Carrasco *et al.*, 2019). Some mosquito populations began biting earlier in the evening before people retired under bed nets. Others increasingly sought hosts outdoors rather than indoors. Certain species even shifted from feeding on humans to feeding more frequently on livestock. These changes reduced contact with insecticide-treated surfaces and contributed to declining effectiveness of control measures. The insects were not necessarily becoming more tolerant of insecticides. Instead, they were changing their lifestyles.

The Cockroach that Refused to Eat

Perhaps the most remarkable example of behavioral resistance comes from the German cockroach (*Blattella germanica*). During the 1980s, insecticide baits became one of the most successful tools for cockroach management. These baits combined toxicants with attractive food ingredients, particularly corn syrup containing glucose and fructose. Initially, the strategy worked exceptionally well. But later, field populations began rejecting the baits. Researchers discovered that some cockroaches had evolved **glucose aversion** (Silverman and Bieman, 1993). While normal cockroaches perceived glucose as a desirable food source, resistant populations treated glucose as a deterrent and avoided consuming bait altogether. Further investigations revealed that this behavior had a genetic basis. A single major gene influenced the trait, allowing it to spread rapidly within populations exposed to glucose containing toxic baits. In effect, the cockroaches had turned one of the bait's strongest attractions into a warning signal.

Rewiring the Sense of Taste

The story became even more fascinating when scientists examined the cockroach nervous system. In most cockroaches, glucose activates gustatory receptor neurons associated with sweet taste, promoting feeding behavior. In glucose-averse cockroaches, however, glucose stimulated not only sweet-sensitive neurons but also bitter-sensitive neurons (Katsumata *et al.*, 2018). As glucose concentrations increased, bitter-neuron responses became increasingly dominant. The result was a dramatic change in perception: a sugar that once tasted sweet now tasted bitter. This represents one of the most striking examples of how evolution can modify sensory systems to enhance survival.

House Flies Strike Again

Behavioral resistance is not restricted to cockroaches. Recent studies demonstrated that house flies can rapidly evolve avoidance of imidacloprid containing sugar baits (Hubbard and Gerry, 2021). Experimental selection produced fly populations in which survival increased dramatically within only a few generations. Remarkably, researchers were able to select both resistant and susceptible lines from the same population, suggesting that genetic variation for behavioral resistance already existed before strong selection occurred. These findings highlight how quickly behavioral traits can evolve when insecticides impose strong selection pressure.

Why Behavioral Resistance Matters?

Behavioral resistance presents unique challenges for pest management. Unlike physiological resistance, it is often difficult to detect using conventional bioassays. Most resistance monitoring programs focus on mortality after exposure rather than behaviors that reduce exposure. As a result, behavioral resistance may remain unnoticed until field failures become apparent. Moreover, behavioral resistance can operate alongside physiological resistance, creating multiple layers of protection against control measures. An insect that avoids insecticides and survives exposure when contact occurs possesses a formidable survival advantage.

Rethinking Resistance Management

The growing recognition of behavioral resistance suggests that pest management programs must look beyond traditional measures of susceptibility. Future strategies may require:

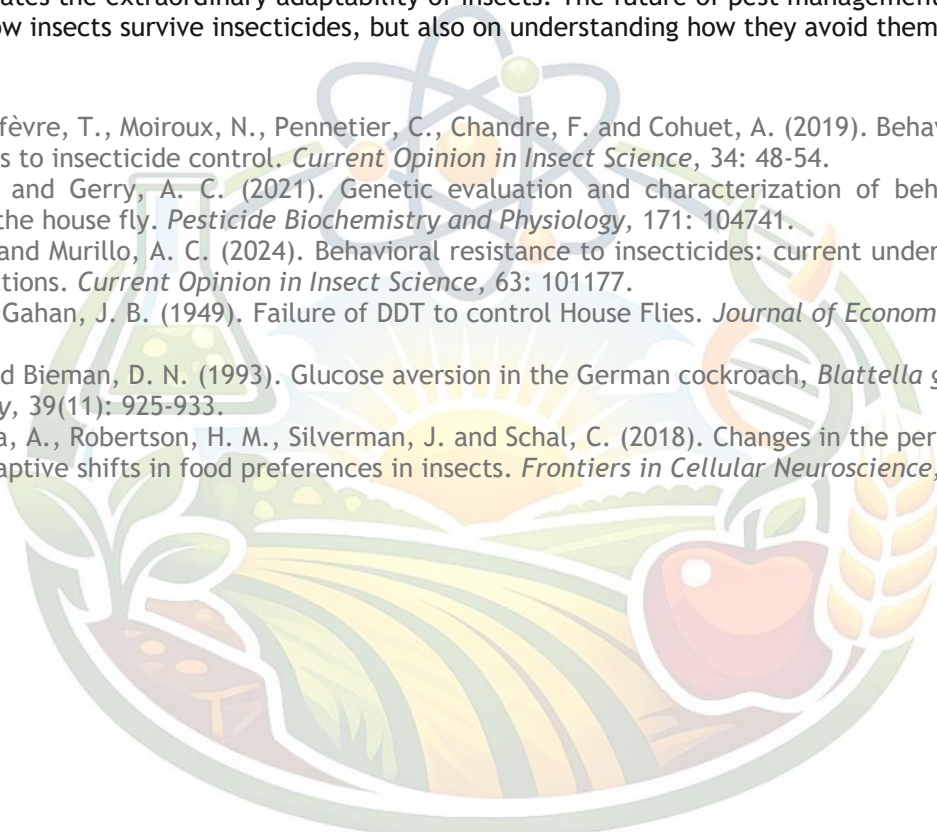
1. Greater emphasis on behavioral monitoring.
2. Rotation of bait formulations and attractants.
3. Integration of chemical and non-chemical control methods.
4. Improved understanding of insect sensory biology.
5. Development of pest-management systems that anticipate behavioral adaptation.

Conclusion

For decades, insecticide resistance has been viewed primarily through the lens of physiology and genetics. Yet insects possess another powerful survival strategy, i.e., changing their behavior. From house flies avoiding DDT treated surfaces to cockroaches transforming sugar into a warning signal and mosquitoes altering their feeding habits, behavioral resistance demonstrates the extraordinary adaptability of insects. The future of pest management will depend not only on understanding how insects survive insecticides, but also on understanding how they avoid them.

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The Ant Colony's Invisible Clock: How Biological Rhythms Organize a Society Without Leaders

Article ID: 74070

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Abstract

Ant colonies are among the most successful social systems on Earth. Despite the absence of managers, supervisors, or central control, thousands of individuals coordinate brood care, foraging, nest maintenance, and defense with remarkable efficiency. Recent research has revealed that this organization is closely linked to biological rhythms operating within individual ants. Circadian clocks, environmental cues, social interactions, and gene-expression rhythms collectively influence when and where workers perform specific tasks. These internal clocks are not rigid; they exhibit remarkable plasticity, allowing colonies to adjust their activities according to changing environmental conditions and colony needs. This article explores how biological rhythms shape task allocation in ant colonies and highlights the fascinating mechanisms that enable ants to function as highly organized societies.

Introduction: A Society Without Managers

Imagine a city where thousands of individuals work continuously without supervisors, schedules, or written instructions. Food is collected, children are cared for, waste is removed, and infrastructure is maintained with remarkable efficiency. Such a system would seem impossible in human society, yet it exists naturally in ant colonies.

Ant societies have fascinated scientists for decades because they achieve extraordinary levels of organization without centralized control. Each worker performs tasks based on local information and interactions with nestmates. Younger workers typically remain inside the nest caring for brood, whereas older workers venture outside to forage and defend the colony. The question that has intrigued researchers is simple: how do ants know when to perform particular tasks? The answer lies partly in an invisible biological system - “The Circadian Clock”.

2017 Nobel Prize in Physiology or Medicine was jointly awarded to Jeffrey C. Hall, Michael Rosbash and Michael W. Young for their discoveries of molecular mechanisms controlling the circadian rhythm.

The Hidden Timekeepers Inside Ants

Like humans, ants possess biological clocks that regulate daily cycles of activity and rest. These circadian rhythms enable organisms to anticipate predictable environmental changes associated with the Earth's rotation.

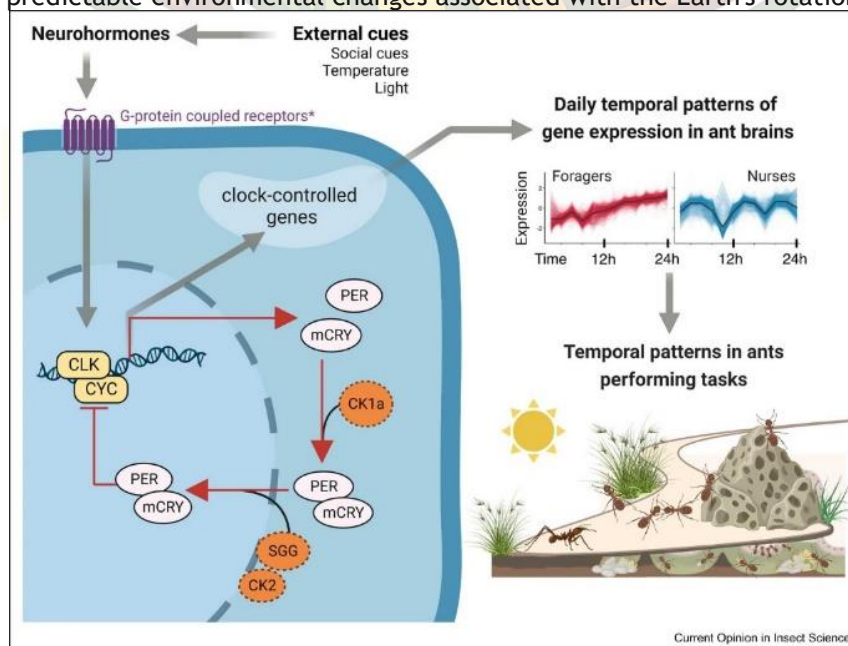


Figure 1. TTFL (Transcription Translation Feedback Loop)

At the cellular level, circadian rhythms are controlled by a molecular mechanism known as the **transcription-translation feedback loop (TTFL)** (Figure 1). In ants, clock genes such as **Period (Per)**, **Clock (Clk)**, **Cycle (Cyc)** and **Cryptochrome (Cry)** interact in a self-regulating cycle that takes approximately 24 hours to complete (Das and Gordon, 2023). Proteins produced by these genes accumulate and subsequently inhibit their own production, creating rhythmic oscillations in gene expression. These molecular clocks generate daily patterns in physiology and behavior, helping ants synchronize their activities with changing environmental conditions.

Around-the-Clock Nurses

Not all ants follow the same daily schedule. Research on the ant *Diacamma* demonstrated that nurse workers isolated from their colony exhibit clear circadian activity rhythms. However, when these nurses were placed with eggs or larvae, their rhythms became substantially weaker. Instead of restricting their activity to particular periods of the day, they remained active almost continuously (Fujioka *et al.*, 2017). Why would this happen?

The answer lies in the needs of the brood. Eggs and larvae are fragile and require constant feeding, grooming, and protection. Pupae, on the other hand, are enclosed within protective cocoons and require less attention. Consequently, nurses caring for eggs and larvae abandon strict daily schedules to provide around-the-clock care. This finding illustrates an important principle of social insect biology: colony needs can override individual biological rhythms.

Why Ants Move their Babies Twice a Day?

Temperature plays a critical role in insect development, and ant nurses carefully regulate the thermal environment experienced by their brood. Studies on *Camponotus mus* revealed that nurse workers repeatedly move brood between warmer and cooler regions of the nest during the day (Roces and Nunez, 1989). Around midday, brood are transferred to warmer locations near 30.8°C. Later at night, they are relocated to cooler areas averaging approximately 27.5°C.

These movements are not random. They follow a predictable daily rhythm controlled by both environmental cues and the ants' biological clocks. Further research showed that these thermal fluctuations influence the development of the ant brain itself. Ants reared under natural temperature cycles developed higher densities of synaptic structures within regions of the brain associated with learning and memory. In other words, nurse ants are not simply moving brood to comfortable locations, instead they are helping shape the neurological development of future colony members.

Following Nature's Work Schedule

While nurse ants care for brood inside the nest, foragers must respond to conditions outside. Research on the giant ant *Dinoponera quadriceps* demonstrated that foraging activity follows both daily and seasonal rhythms (Medeiros *et al.*, 2014). Colonies remained active throughout the year, but the intensity of foraging varied considerably depending on environmental conditions.

During the early dry season, workers displayed two distinct peaks of activity: one during the morning and another during the afternoon. Activity declined sharply during the hottest part of the day when temperatures exceeded 30°C and humidity fell below 60%. In contrast, during wetter periods with lower temperatures and higher humidity, foraging activity became more evenly distributed throughout daylight hours. These observations demonstrate that biological clocks do not function independently of the environment. Instead, they interact continuously with external factors such as temperature, humidity, and resource availability.

A Colony That Can Change Priorities Overnight

One of the most remarkable features of ant societies is their flexibility. Experiments conducted on red harvester ants (*Pogonomyrmex barbatus*) revealed how colonies adjust their activities when confronted with unexpected challenges (Gordon, 1986). Researchers obstructed nest entrances with toothpicks, placed barriers along foraging trails, and even removed groups of workers from the colony.

The results showed that changes in one activity often triggered adjustments in several others. When nest maintenance demands increased, foraging decreased. When foraging became difficult, workers were reassigned from other tasks to maintain food collection. Most surprisingly, when colonies were forced to choose between foraging and nest maintenance, they consistently prioritized foraging. Food acquisition appeared to take precedence over many other colony activities. Such findings suggest that ant colonies possess a dynamic system of task allocation capable of responding rapidly to changing circumstances.

Inside the Ant Brain: The Genetics of Division of Labour

Recent advances in molecular biology have provided unprecedented insights into the genetic basis of task allocation. Researchers studying the carpenter ant *Camponotus floridanus* discovered that foragers and nurses differ dramatically in their patterns of gene expression (Das and Bekker, 2022). More than 3,500 genes exhibited daily rhythmic expression in foragers, compared with approximately 1,300 genes in nurses.

Interestingly, nurse ants were not simply lacking biological rhythms. Instead, many genes that oscillated every 24 hours in foragers showed shorter eight-hour rhythms in nurses. This discovery suggests that nurse ants possess an alternative timing system that allows them to remain active around the clock while retaining the ability to rapidly switch to a forager-like schedule if colony conditions change. Such flexibility provides a molecular explanation for one of the defining features of social insects - their ability to reorganize labour in response to colony needs.

Why Biological Rhythms Matter?

Understanding biological rhythms in ants is more than an academic exercise.

Ants contribute significantly to ecosystem functioning through soil aeration, nutrient recycling, seed dispersal, and regulation of insect populations. Their success depends heavily on efficient task allocation. By understanding how biological clocks influence worker behavior, scientists gain valuable insights into the mechanisms underlying collective decision-making, social organization, and behavioral plasticity. The principles discovered in ant colonies may even inspire solutions in fields such as robotics, artificial intelligence, and decentralized management systems.

Conclusion

Ant colonies function without leaders, yet they achieve levels of coordination that rival many human organizations. This remarkable efficiency emerges from the interaction between biological clocks, environmental cues, social interactions, and gene-expression rhythms. Rather than acting as rigid timers, ant circadian clocks exhibit extraordinary plasticity. They can be modified by brood requirements, environmental conditions, and changing colony demands. This flexibility enables colonies to continuously adapt their workforce to current needs while maintaining overall social organization. The next time an ant trail crosses your path, it is worth remembering that beneath that seemingly simple line of insects lies a sophisticated society governed not by commands, but by millions of synchronized biological clocks.

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Nature's Hidden Nitrogen Factories: How Insect-Microbe Partnerships Sustain Life

Article ID: 74071

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Abstract

Nitrogen is an essential element for the growth and survival of all living organisms, yet atmospheric nitrogen is inaccessible to most animals. While biological nitrogen fixation is widely recognized in legume-Rhizobium associations, a lesser known but equally fascinating phenomenon occurs within insects. Many herbivorous insects survive on nitrogen deficient diets by forming intimate partnerships with nitrogen-fixing microorganisms. These microbial symbionts convert atmospheric nitrogen into biologically useful compounds, enabling insects to thrive on nutritionally poor food sources such as wood, plant sap and leaves. Recent studies have demonstrated the occurrence of nitrogen fixing bacteria in termites, beetles, fruit flies, stinkbugs and leaf-cutter ants, revealing their roles in insect nutrition, fitness and ecosystem functioning. This article explores how these invisible microbial partners sustain insect life and why understanding these associations could contribute to sustainable agriculture and environmental conservation.

Introduction

Nitrogen forms nearly 78% of the Earth's atmosphere, yet this enormous reservoir remains unavailable to most living organisms. Before nitrogen can be incorporated into proteins, enzymes and DNA, atmospheric nitrogen must first be converted into ammonia through a process known as **biological nitrogen fixation (BNF)**. Most people associate this process with legumes and their root-nodule bacteria. Surprisingly, nature has evolved another remarkable strategy—one that operates inside the bodies of insects. Hidden within insect digestive systems are specialized microorganisms capable of converting atmospheric nitrogen into usable nutrients, helping their hosts survive on diets that would otherwise be nutritionally inadequate. These microscopic partnerships represent one of the most fascinating examples of cooperation between insects and microbes.

Why Do Insects Need Nitrogen-Fixing Partners?

Many insects consume foods that are rich in carbohydrates but extremely poor in nitrogen. Wood-feeding termites, bark beetles, sap feeding bugs and leaf-feeding insects face a common nutritional challenge because their diets contain very little usable nitrogen.

For example, woody tissues contain only **0.03-0.1% nitrogen**, and much of it is locked within complex structural compounds that insects cannot easily digest. Plant sap is rich in sugars but contains very low concentrations of free amino acids. Without an additional nitrogen source, insects would struggle to synthesize proteins required for growth, reproduction and survival.

Evolution has solved this problem by recruiting microscopic partners known as **diazotrophs**—bacteria capable of fixing atmospheric nitrogen.

Invisible Partners Living Within Insects

Nitrogen-fixing bacteria occupy specialized niches within insect bodies. Some live freely in the gut lumen, while others colonize crypts, caeca or enlarged hindgut chambers specially adapted to support microbial communities. Researchers have identified several bacterial groups associated with insects, including *Burkholderia*, *Enterobacter*, *Klebsiella*, *Pantoea*, *Azospirillum* and *Rhizobium* (Kneip *et al.*, 2007). These bacteria possess the **nitrogenase enzyme complex**, which enables them to convert atmospheric nitrogen into ammonia that can subsequently be incorporated into amino acids and other essential biomolecules.

Following Nature's Nitrogen Factories

One of the earliest and most convincing examples of insect associated nitrogen fixation comes from termites. These insects feed almost exclusively on wood, a diet extremely poor in available nitrogen. Yet, termites flourish because their hindguts harbour dense microbial communities capable of fixing atmospheric nitrogen. Experiments measuring nitrogenase activity showed that termites feeding on nitrogen poor diets exhibited higher rates of biological nitrogen fixation, demonstrating that microbial activity responds directly to the nutritional needs of the colony.

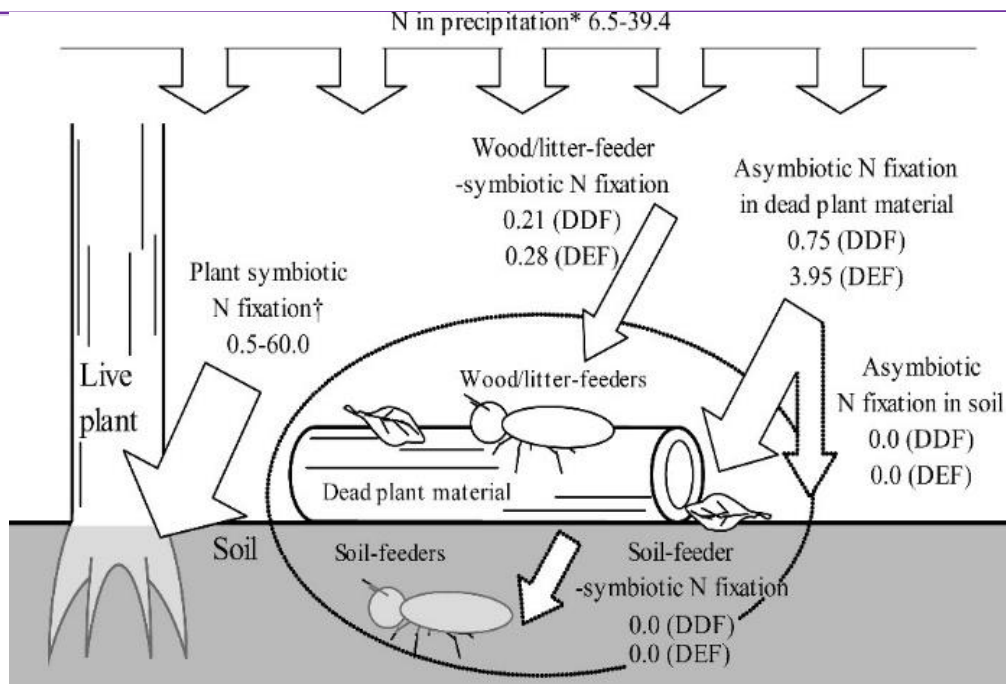


Fig. 1. Schematic of N inputs kg N ha⁻¹ y⁻¹ to dry deciduous forest and the neighbouring dry evergreen forest in Thailand.

Similar discoveries have emerged from wood-boring beetles. The Asian long-horned beetle (*Anoplophora glabripennis*), a destructive forest pest, contains nitrogen-fixing bacteria throughout its larval development (Ayayee *et al.*, 2014). Stable isotope studies confirmed that larvae incorporated atmospheric nitrogen into their tissues, providing direct evidence that microbial nitrogen fixation contributes to insect nutrition.

Fruit flies also harbour diverse bacterial communities with potential nitrogen fixing capabilities. In the Mediterranean fruit fly (*Ceratitis capitata*), bacteria such as *Klebsiella*, *Enterobacter* and *Pantoea* dominate the gut microbiome and contribute to nutrient metabolism (Behar *et al.*, 2008). These microbial partners have attracted considerable attention because manipulating gut bacteria may improve the performance of sterile insects used in pest management programmes.

Among sap-feeding insects, stinkbugs maintain intimate associations with *Burkholderia* bacteria residing in specialized midgut crypts (Kikuchi *et al.*, 2007). Unlike many inherited symbionts, these bacteria are acquired from the surrounding soil during each generation. Nevertheless, they significantly improve insect growth, body size and overall fitness, illustrating the remarkable flexibility of insect-microbe partnerships.

Leaf cutter ants present another extraordinary example. Their famous fungus gardens not only decompose plant material but also harbour nitrogen fixing bacteria that enrich the colony's nitrogen supply. Studies have estimated that a single mature colony may contribute substantial amounts of biologically fixed nitrogen annually, highlighting the ecological importance of these social insects.

More Than Just Nutrition

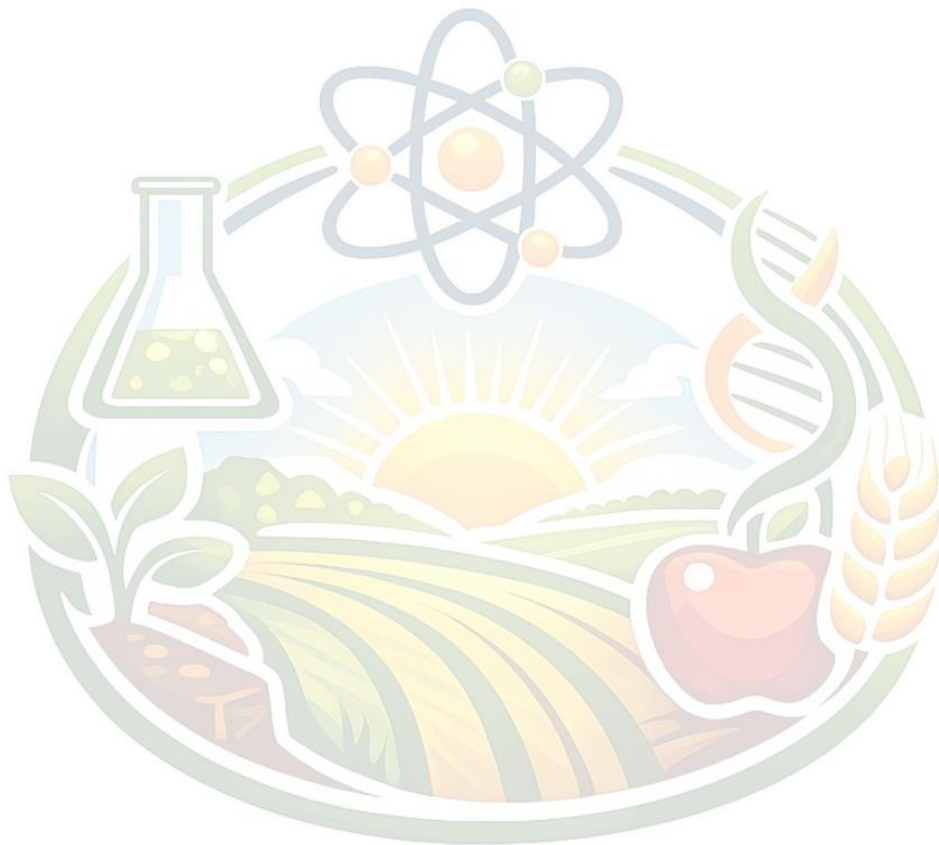
The benefits of nitrogen-fixing microorganisms extend far beyond providing additional nutrients. Studies have shown that insects carrying beneficial symbionts often exhibit faster development, greater body weight, improved reproductive performance and enhanced survival. In broad-headed bugs, individuals harbouring *Burkholderia* were significantly larger than insects lacking the symbiont (Kikuchi *et al.*, 2007). Similarly, supplementation of gut bacteria in the Mediterranean fruit fly reduced mating latency, improving reproductive performance in sterile males used for pest control. These findings demonstrate that microbial symbionts influence not only nutrition but also behaviour, physiology and overall fitness.

Conclusion

For decades, biological nitrogen fixation has been regarded primarily as a feature of legumes and soil microorganisms. Research over the past two decades has revealed another remarkable chapter of this story hidden within insects. From termites and beetles to fruit flies, stinkbugs and leaf cutter ants, diverse insects rely on microbial partners to overcome nitrogen limitation and thrive on nutritionally poor diets. These invisible partnerships illustrate the extraordinary ingenuity of nature and highlight the importance of conserving microbial diversity alongside insect biodiversity. As agriculture seeks more sustainable solutions for food production, understanding these microscopic fertilizer factories may inspire innovative approaches that benefit both ecosystems and society.

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Age-Grading in Adult Insects: How Scientists Determine the Age of Insects

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Abstract

Determining the age of an insect may appear impossible, yet it is one of the most valuable tools in modern entomology. The age structure of insect populations influences disease transmission, pest outbreaks, reproductive potential, migration, and the success of pest management programmes. To overcome the challenge of estimating insect age, scientists have developed a range of age-grading techniques based on changes in morphology, physiology, biochemistry, and molecular biology. From examining ovarian structures and wing wear to analysing fluorescent pigments, cuticular hydrocarbons, proteins, and gene expression, these techniques provide remarkable insights into an insect's life history. This article explores how researchers unravel the biological clocks hidden within insects and highlights the growing importance of age-grading in agriculture, public health, and forensic science.

Introduction: Why Does an Insect's Age Matter?

A mosquito that emerged yesterday poses little threat to human health. However, a mosquito that has survived for two weeks may already have acquired and transmitted disease-causing pathogens. Likewise, an older female insect often produces far more eggs than a newly emerged adult, making age an important factor in predicting pest outbreaks. Knowing the age of insects helps scientists answer questions that are critical to agriculture and public health. Are pest populations increasing? Are insecticide control programmes working? Which insects are responsible for spreading diseases? How long do beneficial insects survive in the field?

These questions have led to the development of **age-grading**, a scientific approach used to estimate the age of insects by examining age-related changes in their bodies.

Every Insect Carries a Biological Clock

Insects accumulate biological changes as they grow older. Scientists generally recognize two types of age. **Chronological age** refers to the actual time elapsed since an insect emerged as an adult. In contrast, **physiological age** reflects the developmental and reproductive status of the insect, which may vary depending on nutrition, environmental conditions, and mating history. The challenge for entomologists is to translate these biological clues into reliable estimates of age.

Reading the Hidden Records Inside an Insect

One of the oldest and most reliable methods involves examining the reproductive organs of female insects (Tyndale-Biscoe, 1984). Each time a female lays eggs, tiny structures known as **follicular relics** remain within the ovaries. Over successive egg laying cycles, these relics accumulate, allowing researchers to distinguish females that have never laid eggs from those that have reproduced multiple times. Similarly, the fine tracheoles supplying oxygen to the ovaries undergo characteristic changes after oviposition. In young females, these tracheoles appear tightly coiled, whereas in older egg-laying females they become permanently stretched. Male insects also reveal signs of ageing. Changes in the seminal vesicles, testes, and seminal ducts provide valuable clues about maturity and reproductive history. Together, these reproductive markers have become indispensable tools for studying insect population dynamics.

Age Leaves Its Mark on the Entire Body

Ageing affects much more than reproduction. As insects grow older, their bodies accumulate biochemical compounds called **pteridines**, pigments that gradually increase in the compound eyes of many flies and mosquitoes (Zhu *et al.*, 2013). By measuring pteridine fluorescence with specialised instruments, scientists can estimate the chronological age of several medically important insects. Other changes occur externally i.e., wings gradually become frayed through repeated flight, feeding, and encounters with vegetation or predators. Mandibles wear down as insects continue feeding, while the hardness and colour of the cuticle change steadily after adult emergence. Although none of these characteristics alone provides a perfect estimate of age, together they offer valuable evidence that complements reproductive observations.

The Molecular Revolution in Age-Grading

Modern technology has transformed age-grading from simple visual observations into a highly sophisticated scientific discipline. One of the most promising developments involves analysing **cuticular hydrocarbons**, the waxy compounds

covering the insect's body. As insects age, the composition of these hydrocarbons changes in predictable ways, providing chemical fingerprints that can be linked to chronological age.

Researchers now examine age-dependent changes in gene expression using **reverse transcription quantitative PCR (RT-qPCR)** and identify proteins whose abundance changes throughout an insect's lifespan. Such molecular biomarkers have shown considerable promise for accurately estimating age in mosquitoes and other insects. Perhaps the most exciting breakthrough is **Near-Infrared Spectroscopy (NIRS)**. This rapid, non-destructive technique measures the absorption of near-infrared light by insect tissues and uses computer algorithms to predict age based on subtle biochemical differences. Studies have reported overall prediction accuracies approaching 80% for important mosquito vectors, making NIRS one of the most promising tools for future surveillance programmes.

Lessons from the Field

Researchers studying the tsetse fly (*Glossina morsitans*), the vector of African trypanosomiasis, successfully estimated age by examining ovarian development and the sequence of ovulations (Saunders, 1960). These observations helped evaluate the effectiveness of aerial insecticide spraying programmes by determining whether surviving flies represented newly emerged adults or insects that had escaped treatment. In malaria vectors (*Anopheles* spp.), Near-Infrared Spectroscopy accurately classified mosquitoes into younger and older age groups, even after exposure to insecticides (Sikulu *et al.*, 2014). Such information is essential because only older mosquitoes generally survive long enough to transmit malaria parasites.

Age-grading has also been successfully applied to rice weevils, flesh flies, blowflies, and several agricultural pests, demonstrating its value far beyond medical entomology.

Looking Towards the Future

Rapid advances in spectroscopy, genomics, proteomics, artificial intelligence, and machine learning are reshaping insect age determination. Future age grading systems may combine molecular biomarkers, hyperspectral imaging, and AI based prediction models to provide rapid, highly accurate, field deployable tools for agriculture and disease surveillance. Such technologies could revolutionize insect monitoring by allowing researchers to estimate age within seconds without damaging valuable specimens.

Conclusion

Although insects are among the smallest animals on Earth, they leave behind an extraordinary record of their lives. Every oviposition, every flight, every biochemical change, and every molecular signature contributes to an invisible biological clock that scientists are learning to read with increasing precision. From protecting crops and controlling disease vectors to supporting forensic investigations, age-grading has evolved from simple ovarian dissections to sophisticated molecular technologies. As these techniques continue to improve, they will play an increasingly important role in sustainable agriculture, public health, and insect ecology.

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Bougainvillea Flower Tea: A Novel Functional Beverage with Nutritional and Health-Promoting Properties

Article ID: 74073

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Introduction

Growing consumer interest in preventive healthcare has significantly increased the demand for functional foods and beverages. Herbal teas prepared from medicinal plants and edible flowers have become popular because they provide bioactive compounds that contribute to health maintenance while serving as refreshing beverages.



Bougainvillea (*Bougainvillea spectabilis* and *Bougainvillea glabra*) is a flowering ornamental plant widely distributed in tropical and subtropical regions. Traditionally, different parts of the plant have been utilised in folk medicine for treating respiratory disorders, digestive problems, and inflammatory conditions. Recent scientific investigations have demonstrated that Bougainvillea flowers contain numerous phytochemicals with antioxidant and therapeutic potential, making them suitable for incorporation into functional beverages. Bougainvillea flower tea is typically prepared by drying the colourful floral bracts and steeping them in hot water, producing a naturally coloured, caffeine-free herbal infusion with potential health benefits.

Nutritional Characteristics

Although Bougainvillea flowers contribute very few calories, they contain several valuable nutrients and biologically active compounds that enhance their functional properties.

The flowers are reported to contain: Phenolic compounds, Flavonoids, Natural pigments such as betalains, Vitamin C (depending on species and maturity), Dietary fibre in dried flower material, Minerals, including calcium, magnesium, potassium, and iron, in small quantities. The presence of these compounds enhances the nutritional value of Bougainvillea flower tea while providing natural colour and antioxidant protection without artificial additives.

Phytochemical Composition

The biological activities of Bougainvillea flower tea are largely associated with its diverse phytochemical profile.

Major phytochemicals identified in Bougainvillea flowers include: total phenolics, flavonoids, betacyanins, betaxanthins, tannins, terpenoids, saponins, and alkaloids (reported in certain varieties). These secondary metabolites play an important role in protecting cells against oxidative damage and may help prevent various chronic diseases.

Health Benefits of Bougainvillea Flower Tea

1. Antioxidant Properties: Bougainvillea flowers contain substantial amounts of antioxidant compounds capable of scavenging free radicals generated during normal metabolism. Regular intake of antioxidant-rich beverages may help minimise oxidative stress associated with cardiovascular diseases, diabetes, ageing, and certain cancers.

2. Anti-inflammatory Effects: Scientific studies have shown that Bougainvillea extracts possess anti-inflammatory activity by reducing inflammatory mediators. Consequently, the tea may contribute to lowering inflammation-related health problems when consumed as part of a balanced diet.

3. Antimicrobial Activity: Several laboratory investigations have demonstrated that Bougainvillea extracts inhibit the growth of various bacterial and fungal pathogens. These antimicrobial properties suggest possible applications in promoting general health and enhancing food preservation.

4. Blood Glucose Regulation: Preliminary experimental studies indicate that Bougainvillea extracts may improve glucose metabolism and exhibit hypoglycaemic effects. However, additional clinical research is required before confirming their role in diabetes management.

5. Respiratory Support: In traditional medicine, Bougainvillea flowers have long been used for relieving cough, sore throat, and mild respiratory ailments. Drinking warm Bougainvillea flower tea is considered beneficial during seasonal respiratory discomfort.

Preparation and Processing of Bougainvillea Flower Tea

The quality of the final herbal tea depends greatly on careful handling and appropriate processing techniques. The recommended processing steps include:

Step 1: Selection of fresh edible Bougainvillea flowers.

Step 2: Wash thoroughly to remove dust and contaminants.

Step 3: Shade drying or hot-air drying (45-50°C) until the moisture content is below 10%.

Step 4: Grinding or packing whole dried petals.

Step 5: Packaging in moisture-proof containers or tea bags.

Proper drying preserves colour, aroma, and antioxidant compounds while extending shelf life. To prepare the beverage, approximately 2-3 g of dried flowers is infused in 150-200 mL of hot water (90-95°C) for 5-7 minutes before filtration. Proper drying helps preserve colour, aroma, flavour, and antioxidant compounds while extending shelf life.



Consumer Interest and Commercial Potential

The worldwide herbal tea market continues to expand due to increasing demand for natural, caffeine-free beverages with functional health benefits. Consumers increasingly prefer products that are minimally processed, naturally coloured, and free from synthetic ingredients.

Bougainvillea flower tea fits well within these market trends by combining aesthetic appeal, pleasant sensory characteristics, and valuable phytochemicals. Since Bougainvillea plants are widely cultivated as ornamentals, their flowers represent an inexpensive and sustainable raw material for producing herbal teas, tea blends, functional beverages, and nutraceutical products. Commercial production may provide additional income opportunities for growers and small-scale food entrepreneurs.

Safety Considerations

Only flowers collected from pesticide-free plants intended for edible use should be utilised for tea preparation. Flowers harvested from roadside plantations or ornamental gardens treated with agrochemicals should be avoided. Although traditional medicinal practices indicate that Bougainvillea flowers are generally safe, comprehensive toxicological evaluations and well-designed human clinical trials remain limited. Therefore, Bougainvillea flower tea should currently be regarded as a functional beverage rather than a substitute for medical therapy.

Future Research Directions

Future scientific investigations should focus on: Standardising processing and drying techniques, evaluating nutritional composition among different Bougainvillea species, assessing the stability of bioactive compounds during storage,

conducting clinical trials to validate health claims, developing innovative products such as instant tea, herbal blends, and ready-to-drink beverages, and studying consumer preferences and market acceptance.

These research areas will facilitate commercialisation and strengthen scientific evidence supporting Bougainvillea flower tea.

Conclusion

Bougainvillea flower tea is gaining recognition as a promising functional beverage because of its rich phytochemical composition and potential health-promoting properties. Its abundance of phenolic compounds, flavonoids, and natural antioxidants contributes to antioxidant, antimicrobial, anti-inflammatory, and traditional respiratory-support activities. Besides offering nutritional advantages, the development of Bougainvillea flower tea promotes sustainable utilisation of ornamental flowers and encourages innovation in the functional beverage sector. Although existing research demonstrates encouraging results, further clinical investigations, safety assessments, and product standardisation are necessary before large-scale commercialisation. With increasing global demand for natural, plant-based beverages, Bougainvillea flower tea has considerable potential to become an important addition to the functional food and nutraceutical industries.

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Role of Organic Amendments in Improving the Yield of Amaranthus Under Sodic Soil

Article ID: 74074

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Introduction

Soil is one of the most important natural resources that supports agricultural production and ecological balance. In Tamil Nadu, diverse soil types exist due to variations in climate, topography, and parent material. However, soil degradation problems such as sodicity and acidity have become major constraints to sustainable agriculture. These problem soils reduce crop productivity by affecting soil structure, nutrient availability, and water infiltration.

Among the problem soils, sodic soils are more extensive and widely distributed across irrigated and semi-arid regions of Tamil Nadu, while acid soils are restricted mainly to hilly and high rainfall areas such as the Western Ghats. To restore productivity, soil amendments are commonly used to improve soil physical, chemical, and biological properties.

Leafy vegetables such as Amaranthus (Amaranthus spp.) are sensitive to sodicity, especially at early growth stages. However, with proper soil amendments, sodic soils can be effectively reclaimed for successful cultivation. A pot culture experiment was conducted to evaluate the effect of different organic and inorganic amendments on the growth and yield of Amaranthus (Amaranthus tricolor L.) variety CO 6 under sodic soil conditions. The experiment was laid out in a Randomized Block Design (RBD) with seven treatments and three replications. The treatments consisted of combinations of gypsum, eggshell powder, and farmyard manure (FYM) as follows:

Treatment	Details
T ₁	Control (No amendment)
T ₂	100% Gypsum + FYM
T ₃	100% Egg Shell + FYM
T ₄	50% Gypsum + 50% Egg Shell + FYM
T ₅	75% Gypsum + 25% Egg Shell + FYM
T ₆	25% Gypsum + 75% Egg Shell + FYM

Treatment Details

T ₇	100% Gypsum + 100% Egg Shell + FYM

The required quantities of gypsum and eggshell powder were applied based on the treatment schedule and thoroughly mixed with the sodic soil before sowing. FYM was incorporated uniformly in all amendment treatments. Seeds of Amaranthus CO 6 were sown in the pots and maintained under recommended agronomic practices throughout the crop growth period.

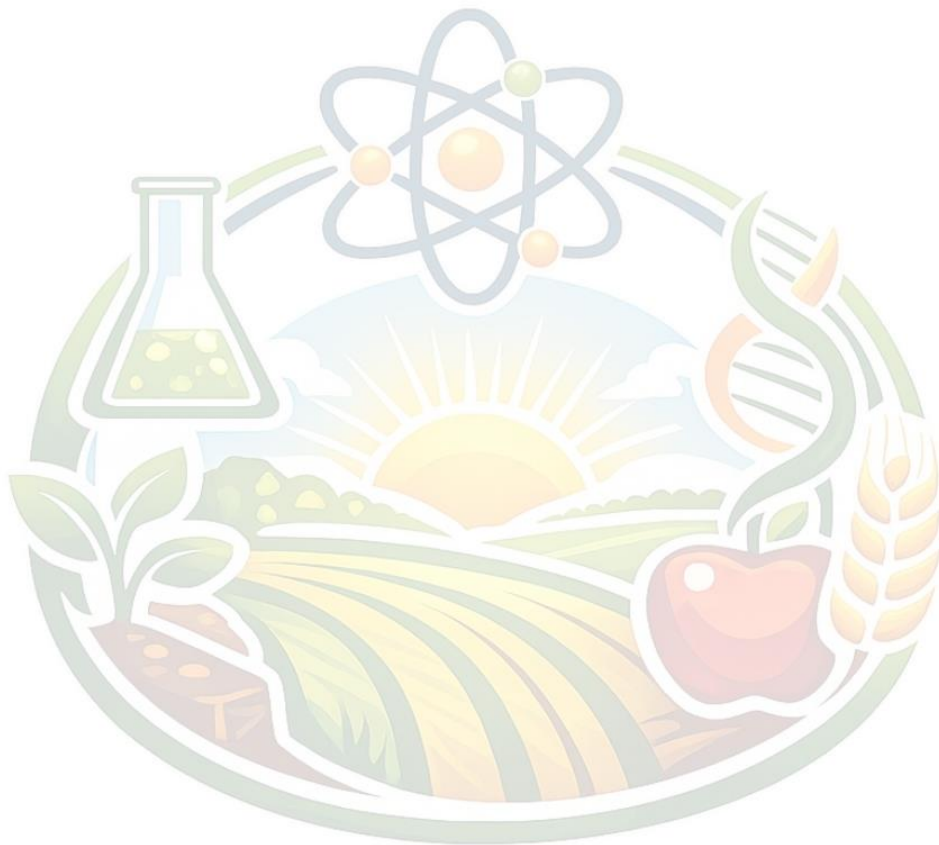
The application of different amendments significantly influenced the growth and yield of Amaranthus under sodic soil conditions. Among the treatments, T₇ (100% Gypsum + 100% Egg Shell + FYM) recorded the highest growth and yield parameters, indicating its superior effectiveness in ameliorating sodic soil conditions. The treatment produced the maximum plant height, number of leaves, leaf area, and fresh biomass yield. This was followed by T₂ (100% Gypsum + FYM), which also showed substantial improvement over the control and other treatments. The control treatment (T₁) recorded the lowest growth and yield due to the adverse effects of sodicity.

The superior performance of T₇ (100% Gypsum + 100% Egg Shell + FYM) may be attributed to the combined beneficial effects of gypsum, eggshell powder, and FYM. Gypsum is a well-known amendment for sodic soils, supplying soluble calcium that replaces exchangeable sodium on soil colloids, thereby improving soil structure, permeability, and root growth. Eggshell powder acted as an additional calcium source, contributing to the amelioration process and enhancing nutrient availability.

The incorporation of FYM further improved soil physical, chemical, and biological properties by increasing organic matter content, microbial activity, nutrient retention, and moisture-holding capacity. The combined application of these amendments likely created a synergistic effect that enhanced nutrient uptake and plant growth, resulting in maximum yield.

The second-best performance of T₂ (100% Gypsum + FYM) highlights the major role of gypsum in reclaiming sodic soils. However, the additional improvement observed in T₇ suggests that eggshell powder can serve as a beneficial supplementary amendment when combined with gypsum and FYM.

The study revealed that T₇ (100% Gypsum + 100% Egg Shell + FYM) was the most effective treatment for improving the growth and yield of Amaranthus under sodic soil conditions, followed by T₂ (100% Gypsum + FYM). The combined application of gypsum, eggshell powder, and FYM significantly enhanced soil conditions and crop performance. Therefore, T₇ can be recommended as an effective amendment strategy for increasing Amaranthus productivity in sodic soils.



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High Pressure Processing of Food

Article ID: 74075

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Introduction

The trend of food consumption has recently changed from traditional thermal-processed goods to minimally processed foods that are healthy, natural, microbiologically safe, shelf-stable, and have a natural texture due to growing consumer awareness. High pressure processing (HPP), which has been gaining traction in the food processing industry over the past few decades, is one such tested technique that satisfies all of these customer criteria. In the food sector, this method is also referred to as Pascalization, ultra-high pressure (UHP), high hydrostatic processing (HHP), and hyperbaric pressure processing. High Pressure Processing (HPP), often known as cold pasteurization, is a nonthermal food processing technique that is recognized for its ability to prolong shelf life by inactivating germs. The procedure uses the concepts of thermodynamics to efficiently lower microbial load while operating at pressures between 100 and 600 MPa. Food products, sealed in flexible pouches, are subjected to uniform pressure through water in a cylindrical pressure vessel made of high-tensile strength steel as part of the HPP system, guaranteeing consistent treatment regardless of the product's size or shape. In contrast to conventional heat-based pasteurization, HPP maintains nutritional and sensory qualities, impacting primarily baro-sensitive higher-molecular weight components while leaving lower-molecular weight substances unaltered, improving organoleptic qualities and health advantages. HPP cannot completely replace traditional processing methods, even though it improves process efficiency when paired with techniques like γ -irradiation and ultrasound. Notably, the initial expenses are a barrier; nevertheless, lower energy consumption may result in cheaper operating costs, which could lead to wider adoption (Verma *et al.*, 2020). High Pressure Processing has drawn a lot of interest from researchers and the food industry because it can enhance food safety while maintaining the product's inherent quality. Fruits, vegetables, dairy products, meat products, seafood, and drinks are just a few of the many food items that employ it these days. The use of HPP is anticipated to develop in the future due to the rising demand for wholesome, minimally processed, and fresh meals.

Principles of High-Pressure Processing (HPP)

High Pressure Processing Fundamentals Increasing the free energy during pressure treatment in a closed system by mechanical volume reduction can produce hydrostatic pressure. Depending on the makeup of the food product being processed, HPP is typically accompanied with a slight temperature increase known as adiabatic heating. Le-Chatelier's concept, the isostatic principle, and the principle of microscopic ordering are the three basic operational principles that underpin HPP. The first principle states that under pressure, biomolecules follow the Le-Chatelier principle, which states that whenever a stress is applied to a system in equilibrium, the system will react to counteract the applied stress. High pressure will encourage reactions that result in reduced volume, which may inactivate microorganisms or enzymes. The second concept, known as the isostatic principle, states that when food products are crushed by constant pressure in all directions, they revert to their original shape when the pressure is released. Because pressure transmission to the core is independent of mass and time, the products are compressed regardless of their size and shape. For this reason, HPP is also known as the isostatic processing approach. According to the concept of microscopic ordering, an increase in pressure causes the molecules of a given substance to become more ordered at constant temperature. As a result, temperature and pressure have opposing effects on chemical reactions and molecular structure (Naik *et al.*, 2013).

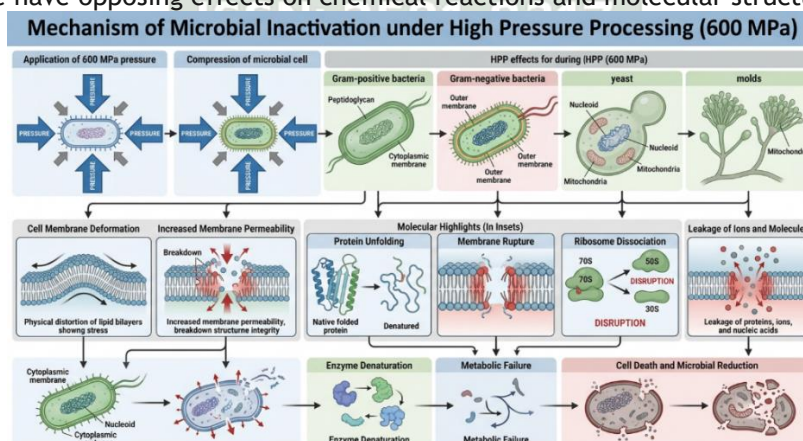


Fig 1. Mechanism of Microbial Inactivation under HPP

HPP's Components and Working

As seen in Figure 1, a pressure vessel, pressurizing system, and auxiliary units like heating or cooling components are the fundamental parts of an HP system. The vessel is filled with a pressure-transmitting material once it has been loaded and sealed. A low-pressure quick fill-and-drain pump uses an automatic deaeration valve to remove air from the vessel. High hydrostatic pressure is then produced by either direct or indirect compression or by heating the pressure medium. HPP processing often takes place in a liquid with limited compressibility, such as water.

The aforementioned principles state that phase transition and chemical changes are accompanied by a decrease in volume, which is favored by pressure and vice versa. Regardless of the food's size or shape, pressure is transferred instantly and consistently. The majority of metabolic events that take place in food are regulated by the resulting pressure. Denaturation of proteins, gelation, hydrophobic reactions, phase changes in lipids (consequently, in cell membranes), and increases in the ionization of dissociable molecules due to "electrostriction" are among the most significant volume-decrease reactions in biological systems that are affected by HPP. When compared to heat preservation, the high pressure procedure is defined by three parameters: temperature (T), pressure (p), and exposure duration (t). Procedure that relies solely on two parameters (T, t). The three-parametric HPP provides a wide range of options for improving shelf life and process design. Process effectiveness is evaluated using a qualitative method based on the treatment's lethality and structural effects on the food matrix. Evidently, treatments that are effective in eliminating microorganisms typically have a detrimental impact on the food matrix's integrity, which has serious repercussions for both quality and customer acceptance. Foods are preserved and altered with HPP. As a result, foods are frequently exposed to hydrostatic pressures more than 350 MPa for brief intervals ranging from a few seconds to several minutes. While important low molecular components like vitamins, colors, and flavoring compounds are mostly unaffected, this treatment allows the inactivation of microbes and enzymes at low temperatures with the goal of maintaining the processed food's freshness (Naik *et al.*, 2013).

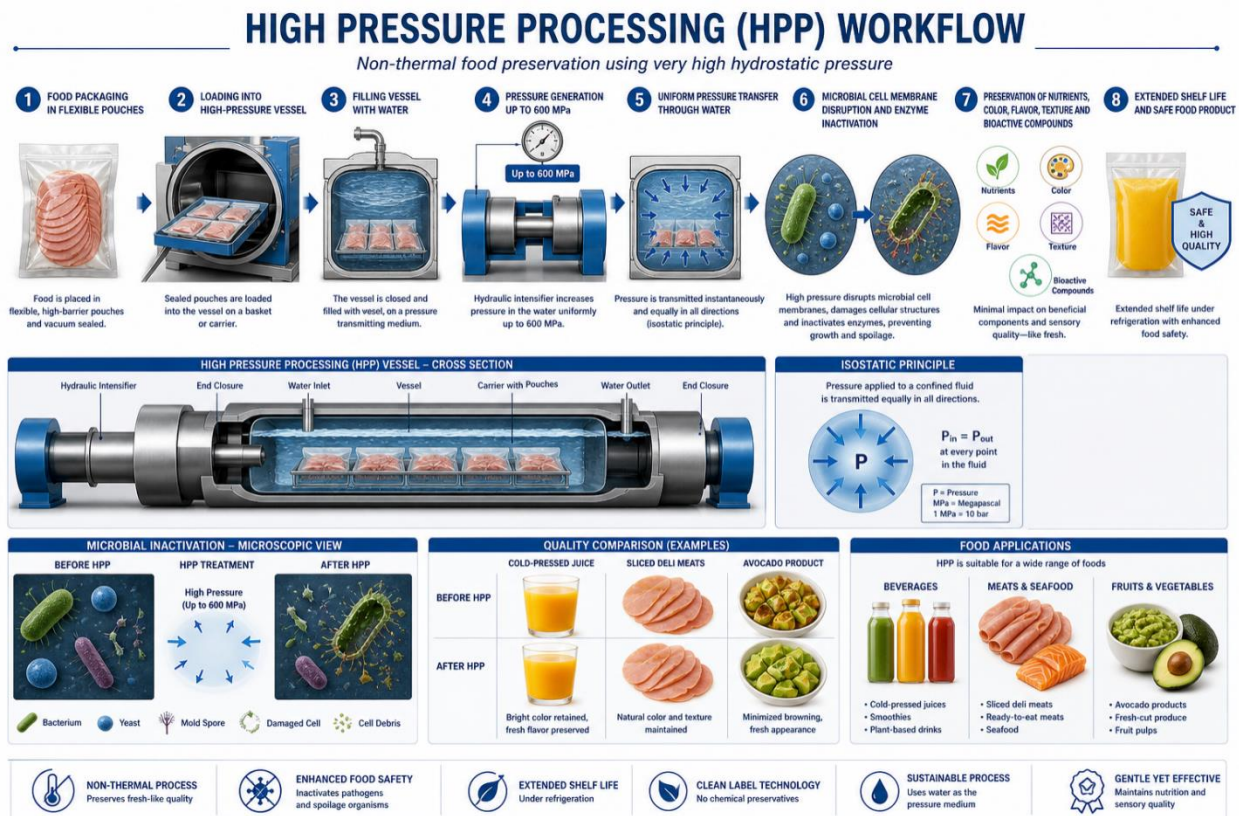


Figure 2. Fundamental components of a High-Pressure Processing (HPP) system

Applications for High-Pressure Processing (HPP) in Food Processing

In today's food industry, high-pressure processing, also called cold pasteurization or high hydrostatic pressure processing, is a new way to preserve food without using heat. Water acts as the pressurizing fluid, applying pressures between 100 and 600 MPa to food packages. The main goal of HPP is to eliminate pathogens and enzymes that cause spoilage while keeping the food fresh (EFSA BIOHAZ Panel *et al.*, 2022).

Consumer demands for minimally processed food with no additives and free from health risks have spurred the increased application of HPP (Khouryieh, 2025). Fruit and vegetable products happen to be among the most widely consumed products that are subjected to HPP. HPP extends the shelf-life of fresh fruit juices, smoothies, purees, guacamole, salsa,

and dips of vegetables without any effects on colour, smell, or the vitamins in the food. The taste is also maintained because the process uses pressure and not heat (Waghmare, 2024; Saputra et al., 2025).

Another group that makes extensive use of HPP is that of meat and poultry products. HPP technology is applied in order to kill microorganisms such as the *Listeria monocytogenes* in order to ensure microbiological safety in terms of ready-to-eat meats, sliced meat products, sausages, and marinated meats. While sensory attributes are retained, the shelf-life of the product in its refrigerated state is enhanced due to the application of the technology (Shams et al., 2024; EFSA BIOHAZ Panel et al., 2022). Shellfish such as oysters, lobster, crab, prawn, and fish products also undergo processing using HPP technology (Shams et al., 2024).

Another field where the application of high pressure processing is extremely valuable is dairy products. As opposed to those which were traditionally processed, dairy products like milk, yogurt, cheese, and dairy drinks processed by high-pressure processing method are safer from microbial standpoint, have extended shelf life, and retain the integrity of their nutritional and taste qualities (Saputra et al., 2025; Khouryieh, 2025).

In recent years, the technique of high pressure processing has become widely applied to plant beverages, pet food, baby food, and ready-to-eat products. This method allows retaining the quality of the products without posing any threats or concerns for consumer safety and convenience. Besides, in some dietary systems, high pressure processing changes the texture and functional properties of proteins and carbohydrates (Khouryieh, 2025; Saputra et al., 2025).

Advantages of HPP

There are many advantages of using HPP over the conventional thermal processing techniques. When it comes to maintaining the color, flavor, texture, and nutrients in food products, the benefit of using HPP is very evident as this is not a thermal process. In addition to that, it assists in maintaining the nutrients while ensuring the removal of any bacteria and preventing spoiling. Another advantage is that it ensures the manufacturing of healthy food products by ensuring an extended shelf life without any preservatives. One more thing worth mentioning is that it applies pressure evenly to the entire food product regardless of its shape and size. Another big advantage of HPP is that it is environment-friendly as it produces minimal waste and utilizes water for generating pressure (EFSA BIOHAZ Panel et al., 2022; Khouryieh, 2025; Saputra et al., 2025; Waghmare, 2024; Shams et al., 2024).

Limitations of HPP

1. High equipment and operational cost (Khouryieh, 2025; EFSA BIOHAZ Panel et al., 2022).
2. Mostly suitable for high-moisture foods (Waghmare, 2024)
3. Limited effectiveness against bacterial spores at low temperatures (EFSA BIOHAZ Panel et al., 2022; Khouryieh, 2025)
4. Batch processing may reduce production efficiency (Shams et al., 2024)
5. Some foods may undergo texture or color changes under high pressure (Saputra et al., 2025)
6. Requires flexible packaging materials compatible with pressure treatment (Shams et al., 2024)

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L. monocytogenes: A Silent Killer in Dairy and Food Ecology

Article ID: 74076

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Introduction

India is the world's top rank producer of milk, making a substantial contribution to the world's dairy output. The fast expansion of the dairy sector has increased the demand for stringent quality assurance systems to ensure the safety and shelf life of milk and milk products. Extended-shelf-life dairy goods, such as canned milk and ultra-high-temperature (UHT) processed milk, are becoming more and more popular in tropical nations like India because these technologies enhance maintaining quality, make long-distance distribution easier, and boost export prospects. However, this shifting tendency highlights the necessity of controlling heat-resistant microbial contamination, particularly spore-forming bacteria, which can survive processing and so impair product quality and safety. Spore-forming bacteria continue to be one of the most difficult groups to control among the several microbial pollutants found in dairy processing. Sulfite-reducing clostridia (SRC) have emerged as one of the most problematic families of spore-forming bacteria in modern dairy processing, owing to their capacity to survive unfavorable climatic conditions and thermal treatments typically used during milk preservation. The rising production of extended-shelf-life dairy products, such as UHT and canned milk, has drawn attention to SRC since their spores can survive processing and potentially germinate during storage, resulting in spoiling, quality problems, and economic losses. In addition, certain SRC species are associated with food safety concerns, making their presence an important indicator of hygienic conditions and process effectiveness. Consequently, the detection and control of SRC have become increasingly important for ensuring the microbiological stability, safety, and export quality of dairy products.

The Devastating Health Impact

When people eat food contaminated with *L. monocytogenes*, they get a fever, diarrhea, nausea, and vomiting, which is called listeriosis. In healthy adults, this illness is usually mild and resolves in a few days, but for vulnerable people, it can be a nightmare. Pregnant women face the greatest risk because the bacteria can cross through the placenta and infect the baby, causing miscarriage, abortion, stillbirth, premature delivery, and life-threatening infections in newborns. What makes this especially tragic is that pregnant women might only have mild flu-like symptoms that they barely notice, while their unborn baby suffers severely. For elderly people over 65 years old, *Listeria* attacks the brain. It causes meningitis, which is inflammation of the brain and spinal cord covering, encephalitis, which is brain infection, and sepsis, which is blood infection spreading throughout the body. The mortality rate is a shocking 20-30%, and even those who survive often suffer permanent brain damage or neurological problems. People with weak immune systems face similar dangers, including HIV/AIDS patients, cancer patients on chemotherapy, transplant recipients, and diabetics with poor control. For them, listeriosis often becomes invasive disease with brain and spinal cord involvement, and many die. Newborns and infants face life-threatening infections, brain damage, spinal cord damage, and high mortality rates.

Where Does This Bacterium Hide?

The story of *Listeria* contamination begins at the farm. Soil and dust are primary sources where the bacterium lives naturally. When your cow walks on contaminated soil, *Listeria* sticks to its legs and udder. The animal carries *Listeria* in its digestive system, and when it defecates, the bacteria spread through manure. Farmers store grass as silage for animal feed, and if this silage is not fermented properly with pH above 5.0, *Listeria* grows in it. The cow eats this contaminated silage, and the bacteria end up in the milk. Contaminated water that cows drink can also infect them, and dirty milking machines with cracked seals and crevices harbor *Listeria*, transferring it to milk during milking. If milk storage tanks are not cleaned properly, *Listeria* lives there too.

The contamination continues in dairy processing plants where *Listeria* finds ideal hiding places. Floor drains are the number one location because they have standing water, which *Listeria* loves, and they are notoriously hard to clean properly. Equipment drains have the same problem as floor drains. Cold storage condensers create condensation, and *Listeria* grows there. Floor-wall junctions have cracks and crevices where dirt accumulates. Pasteurizer seals and gaskets, if not cleaned properly, allow *Listeria* to hide there and contaminate pasteurized milk. Post-pasteurization equipment like filling machines, valves, and pipes are critical contamination points. Conveyor belts accumulate moisture where *Listeria* grows. Cheese slicers and cutters are hard to clean, so *Listeria* forms biofilms there. Filling machine nozzles have direct contact with milk or dairy products. Any moist area where water or milk accumulates becomes a breeding ground for *Listeria*.

The most terrifying aspect is that *Listeria* forms biofilms, which are protective layers that shield the bacteria from cleaning chemicals and sanitizers. Once biofilms form, they can persist for years, constantly contaminating products. This makes *Listeria* exceptionally difficult to eliminate from dairy processing plants.

How Contamination Happens

Raw milk becomes contaminated when the cow's udder touches contaminated soil, manure, or equipment. Studies show that 15.2% of raw milk contains *Listeria*. Udder contamination from soil, manure, and bedding on the cow's udder transfers *Listeria* to milk during milking. Dirty milking equipment that doesn't clean properly transfers *Listeria* to milk. The most critical problem is post-pasteurization contamination because even if pasteurization kills *Listeria*, it can contaminate milk after pasteurization through contaminated equipment, dirty employee hands, cross-contamination from raw areas, or contaminated air.

Cross-contamination happens when raw milk areas transfer *Listeria* to pasteurized milk areas through employees, equipment, or air. Employee transfer occurs when workers who go from dirty raw areas to clean processed areas spread *Listeria* on their clothes, shoes, and hands. Equipment contamination happens when biofilms on equipment surfaces continuously release *Listeria*. Airborne contamination occurs when dust and aerosols carry *Listeria* through the plant. Contaminated water used for cleaning spreads *Listeria* everywhere, and inadequate cleaning with missed spots in equipment allows *Listeria* to survive.

The Solution: How We Fight Back

Pasteurization is our first and most important weapon because when done correctly, it kills 99.99% of *Listeria*. LTLT pasteurization heats milk to 63°C for 30 minutes, HTST pasteurization heats milk to 72°C for 15 seconds which is most common, and UHT processing heats milk to 135-140°C for 2-4 seconds which kills 100%. But improper pasteurization and post-pasteurization contamination are the main reasons *Listeria* appears in pasteurized milk, so proper temperature-time control, automatic temperature recording, regular testing of pasteurized milk, and maintenance of pasteurization equipment are essential.

After pasteurization, milk must never touch anything contaminated. Physical separation is required where raw and processed areas must be completely separate buildings or rooms. Air curtains should be installed between raw and processed zones, and positive pressure should be kept higher in processed areas so cleaner air flows out, not in. Use separate equipment for raw and processed milk and never mix them. Workers in raw areas should not enter processed areas, so employee dedication is required. Air filtration should be installed in processing areas to remove contaminants, and truck drivers and milk receivers should never enter processing areas.

Cleaning must be thorough with written procedures that document every cleaning step, called SSOPs or Sanitation Standard Operating Procedures. Employee training must teach workers cleaning procedures, and training dates and times must be documented. Hand washing requires 20 seconds with soap and water, boot cleaning needs foot baths and boot cleaning stations at entry points, and dedicated tools must be used for raw and processed areas. CIP systems or Clean-in-Place systems must use proper temperature and concentration of cleaning chemicals. Manual cleaning requires disassembling valves, gaskets, and seals and cleaning them thoroughly. Hard-to-clean areas like drains, cracks, and crevices need special attention. Proper chemicals must be used with appropriate detergents and sanitizers, and post-cleaning inspection checks that cleaning was done properly and documents it.

Testing your plant regularly catches *Listeria* before it contaminates products. Zone-based sampling includes Zone 1 for product contact surfaces tested daily, Zone 2 for non-product contact near product tested daily, Zone 3 for floors, walls, drains tested weekly, and Zone 4 for plant exterior tested monthly. Test specific locations by marking specific spots on equipment for testing, use rapid methods like PCR, ELISA, and ATP bioluminescence which give quick results, and confirm with culture methods where ISO 11290-1 is the gold standard. Document everything by recording all results and corrective actions, and take action immediately by cleaning and sanitizing if you find *Listeria*.

Who is At Risk and How are they Treated?

When someone gets listeriosis, treatment depends on how sick they are. For healthy adults with mild cases, rest is required to let your body recover, hydration means drinking plenty of fluids, home care usually resolves in a few days, no antibiotics are needed because the immune system handles it, and you should monitor symptoms and see a doctor if they worsen. For high-risk groups with severe cases, antibiotics are essential. First-line treatment is ampicillin at 2 grams every 4-6 hours intravenously, alternative is gentamicin added to ampicillin, and for penicillin-allergic patients it's trimethoprim-sulfamethoxazole. Duration is 14-21 days for severe cases, pregnant women must start antibiotics immediately to prevent fetal infection, hospitalization is required for severe cases, supportive care includes IV (intravenous) fluids, oxygen, and monitoring, early treatment significantly improves outcomes, without treatment the mortality rate is 20-30%, and with treatment the mortality rate drops to 10-15%.

Pregnant women need antibiotics immediately even if symptoms are mild, monitoring of the fetus to check for infection, amniocentesis may be needed to test the baby, and induced delivery may be required if the baby is infected. Newborns

with infection need IV (intravenous) antibiotics immediately, supportive care in the neonatal intensive care unit, monitoring for meningitis and sepsis to watch for brain and blood infections, and long-term follow-up to check for neurological damage after recovery. Elderly and immunocompromised patients need hospitalization which is usually required, IV antibiotics for 2-3 weeks with extended treatment, monitoring for brain involvement to watch for meningitis and encephalitis, and long-term neurological monitoring to check for lasting damage.

What Consumers Can Do?

Consumers can protect themselves and their families by following simple but critical rules. Pregnant women and high-risk individuals should avoid unpasteurized milk and dairy products completely and only buy pasteurized. Soft cheeses like brie and camembert should be avoided unless cooked until steaming hot, all types of pate including vegetable pate must be avoided, cold-smoked or cured fish like smoked salmon should be avoided unless cooked thoroughly, and ready-to-eat cold meats and hot dogs must be avoided unless reheated until steaming hot. Refrigerate at 5°C or below by checking your fridge regularly, eat ready-to-eat foods within 4 hours by taking them out of the fridge promptly, follow use-by dates strictly without eating expired food, follow storage instructions by reading labels carefully, use opened food within 2 days unless the package says otherwise, keep raw and ready-to-eat foods separate to prevent cross-contamination, cook or reheat until steaming hot by heating food thoroughly, wash hands regularly using soap and water, wash fruits and vegetables by cleaning them thoroughly before eating, and clean kitchen surfaces and cutting boards by sanitizing regularly. General population should buy pasteurized milk only by checking labels, check labels for "made with pasteurized milk," refrigerate promptly by putting dairy products in the fridge immediately, keep fridge at 4°C or below using a thermometer, don't leave dairy at room temperature for maximum 2 hours, clean the refrigerator regularly especially spills, wash hands before handling food using soap and water, don't cross-contaminate by keeping raw and cooked foods separate, follow expiration dates without eating expired food, and when in doubt, throw it out because it's better than getting sick.

Conclusion

Listeria monocytogenes deserves special attention in dairy ecology because it is not only a persistent environmental contaminant but also a deadly public health hazard that can silently move from farm to dairy plant and finally to the consumer's table. Its ability to survive cold storage, tolerate stress, and persist in hidden niches of dairy equipment makes it especially challenging for the dairy industry, where even a small lapse in hygiene after pasteurization can lead to serious consequences. For vulnerable people such as pregnant women, newborns, elderly persons, and immunocompromised patients, infection may result in abortion, stillbirth, meningitis, brain infection, septicemia, and death, which makes prevention far more important than cure. The way forward lies in strict farm hygiene, safe silage preparation, effective pasteurization, separation of raw and processed areas, regular environmental surveillance, and strong food safety culture in dairy plants. At the same time, awareness among consumers and timely medical treatment with appropriate antibiotics can greatly reduce the burden of listeriosis and help protect both the dairy industry and public health.

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Sulphite-Reducing Clostridia in Dairy and Food Product

Article ID: 74077

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Introduction

India is the world's top rank producer of milk, making a substantial contribution to the world's dairy output. The fast expansion of the dairy sector has increased the demand for stringent quality assurance systems to ensure the safety and shelf life of milk and milk products. Extended-shelf-life dairy goods, such as canned milk and ultra-high-temperature (UHT) processed milk, are becoming more and more popular in tropical nations like India because these technologies enhance maintaining quality, make long-distance distribution easier, and boost export prospects.

However, this shifting tendency highlights the necessity of controlling heat-resistant microbial contamination, particularly spore-forming bacteria, which can survive processing and so impair product quality and safety. Spore-forming bacteria continue to be one of the most difficult groups to control among the several microbial pollutants found in dairy processing.

Sulfite-reducing clostridia (SRC) have emerged as one of the most problematic families of spore-forming bacteria in modern dairy processing, owing to their capacity to survive unfavorable climatic conditions and thermal treatments typically used during milk preservation. The rising production of extended-shelf-life dairy products, such as UHT and canned milk, has drawn attention to SRC since their spores can survive processing and potentially germinate during storage, resulting in spoiling, quality problems, and economic losses.

In addition, certain SRC species are associated with food safety concerns, making their presence an important indicator of hygienic conditions and process effectiveness. Consequently, the detection and control of SRC have become increasingly important for ensuring the microbiological stability, safety, and export quality of dairy products.

Understanding Sulphite-Reducing Clostridia

Sulfite-reducing Clostridia belong primarily to the genus *Clostridium*, a diverse group of Gram-positive, rod-shaped, spore-forming, obligately anaerobic bacteria. The most important species associated with dairy and food products include:

1. *Clostridium perfringens*
2. *Clostridium tyrobutyricum*
3. *Clostridium sporogenes*
4. *Clostridium butyricum*
5. *Clostridium botulinum*

These microorganisms have a unique survival mechanism that involves the creation of endospores. clostridial spores are extremely resistant to a variety of harsh conditions, including heat treatment, drying, desiccation, chemical sanitizers, and other environmental challenges. Because of their exceptional durability, they can withstand processing procedures like pasteurization and other food preservation techniques that successfully eradicate the majority of vegetative bacterial cells. As a result, clostridial spores can survive throughout the dairy production chain and, under ideal conditions, germinate and multiply, causing product deterioration, reduced shelf life, and potential food safety concerns.

Natural Occurrence and Sources of Contamination

SRC are widely distributed in nature and are frequently found in silage, soil, animal digestive tracts, and agricultural settings. Soil particles can readily infect fodder and silage during harvesting or feed preparation, and agricultural soils serve as a significant reservoir for clostridial spores. Manure is a major source of contamination since many clostridial species naturally live in the digestive tracts of cattle and other animals. Furthermore, one of the main ways that clostridial spores infiltrate dairy farms is through inadequately fermented silage, which has been directly connected to higher spore counts in raw milk. These spores are further dispersed throughout dairy production systems via contaminated water supplies, bedding materials, feed storage facilities, and farm dust.

Entry of SRC into the Dairy Chain

There are multiple points in the milk production chain where contamination might happen. Spores from the udder surface, teats, milking equipment, or the farm environment can readily get into the raw milk during milking. Spores can build up and spread during storage and transit if bulk milk tanks, milk cans, pipelines, and transport tankers are not properly cleaned. Pasteurization may kill vegetative cells during processing, but under the right circumstances, spores

may survive and eventually germinate during manufacturing or storage. If equipment surfaces or the processing area itself become contaminated after processing, the risk increases even further.

Significance in Dairy Products

Cheese deterioration is one of the most significant financial losses associated with SRC contamination. Particularly well-known for creating the late blowing defect in hard and semi-hard cheeses, *Clostridium tyrobutyricum* germinates during ripening and ferments lactate to produce butyric acid, carbon dioxide, and hydrogen gas. The cheese becomes unfit for sale when these gasses build up and cause internal fissures, undesired openings, swelling, off flavors, and rancid odors. Similar damage can also occur in milk powder, where spores can withstand spray drying and continue to be viable while being stored, and posing issues for export quality, microbiological compliance, and shelf life. In UHT goods, spore survival is similarly troublesome since, even if the product is heat treated, surviving spores may cause can swelling.

Food Safety Implications

While spoilage is a major concern, some sulfite-reducing clostridium (SRC) species also represent food safety risks.

Clostridium perfringens: *Clostridium perfringens* is a major global cause of foodborne disease. Abdominal pain, diarrhea, and digestive discomfort are the symptoms of food poisoning, which is usually caused by consuming a lot of vegetative cells. While meat products are more frequently linked to outbreaks, contaminated dairy products can also act as carriers. Controlling *C. perfringens* in dairy processing facilities is made more difficult by its ability to produce heat-resistant spores.

Clostridium botulinum: *Clostridium botulinum* can produce botulinum neurotoxin, one of the most deadly biological poisons known, it deserves special consideration even though it is rarely seen in dairy products. Its spores can germinate and create toxins that can cause severe and perhaps fatal botulism under the right anaerobic conditions. While the risk in dairy products is normally modest, the existence of heat-resistant clostridial spores emphasizes the significance of proper processing, hygiene, and quality control. As a result, controlling clostridial contamination continues to be a crucial goal for guaranteeing dairy product safety and shelf life.

Economic Impact on the Dairy Industry

The dairy business may suffer significant financial consequences from SRC contamination. Contaminated items could result in direct financial loss if they are rejected by processors or do not meet export quality standards. Spores that germinate during storage diminish the product's shelf life and cause it to lose its value far sooner than anticipated. Late blowing flaws can ruin whole batches of cheese and render them un-saleable. Furthermore, quality testing, product recalls, cleanliness, and modifications to processing procedures frequently result in additional expenses for dairy facilities. Because overseas buyers and regulatory systems are becoming more stringent regarding microbiological quality, maintaining low spore counts is particularly crucial for dairy companies that are export-oriented.

Control Strategies

Prevention is still the best course of action because clostridial spores are extremely resistant and challenging to eradicate once they get into the dairy chain. clostridial growth can be inhibited at the farm level by producing high-quality silage by appropriate fermentation, sufficient dry matter content, quick pH lowering, and airtight storage. Contamination can be further decreased by utilizing good hygiene procedures during milking, such as cleaning the udder, sanitizing the equipment, and keeping the housing clean. Spore proliferation can be stopped by quickly chilling milk and keeping storage and transportation equipment clean. Effective Cleaning-in-Place (CIP) systems, environmental monitoring, sanitary equipment design, and staff hygiene are crucial control measures in dairy operations. Additional defence against spore-related quality and safety problems is offered by cutting-edge technologies like microfiltration, bacto-fugation, high-pressure processing, and spore monitoring systems.

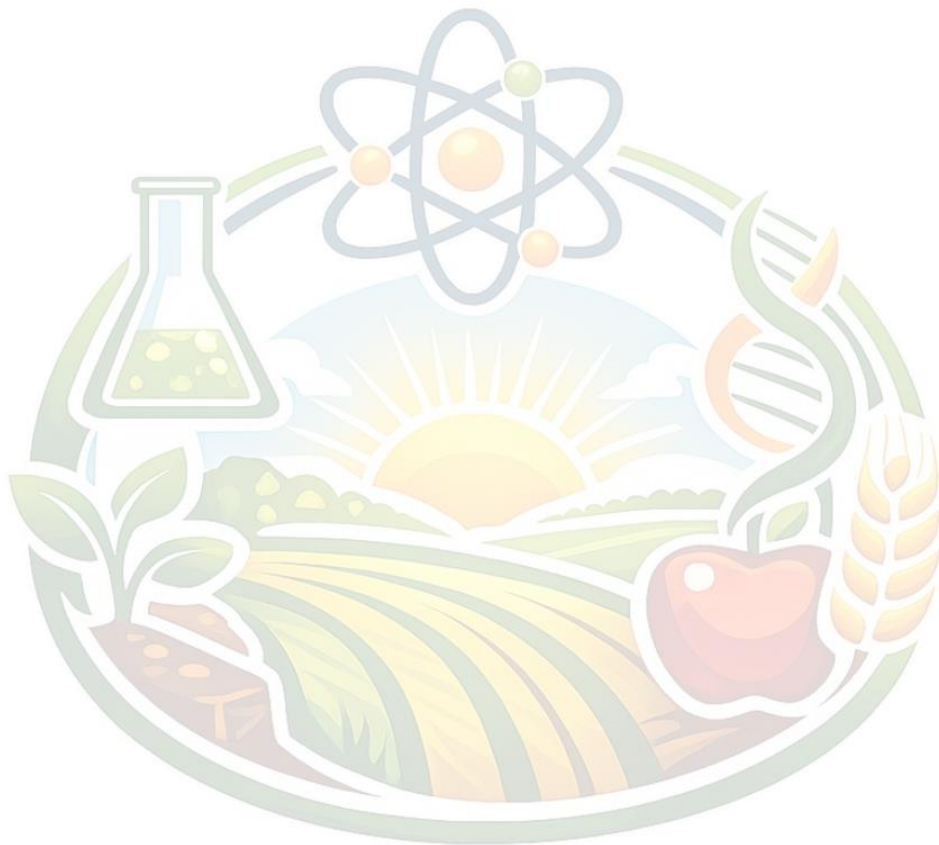
Regulatory and International Perspectives

SRC monitoring is currently a component of food quality control in a number of nations. Buyers in international dairy trade are increasingly requesting adherence to microbiological limitations for sulfite-reducing clostridia, clostridial spores, and anaerobic spore counts. Dairy processors also depend on food safety systems like HACCP and ISO 22000 to better control these hazards. Such tools lessen the possibility of spore-related flaws in dairy products, enhance cleanliness, and pinpoint critical control points.

Conclusion

Sulphite-reducing clostridia continue to cause major problems to the dairy and food industries due to their widespread presence, spore-forming ability, and potential to degrade product quality and safety. They are useful markers in quality assurance programs since their presence in milk and dairy products frequently indicates flaws in cleanliness and process control. A whole farm-to-fork strategy that includes hygienic milk production, good agricultural practices, cutting-edge

processing technology, and reliable monitoring systems is necessary for effective management. As India's dairy sector grows and integrates with global markets, preventing SRC contamination will be critical to assuring high-quality, safe, and internationally competitive dairy products.

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Applications of Artificial Intelligence (AI) in Food Quality Assessment: Current Trends, Challenges and Future Perspectives

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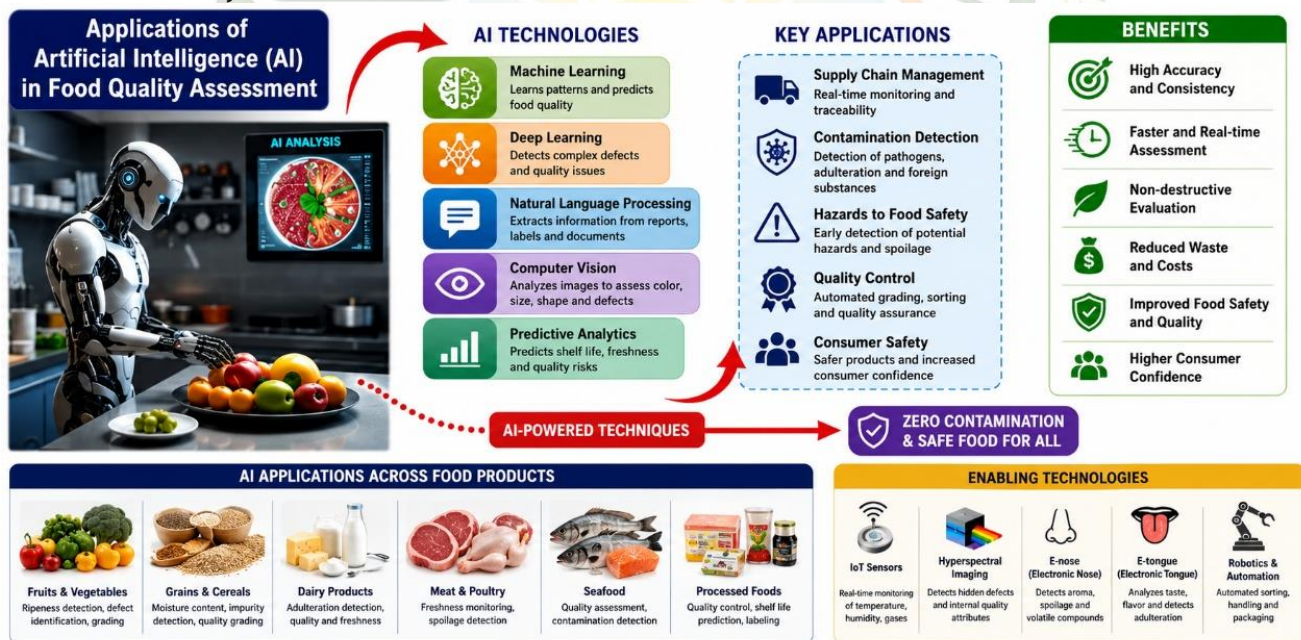
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Introduction

Food quality and safety monitoring is a crucial need with an estimated 600 million people suffering from foodborne illnesses every year from contaminated food. With the complexity of food production and food supply chains, quality assurance is crucial for food products to ensure consumer health, food waste reduction and competitiveness in the market.

Traditionally, food quality assessment has been based on manual inspection and laboratory testing which are time consuming, labour intensive and prone to human error. Artificial Intelligence (AI) is revolutionizing the process with its ability to quickly, accurately, and non-destructively evaluate food products. AI fusion integrates technologies like Machine Learning, Deep Learning, Computer Vision, and Internet of Things (IoT) to analyze images and sensor measurements for defect detection, product grading, adulteration detection, shelf life prediction, and freshness monitoring.

AI has revolutionized food quality assessment through its ability to enhance accuracy, consistency, and efficiency, minimize operational expenses, and decrease post-harvest losses. It can be used in a wide range of products, including fruits and vegetables, grains, dairy products, meats, seafoods and processed food, in order to contribute to safer and more sustainable food systems.



What is AI-Based Food Quality Assessment?

AI based food quality evaluation is the implementation of Artificial Intelligence (AI) technology to quickly and accurately assess the quality, safety and freshness of food products. Unlike the traditional approach of manual inspection or laboratory testing, AI utilises images, sensors and data to make quick and accurate decisions.

Artificial Intelligence (AI) is the ability of computers to emulate human intelligence, including pattern recognition and decision-making. Machine Learning (ML) is a subset of AI that uses past data to discover quality attributes and continually strives to enhance its performance. An advanced version of ML, Deep Learning (DL) is able to analyze complex images and detect small defects with high accuracy, relying on artificial neural networks. Computer Vision is a technology that enables machines to capture and interpret images to grade food by colour, size, shape, ripeness and defects. Internet

of Things (IoT) is the technology that enables smart sensors and devices to gather real-time data like temperature, humidity and concentration of gases in storage and transport.

These technologies collectively go through a straightforward process: Food Sample, Image/Sensor Data Collection, AI Analysis, Quality Classification and Decision Making. Food quality assessment with AI-based systems is fast, non-destructive, and consistent, ensuring food safety, minimizing waste, and enhancing consumer confidence.

Current Applications of AI in Food Quality Assessment

Artificial Intelligence (AI) is transforming food quality assessment by enabling rapid, accurate, and non-destructive evaluation across the entire food supply chain. Using computer vision, machine learning, deep learning, and smart sensors, AI improves product quality, food safety, and operational efficiency.

1. Fruit and Vegetable Quality: AI-powered imaging systems automatically inspect fruits and vegetables for **ripeness**, **colour uniformity**, **size**, **shape**, and **surface defects**. Computer vision can also identify **diseases**, bruises, cracks, and pest damage, enabling precise grading and reducing post-harvest losses.

2. Grain Quality: AI technologies are widely used in grain processing industries to assess **seed purity**, detect **broken or damaged grains**, estimate **moisture content**, and identify **foreign materials** such as stones, husks, or weed seeds. These systems improve grading accuracy and ensure better storage and market value.

3. Dairy Products: In the dairy sector, AI helps detect **milk adulteration**, monitor **cheese quality**, and predict **shelf life** by analysing chemical, microbial, and sensor data. These applications ensure product safety, maintain quality standards, and reduce spoilage during storage and distribution.

4. Meat and Fish: AI-based computer vision and sensor technologies evaluate the **freshness** of meat and fish by analysing colour, texture, odour, and microbial indicators. Early detection of spoilage and contamination helps maintain food safety and extends product shelf life.

5. Food Packaging: AI supports **smart packaging** by integrating sensors that continuously monitor temperature, humidity, and gas composition. It also predicts shelf life and detects packaging defects, ensuring product integrity throughout transportation and storage.

Technologies Powering AI-Based Food Assessment

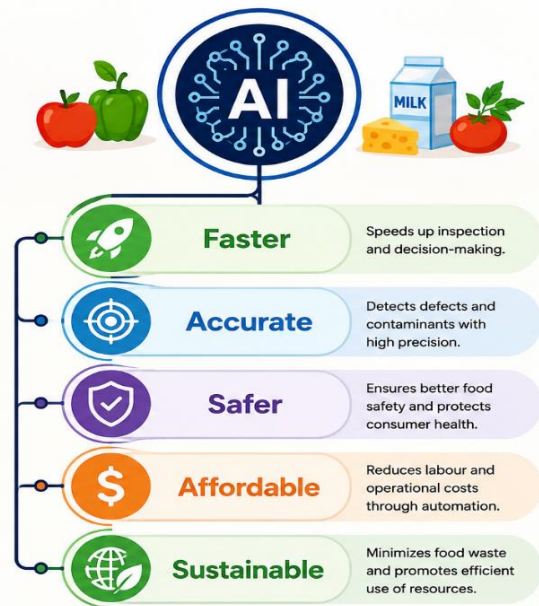
The rapid advancement of Artificial Intelligence (AI) has revolutionized food quality assessment by integrating advanced imaging systems, intelligent algorithms, and smart sensing technologies. These technologies enable rapid, accurate, and non-destructive evaluation of food products throughout the production and supply chain.

Technology	Application in Food Quality Assessment
Computer Vision	Captures and analyses images to detect surface defects, colour, size, shape, bruises, and ripeness of food products.
Machine Learning (ML)	Learns from historical data to predict food quality, classify products, detect adulteration, and estimate shelf life.
Deep Learning (DL)	Uses artificial neural networks to classify images, identify complex defects, detect diseases, and improve grading accuracy.
IoT Sensors	Continuously monitor environmental conditions such as temperature, humidity, gas concentration, and storage conditions in real time.
Hyperspectral Imaging	Detects internal quality attributes such as moisture content, sugar level, bruises, and hidden defects that are invisible to the human eye.
Electronic Nose (E-nose)	Mimics the human sense of smell to evaluate aroma, detect spoilage, identify volatile compounds, and assess freshness.
Electronic Tongue (E-tongue)	Simulates human taste perception to evaluate flavour, bitterness, sweetness, acidity, and detect food adulteration.
Robotics	Performs automated sorting, grading, packaging, and handling of food products with high speed, precision, and consistency.

Benefits of AI

Benefits of AI in Food Quality Assessment

✓	Fast inspection	AI analyzes food quality in seconds, enabling quick decision-making.	
✓	Non-destructive testing	AI uses advanced sensors and imaging to assess quality without damaging the food.	
✓	High accuracy	AI systems detect defects and contaminants with high precision and reliability.	
✓	Reduced labour cost	Automation reduces the need for manual inspection, saving time and labour costs.	
✓	Real-time monitoring	AI enables continuous monitoring of food quality during production and storage.	
✓	Consistent quality	AI ensures uniform quality by minimizing human error and subjective judgment.	
✓	Reduced food waste	AI helps identify quality issues early, reducing spoilage and food wastage.	
✓	Better consumer safety	AI detects harmful contaminants and ensures safer food for consumers.	



Challenges in AI Adoption

The integration of Artificial Intelligence (AI) in food quality assessment has transformed quality control, but there are several challenges impeding its broader adoption.

Technical Challenges: Limited datasets hinder accurate training, while poor-quality data affects prediction reliability. AI models may struggle to generalize across different food types and conditions.

Economic Challenges: High installation and ongoing maintenance costs pose barriers, particularly for small-scale industries.

Practical Challenges: A skilled workforce is necessary for developing and managing AI systems, along with essential infrastructure such as internet access and reliable power supply. Additionally, sensor calibration is critical for accurate AI performance.

Ethical Issues: Concerns about data privacy, the need for explainable AI, and the importance of trustworthiness are crucial for the successful implementation of AI in this sector.

Future Perspectives

Artificial Intelligence is expected to transform food quality assessment through advanced automation, real-time monitoring, and predictive analytics. Future developments will integrate AI with robotics, digital twins, blockchain, IoT sensors, and precision agriculture to improve quality, traceability, and food safety across the supply chain. Smart food factories will employ AI-powered cameras and autonomous systems for rapid defect detection and process optimization. Smartphone-based AI applications will enable on-site quality testing by farmers, retailers, and consumers. Generative AI will support data-driven decision-making, while cloud-based platforms will facilitate continuous monitoring, reducing food waste, ensuring regulatory compliance, and enhancing consumer confidence.

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The Secret Tenants of Old Trees: Hidden Stingless Bee Colonies on the IARI Campus

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Abstract

Tucked inside the trunks of old, unremarkable trees on the IARI campus live colonies of stingless bees, tiny pollinators that most people never notice. Recent observation of their natural nests on campus offers a window into how these insects build, defend, and run their hidden homes, and why such overlooked corners of an institutional landscape may be quietly supporting pollination across nearby crops, orchards and ornamental plantings. This article walks through what these natural nests look like, how the bees that built them survive without a sting, and why protecting a few old trees could matter more than it first appears.

Introduction

Anyone walking briskly across a research campus could pass an old, hollow-trunked tree a hundred times without a second look. Yet a closer look at a crack or knot near the base of such a tree sometimes reveals a slender, dark tube made of wax and resin, barely as thick as a pencil, with small black insects moving steadily in and out. This unassuming structure is the entrance to a stingless bee colony, and several such natural nests have recently been observed on trees across the IARI campus, prompting closer documentation of their biology and ecological role.

Stingless bees belong to the subfamily Meliponinae, a group separate from the familiar honeybee genus *Apis*. Lunagariya and Sisodiya (2024) found that feral colonies of *Tetragonula* commonly nest in wall cavities, window cavities, tree hollows, pipes, and even electric meters, with the entrance tube of each colony varying in shape and size depending on the substrate. The reduced sting of these bees cannot be used for defense, making them essentially harmless to people standing nearby, in sharp contrast to the more aggressive reputation of *Apis* species. Lunagariya and Sisodiya (2024) found that despite lacking a functional sting, stingless bees defend their nests vigorously by biting and entering the eyes, nose, and ears of intruders.

Beyond biting, stingless bees rely on several other defensive tactics. Shackleton *et al.* (2015) found that worker bees of various *Trigona* species attack intruders at the nest entrance through prolonged biting, and in some species this biting is so persistent that the defending workers themselves do not survive the encounter, a striking example of self-sacrifice in defense of the colony. Resin also plays a defensive role: sticky plant resin gathered by foragers is deposited at the entrance and on intruders such as ants, immobilizing them before they can reach the brood within.

Saaivignesh *et al.* (2023) found that feral *Tetragonula* colonies in Tamil Nadu predominantly nested in old mud and stone walls, with nest entrance tubes that were mostly elliptical in shape and black in colour, ranging between roughly 9 to 13 millimetres in length and 3 to 9 millimetres in width. The same study found that hive entrances were oriented mainly towards the northeast and east, and that nest entrances were frequently camouflaged with dried leaf bits or grease to blend in with the surrounding surface. On the IARI among the trees examined, the entrance tube was frequently the only outward sign that a hollow trunk concealed an active, established colony inside.

Behind that narrow doorway lies a tightly organized society. A single egg-laying queen is supported by worker bees that divide labour by age and task, including comb-building, brood care, and foraging. The brood is housed in compact comb built from cerumen, a mixture of wax and plant resin, and stingless bees are sometimes called “dammer bees” precisely because of this resin-rich nest material (Lunagariya and Sisodiya, 2024). Honey and pollen are stored separately from the brood in small, rounded pots rather than in continuous comb sheets, a structural pattern distinct from the open honeycomb built by *Apis* bees.

Despite their small size, the ecological contribution of these insects is considerable. Chauhan, Singh and Kumaranag (2019) found that the stingless bee *Tetragonula iridipennis* is an effective pollinator of ash gourd, visiting flowers reliably and contributing to fruit set in a crop that depends heavily on insect pollination. More recent work has extended this picture to protected cultivation: researchers at Nagaland University found that stingless bees, with a limited foraging range of about 50 to 100 metres and tolerance for temperatures up to 40°C, successfully pollinated around ten different crops under polyhouse conditions, including chilli, cucumber, watermelon, and pumpkin (All Gain, No Pain with Stingless Bees, 2025). Divekar, Mishra and Kumar (2024) found that bee pollination more broadly has a measurable effect on vegetable yield, quality, and seed production, and that the decline of wild pollinator populations remains a significant obstacle to achieving high productivity in vegetable crops.

On a campus such as IARI, where orchards, experimental plots, and ornamental plantings sit close together, the presence of naturally occurring stingless bee colonies suggests that these pollinators may contribute to pollination within the campus landscape. The presence of undisturbed, naturally occurring stingless bee colonies, with no artificial hives or active management, can also serve as a simple, low-cost indicator of how well a green campus or urban landscape is supporting smaller, less conspicuous wildlife.

Personal Opinion

In my view, the most striking part of observing these natural nests is how easily they go unnoticed despite their ecological importance. We tend to associate pollinator conservation with managed beehives or flowering gardens, while overlooking the much older, quieter relationship between insects and the trees we walk past every day. Where safety permits, retaining selected mature trees with natural cavities can provide valuable nesting habitats for stingless bees and other beneficial wildlife. Such simple conservation measures can help sustain pollinator diversity while preserving the ecological value of institutional and urban green spaces.

Conclusion

The natural stingless bee nests observed at IARI reveal a small but well-organized society thriving quietly inside ordinary-looking tree cavities. From the resin-dark entrance tube to the brood, food stores, and defensive biting behaviour within, each colony reflects adaptations built around the absence of a functional sting. Their pollination services, though easy to overlook, support fruit and seed set in nearby crops and contribute meaningfully to campus biodiversity. Continued observation of such feral colonies, on campuses and in surrounding landscapes, can help build a clearer picture of how widespread and ecologically important these insects already are.



Figure 1. Representative natural stingless bee nest entrances observed in mature tree cavities on the ICAR-Indian Agricultural Research Institute (IARI), New Delhi. The dark entrance tubes constructed from wax and plant resin are the only visible clues to thriving colonies hidden within the tree trunks. (Photographs by Anil Kumar Kalwa.).

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Insects in Fish Feed: A New Protein Source for Sustainable Aquaculture

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Abstract

Aquaculture is one of the fastest-growing food production sectors and plays a crucial role in global food security. But, increasing dependence on fishmeal in aquafeeds has raised concerns regarding sustainability, cost and pressure on wild fish stocks. In this context, insects have emerged as a promising alternative protein source for aquaculture feeds. Insect meals possess high protein content, good digestibility, favourable amino acid profiles and valuable bioactive compounds that support fish growth, immunity and health. Species such as black soldier fly, mealworm, silkworm and housefly have shown encouraging results in replacing fishmeal in diets of several aquatic species. In addition to their nutritional benefits, insects can be mass-produced using organic wastes with lower land, water and energy requirements, thereby supporting circular economy principles and environmental sustainability. Despite certain challenges related to digestibility, nutrient composition and large-scale production, insect-based feeds hold immense potential for sustainable aquaculture development.

Introduction

Aquaculture involves the farming of commercially important aquatic plants and animals. It plays a vital role in enhancing global food security alongside conventional food production sectors such as agriculture. With the global population projected to reach nearly 10 billion by 2050, the demand for nutritious and sustainable protein sources is increasing rapidly (FAO, 2024). In recent years, aquaculture has become one of the fastest-growing food production sectors worldwide. In 2022, aquaculture production surpassed capture fisheries production for the first time and in 2023, it contributed nearly 52% of the total global fish production (FAO, 2025). Due to its high production efficiency and comparatively lower environmental impact, aquaculture is considered one of the most sustainable methods of producing animal protein. But, the sustainability of aquaculture largely depends on the availability of quality feed ingredients, particularly fish meal, which remains a major protein source in commercial aquafeeds. Fish meal, mainly derived from capture fisheries, is valued for its high protein content, balanced amino acid profile and excellent digestibility. Nevertheless, the increasing cost, fluctuating availability and growing demand for fishmeal have intensified the search for alternative protein sources.

Among the available alternatives, soybean meal is widely used because of its affordability and nutritional value. However, high inclusion levels of plant-based ingredients may negatively affect fish growth, gut health, immunity and feed utilization due to the presence of anti-nutritional factors (ANFs) and comparatively inferior amino acid and fatty acid profiles. In carnivorous fish species, excessive inclusion of soybean meal has been associated with intestinal inflammation and enteritis (Randazzo et al., 2021).

In this context, insect-based feed ingredients have emerged as a promising and sustainable alternative protein source for aquaculture. Insects possess high protein content, good digestibility and favorable amino acid profiles, while also being cultured using organic waste materials with minimal land and water requirements. Therefore, the use of insect-based proteins in aquafeeds offers an effective strategy to reduce dependence on fishmeal and promote sustainable aquaculture development.

Potential Major Insect Species in Aquaculture Feeds

Insects are a natural component of the diet of many fish species, particularly during the larval and juvenile stages of carnivorous and omnivorous fishes. They provide essential nutrients such as high-quality proteins, amino acids, fatty acids, vitamins and minerals required for proper growth and development. In fact, humans have been consuming insects as a food source in several countries for more than 2,000 years.

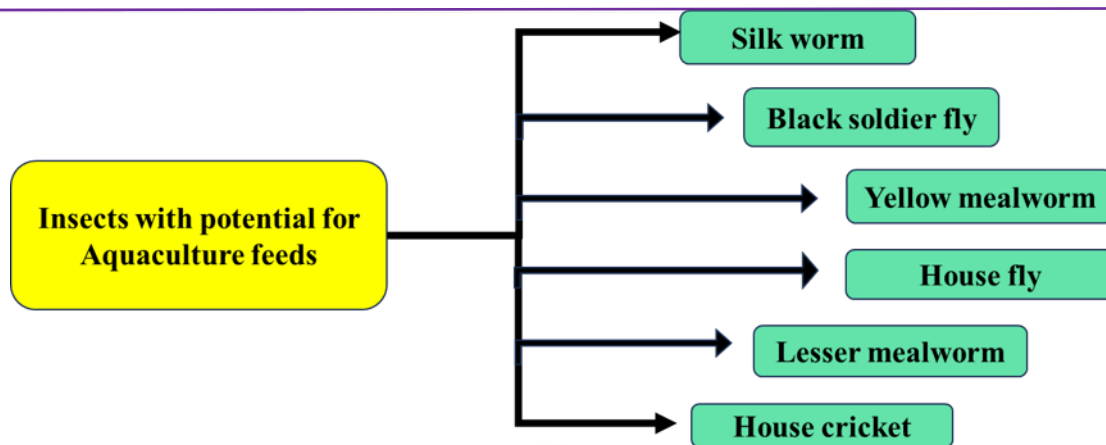


Fig 1: Potential insects suitable for inclusion in aquaculture feeds

Several insect species possess desirable characteristics such as rapid life cycles, high reproductive potential, efficient feed conversion and the ability to grow on a wide range of organic substrates. These features enable the production of high-quality protein, highly unsaturated fatty acids (HUFAs), vitamins and various bioactive compounds. As a result, insect meals have increasingly been incorporated into aquafeed formulations for different aquatic species, yielding promising results in terms of growth performance and feed utilization.

At present, insect meal production is expanding rapidly in regions such as China, Europe, North America, Australia and Southeast Asia. Among the various insect species evaluated for aquafeed production, the most promising include silkworm (*Bombyx mori*), black soldier fly (*Hermetia illucens*), housefly (*Musca domestica*), yellow mealworm (*Tenebrio molitor*), lesser mealworm (*Alphitobius diaperinus*) and house cricket (*Acheta domesticus*) (fig 1).

Nutritional Importance of Insects in Aquafeeds

Insects are gaining considerable attention as sustainable alternatives to conventional aquafeed ingredients because of their high nutritional value and environmental benefits. Recognizing their potential, the European Union approved the use of proteins derived from these insect species in aquafeeds (Ragozzino-Paulino et al., 2025). Generally, most insect meals contain approximately 60-70% crude protein on a dry matter basis, which is comparable to the protein content of fishmeal.

In addition, insect meals generally contain 10-50% lipids, although their nutritional composition varies depending on insect species, developmental stage, feeding substrate, and processing methods (Carvalho et al., 2023). For example, larvae of insects such as black soldier fly and housefly usually contain higher crude protein levels than the adult stages of silkworms and crickets (Alfiko et al., 2022). With respect to amino acid composition, Insect meals possess crude protein levels comparable to fishmeal, with an amino acid profile intermediate between plant proteins and fishmeal. Most insect species contain adequate essential amino acids, particularly valine, lysine, and leucine, making them promising alternatives to fishmeal (Zulkifli et al., 2022; Schiavone et al., 2017).

A major advantage of insect meals over plant-based ingredients is the presence of functional nutrients such as taurine and hydroxyproline. Taurine is essential for fish growth, metabolism, osmoregulation, and normal physiological functions, especially during broodstock development and larval stages in marine fishes. Taurine deficiency can lead to poor growth, physiological abnormalities, and disorders such as green liver syndrome (Henry et al., 2015; Takagi et al., 2008).

In terms of lipid composition, insect meals contain considerable amounts of lipids but cannot completely replace fish oil due to their comparatively lower levels of omega-3 fatty acids. Instead, insect lipids are generally rich in saturated fatty acids.

Insects accumulate lipids mainly during their larval stages, resulting in considerable variation in fat content and lipid composition among species and even within the same species depending on diet and environmental conditions. They commonly contain higher levels of saturated fatty acids (SFA) such as lauric acid, palmitic acid, and stearic acid (Lawal et al., 2021; Rawski et al., 2020; Ferdousi et al., 2020; Spranghers et al., 2017), along with monounsaturated fatty acids (MUFA) such as oleic acid (Mahanta et al., 2023).

Also, Insects are rich sources of B-complex vitamins, particularly vitamins B2, B3, and B12, as well as antioxidant vitamins such as vitamin E (Pilco-Romero et al., 2023; Zulkifli et al., 2022; Shukurova et al., 2021). Insects also serve as significant sources of minerals including calcium (Ca), phosphorus (P), potassium (K), sodium (Na), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu). However, the bioavailability of these minerals varies considerably among insect species and is influenced by factors such as diet and developmental stage (Ragozzino-Paulino et al., 2025).

Effects of Insect Meal on Aquatic Animals

Several studies have shown that insect meals can serve as a good alternative to fishmeal in aquaculture feeds. Among the different insect species, black soldier fly larvae (BSFL) is the most widely studied ingredient. Several studies have reported that replacing fishmeal with BSFL can improve growth and feed utilization in many aquatic animals. For example, better growth performance has been observed in Nile tilapia (*Oreochromis niloticus*) and magur (*Clarias magur*) fed diets containing BSFL compared to conventional fishmeal-based feeds (Maulu et al., 2025; Bordoloi et al., 2025). Another important insect used in aquafeeds is the yellow mealworm (*Tenebrio molitor*), which is also considered a promising protein source for fish and shellfish diets. In rohu (*Labeo rohita*), replacing 50% of fishmeal with yellow mealworm meal resulted in improved growth performance (Ismat et al., 2026). Similar improvements in growth and feed efficiency have also been reported in freshwater prawn (*Macrobrachium rosenbergii*) and mandarin fish (*Siniperca scherzeri*) fed mealworm-based diets (Feng et al., 2019; Sankian et al., 2018). Apart from promoting growth, insect meals have also shown promising effects on the antioxidant activity and overall physiological health of aquatic animals. Studies have shown that replacing fishmeal with maggot meal and black soldier fly larvae can enhance antioxidant enzyme activity (Naveed et al., 2023). Similar improvements were observed in red claw crayfish (*Cherax quadricarinatus*), where the inclusion of black soldier fly larvae increased superoxide dismutase (SOD) activity (Wang et al., 2022). Insect meals have also demonstrated beneficial effects on immunity and disease resistance. Many studies suggest that insect meal-based diets contain antimicrobial peptides (AMPs) and polysaccharides that help improve mucus production, epidermal thickness, and skin barrier functions in fish. These compounds strengthen the natural defense system of aquatic animals and improve their resistance against diseases (Islam et al., 2024). Overall, most studies have reported encouraging results with the inclusion of insect meals in aquaculture feeds. However, some studies have also noted that replacing fishmeal at very high levels, especially above 30%, may sometimes reduce growth performance in fish (Alfiko et al., 2022).

Insects as a Sustainable Feed Source for Aquaculture

The increasing global population has intensified the demand for fish and aquatic food products, placing heavy pressure on marine fisheries and wild fish stocks. In this regard, insect meals have emerged as promising and eco-friendly alternative protein sources for aquafeeds. Insects can be mass-produced using organic wastes and agricultural by-products, converting low-value materials into high-quality protein. Compared to conventional protein sources, insects have rapid reproduction rates, high feed conversion efficiency and require less land, water and energy. In addition, insect farming produces lower greenhouse gas emissions making it an environmentally sustainable feed alternative for aquaculture.

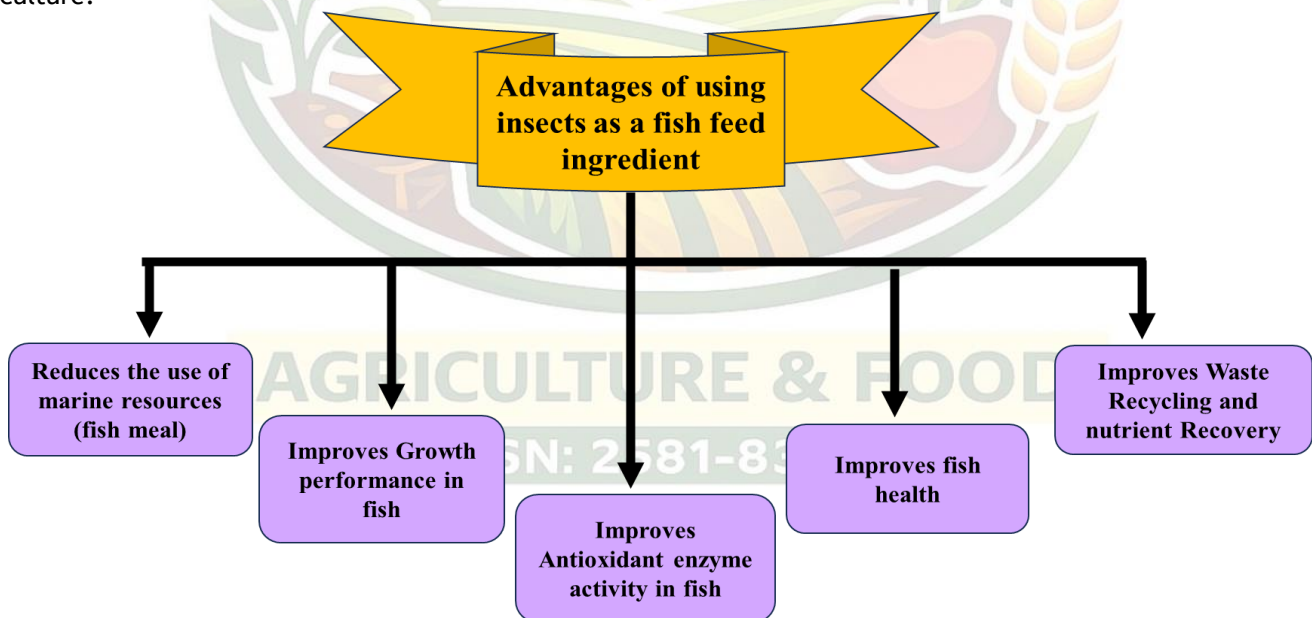


Fig 2: Advantages of using insects as a fish feed ingredient

Another major advantage of insect farming is its contribution to waste recycling and nutrient recovery. Organic wastes that would otherwise contribute to environmental pollution can be converted into valuable insect biomass, supporting the principles of circular economy and zero-waste management. Species such as black soldier fly are widely recognized for their ability to efficiently bio convert the organic waste into protein and lipid-rich biomass, which can be utilized in aquafeeds as well as biodiesel production (Surendra et al., 2016). Furthermore, certain insects such as *Tenebrio molitor* (mealworm) have shown the ability to biodegrade plastic waste, highlighting their additional environmental benefits (Wang et al., 2025). Thus, the utilization of insect-based ingredients in aquaculture not only reduces dependence on marine resources but also promotes sustainable waste management and environmental conservation.

Challenges and Solutions in the Use of Insects for Aquaculture

Despite their promising potential, the use of insect meals in aquaculture still faces several nutritional, technical, and regulatory challenges. One of the major limitations is the presence of chitin, a non-protein compound found in the exoskeleton of insects, which can reduce feed digestibility and growth performance in fish. The chitin content in insect meals varies widely depending on the insect species and developmental stage, ranging from very low levels (around 0.1% dry matter) to more than 10% dry matter (Alfiko et al., 2022). Although small amounts of chitin may provide beneficial effects by acting as a prebiotic and improving gut health, excessive chitin is generally considered a limiting factor in aquafeeds. For instance, high inclusion levels of black soldier fly (BSF) pre-pupae meal in the diet of juvenile turbot (*Psetta maxima*), with chitin levels ranging from 47 to 73 g/kg dry matter, resulted in reduced feed intake, poorer feed conversion, and lower growth performance (Maulu et al., 2022). Even though chitin can be removed through alkaline extraction methods, these processes are expensive and may leave chemical residues. Alternatively, supplementation with chitinase-producing bacteria has shown potential in improving digestibility while also enhancing fish immune response and reducing environmental impacts from fish waste (Zhang et al., 2014).

Another challenge is the comparatively lower levels of omega-3 fatty acids and certain essential amino acids in insect meals when compared to fish meal. This may affect fish growth and nutritional quality unless insects are reared on nutrient-enriched substrates. Defatting techniques can improve protein quality and amino acid concentration. But these methods require high energy input and increase production costs such as optimizing the rearing conditions of insects, formulating diets that improve the nutrient profile and processing techniques that enhance the digestibility and safety of the insect meal.

The safety of insect meals is another important concern, particularly when insects are reared on organic waste substrates. There is a possibility of bioaccumulation of pesticides, heavy metals, toxins and microbial contaminants. Therefore, strict monitoring of rearing substrates and quality control during mass production are essential to ensure feed safety. Large-scale insect production also faces challenges related to labour-intensive rearing systems, limited automation and a lack of standardized regulations in many countries. Consumer acceptance remains another critical factor influencing the adoption of insect-based aquafeeds. Increasing public awareness, ensuring product safety and establishing clear regulatory guidelines can improve consumer confidence and support the wider use of insect meals in sustainable aquaculture.

Conclusion

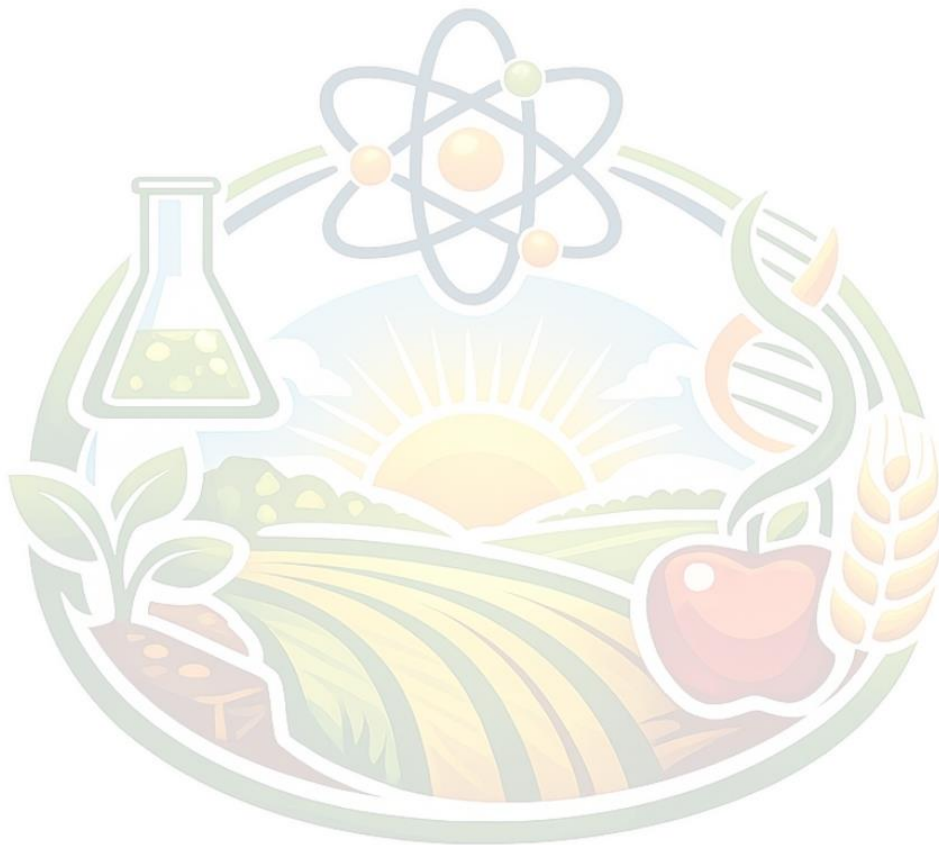
Insect-based feeds have emerged as a promising and sustainable alternative to conventional aquafeed ingredients, especially for reducing dependence on fishmeal and lowering pressure on marine resources. But, for the successful adoption of insect meals in aquaculture, large-scale insect farming systems with cost-effective, standardized and environmentally sustainable production methods are needed. Improvements in insect mass-production technology, processing methods and nutritionally balanced rearing substrates are also important to ensure better feed quality and safety. Since some insect meals may contain lower levels of certain essential amino acids and polyunsaturated fatty acids (PUFAs), proper nutrient supplementation is necessary for their effective use in aquafeeds. Although fishmeal still remains a reliable and widely used protein source in commercial aquaculture due to its high nutritional quality and availability, partial replacement of fishmeal with insect meals can be a practical approach to improve aquaculture sustainability. Overall, insect-based aquafeeds have great potential to support sustainable, economical and environmentally friendly aquaculture development in the future.

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Nature's Colours on Your Plate: Exploring Natural Pigments in Vegetables and Their Health Benefits

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Abstract

Natural substitutes that not only improve aesthetic appeal but also good for health are becoming more popular lately in an era where processed foods with vibrant colours frequently include artificial ingredients. Chlorophylls, carotenoids, anthocyanins, betalains, flavonoids and sulphur-containing chemicals are some of the most abundant natural pigments found in vegetables, each of which contributes unique colours and biological activities. These pigments have antioxidant, anti-inflammatory, cardioprotective, neuroprotective and chemopreventive qualities. Chlorophyll, lutein, zeaxanthin and sulforaphane are the compounds known to promote detoxification, eye health and cellular defense mechanisms which are found abundant in green vegetables like spinach and broccoli. Lycopene, betalains and anthocyanins, which give vegetables their red colour, have been linked to lower risks of heart disease, several types of cancer and conditions brought on by oxidative stress. Provitamin A carotenoids, which are essential for growth, immunity and vision, are abundant in orange and yellow vegetables, especially in sweet potatoes, pumpkins and carrots. High concentrations of anthocyanins, which have anti-inflammatory and neuroprotective properties are found in purple foods including purple cabbage and brinjal. Moreover, bioactive substances like allicin, quercetin and glucosinolates found in white vegetables like garlic, onion and cauliflower have antibacterial, immune-boosting and anti-carcinogenic qualities. Promoting the consumption of a wide range of coloured vegetables through the “eat the rainbow” approach can improve dietary diversity and reduce the risk of chronic diseases. Thus, vegetable pigments represent a remarkable integration of nutrition, health and sustainability, demonstrating that the colours on our plate are powerful indicators of nature’s protective compounds.

Keywords: Vegetable Pigments, Bioactive Compounds, Antioxidant Activity Nutritional health, Chemo-preventive.

Colour on Your Plate, Chemistry in Your Body

Nowadays, our kitchen shelves are filled with processed foods that often get their striking colours from artificial additives. As we think of those bright coloured snacks- these artificial food colours are everywhere, and they are quite popular because they make food look more appealing. But growing scientific evidences has raised concerns about their potential effects, with some studies relating them to hyperactivity in children, allergic reactions, and other health issues. As people are becoming more health conscious, their main attention is shifting towards natural alternatives- not just as a source of nutrients, but as a colourful, natural, and health-boosting choice (Slavin & Lloyd, 2012; World Health Organization, 2020).

The vibrant colours present in vegetables are far more than nature’s creativity. Plants produce colourful pigments for survival: to attract pollinators, repel pests and herbivores, and safeguard themselves from the intense sunlight and diseases. In this evolutionary process, they’ve provided us some of the most remarkable natural compounds known. By including these vegetables, we gain the advantages of pigments that have been refined in millions of years. Each group known to us like chlorophyll, carotenoids, anthocyanins, betalains, and flavonoids: offers unique health benefits to our plates (Del Rio et al., 2013; Bohn, 2019).

India’s rich agricultural heritage is reflected in the incredible diversity of vegetables grown across its varied agro-climatic regions. From the bright red, lycopene-rich tomatoes cultivated in the hills of Himachal Pradesh to the deep purple, anthocyanin-rich cabbages grown in the cool climate of the Nilgiris, the country offers a colourful array of naturally pigmented vegetables. These vibrant colours are not merely pleasing to the eye; they represent valuable natural compounds that contribute to both nutrition and health.

Starting with the green vegetables, these are the backbone of any healthy diet, and their colour comes from chlorophyll- the same pigment that helps regulate photosynthesis. Chlorophyll exists in two principal forms: chlorophyll-a, which gives a blue-green hue, and chlorophyll-b, which is more yellow-green. Together they create the lush, vibrant greens we call spinach (Palak), broccoli, French beans, peas, fenugreek (Methi), and coriander (Dhaniya).

Beyond aesthetics, chlorophyll has impressive bioactive properties. As a potent antioxidant, it neutralizes free radicals which are unstable molecules that damage cells and accelerate ageing (Ferruzzi & Blakeslee, 2007). Chlorophyll also promotes detoxification by binding to toxic compounds and heavy metals in the gut, facilitating their excretion. It is a

rich source of magnesium, which is central to over 300 enzymatic reactions in the human body, including energy production and protein synthesis.

Spinach, one of the most nutritionally dense green vegetables, contains not only chlorophyll but also lutein and zeaxanthin, two carotenoids present in the macula of the eye (Johnson, 2014). Regular spinach consumption is strongly associated with a reduced risk of age-related macular degeneration (AMD). Similarly, Broccoli is exceptionally rich in sulforaphane, a compound derived from glucosinolates that has shown powerful anti-cancer properties in numerous studies (Fahey et al., 2012; International Agency for Research on Cancer, 2004). Sulforaphane activates the *Nrf2* pathway, which upregulates the body's antioxidant defense systems.

Aspect	Details
Pigment	Chlorophyll-a and Chlorophyll-b
Key Vegetables	Spinach, Broccoli, Peas, Cabbage, Fenugreek, Coriander, Green beans
Key Nutrients	Magnesium, Iron, Folate, Vitamin K, Vitamin C, Zeaxanthin
Health Benefits	Detoxification, bone health, blood circulation, eye protection, immunity
Bioactive Compound	Sulforaphane (broccoli), sinigrin (cabbage) Lutein (spinach), Folate (leafy greens), diosgenin (fenugreek), chlorogenic acid (coriander), peas (pisatin)

Red vegetables obtain their vivid colour from two distinct classes of pigments: lycopene, a carotenoid, and anthocyanins, a class of flavonoids. Understanding these pigments separately is important because they come from different vegetables.

Lycopene is the pigment responsible for the deep red of tomatoes, red carrots, and red capsicum. It is one of the most powerful antioxidants found in food, with singlet oxygen-quenching ability nearly twice that of beta-carotene. Epidemiological studies consistently show that high dietary lycopene intake is associated with a significantly reduced risk of prostate cancer, cardiovascular disease, and certain neurological conditions (Giovannucci, 2002; Rao & Rao, 2007). Importantly, lycopene is a fat-soluble compound whose bioavailability dramatically increases when vegetables are cooked with a small amount of fat- making traditional Indian cooking with tomatoes in oil a nutritionally intelligent practice (Kopsell & Kopsell, 2006).

Beetroot's vibrant red-purple colour comes from betalains- a unique group of pigments found almost exclusively in the plant order Caryophyllales. Betalains are divided into betacyanins (red-violet) and betaxanthins (yellow-orange). They are both powerful antioxidants and anti-inflammatory agents (Rao & Rao, 2007; Saini et al., 2015). Beetroot is also one of the richest natural sources of dietary nitrates, which the body converts to nitric oxide- a molecule that relaxes blood vessels, lowers blood pressure, and improves oxygen delivery to muscles. Athletes increasingly consume beetroot juice for its evidence-based ergogenic benefits (Clifford et al., 2015; Ninfali & Angelino, 2013).

Red cabbage and red onion obtain their colour primarily from anthocyanins (Khoo et al., 2017; Wallace & Giusti, 2015). These water-soluble pigments are pH-sensitive and appear red in acidic conditions and turning blue-purple in alkaline environments. Anthocyanins from red vegetables have demonstrated anti-inflammatory, cardioprotective, and neuroprotective properties in both in vitro and in vivo studies.

Orange and yellow vegetables get their characteristic colour from carotenoids- a large family of over 750 naturally occurring fat-soluble pigments. The most nutritionally important carotenoids in vegetables are beta-carotene, alpha-carotene, and lutein. Beta-carotene, found abundantly in carrots, pumpkin, sweet potato, and yellow capsicum, is often called pro-vitamin A because the body can convert it to retinol (Vitamin A) as needed.

Vitamin A deficiency remains a significant public health problem in India, particularly in rural areas, affecting children's vision, immune function, and growth. Promoting the consumption of orange-coloured vegetables is a cost-effective dietary strategy to address this deficiency. The Indian Council of Medical Research (ICMR) recommends that orange and yellow vegetables be included regularly in children's meals for this reason.

Carrot (*Daucus carota*) is the flagship orange vegetable. Beyond beta-carotene, it contains polyacetylenes that have shown anti-tumour activity, and falcarinol, a compound with demonstrated anti-cancer properties in animal models (Arscott & Tanumihardjo, 2010). Carrot consumption has also been associated with improved skin health due to carotenoid deposition in the skin, which provides mild protection against UV-induced photodamage (Bohn, 2019). **Pumpkin** and **sweet potato** are similarly rich in beta-carotene, along with significant quantities of dietary fibre and potassium, contributing to cardiovascular and digestive health.

Purple and blue-hued vegetables have captured the imagination of nutritionists, chefs, and food scientists alike in recent years. Their striking colours come from anthocyanins: the same class of pigments found in red vegetables but at higher concentrations and with different structural forms, shifting the colour spectrum toward violet and indigo (Lila, 2004; Khoo et al., 2017).

Brinjal is perhaps India's most familiar purple vegetable and a dietary staple across the country. The deep purple skin of brinjal is packed with nasunin, a specific anthocyanin that has shown remarkable neuroprotective properties in studies (Lila, 2004). Nasunin protects neuronal cell membranes from oxidative damage and has demonstrated the ability to

inhibit angiogenesis (formation of new blood vessels) in tumours, a property of significant interest to cancer researchers. Importantly, nasunin is concentrated in the peel, so consuming brinjal with its skin intact maximizes these benefits.

As compared to green cabbage, purple cabbage has four to six times more anthocyanin. It is also fairly high in glucosinolates and vitamin C. According to studies, those who frequently eat purple cabbage had far lower levels of systemic inflammation, which is linked to heart disease, diabetes, and Alzheimer's disease. Cultivated for centuries in South Asia, purple carrot varieties are now gaining worldwide recognition as a natural food colorant and functional food with two advantages: the purple anthocyanin-rich skin offers additional antioxidant protection, while the orange carotenoid core provides pro-vitamin A.

Despite having some of the most powerful bioactive chemicals in the vegetable kingdom, white vegetables are often overlooked in the favour of colorful vegetables. The characteristic pale or creamy colouration of these vegetables is due to the presence of bioactive phytochemicals like flavonoids (quercetin and kaempferol), allicin (onion and garlic) and glucosinolates (cauliflower and radish).

For more than 5,000 years, garlic (*Allium sativum*) has been honored as a curative food, and research confirms this claim (Heber, 2004). Allicin, formed when garlic is crushed or diced (triggering the enzyme alliinase), a strong antibacterial chemical effective against a broad spectrum of bacteria, fungi, and viruses. Consuming garlic is related to lower blood pressure, decreased LDL cholesterol, improved immunity, and a lower risk of some types of cancer. Additionally, it promotes a healthy gut microbiota as a prebiotic. Quercetin, a flavonoid having anti-inflammatory, antiviral, and antihistamine qualities is most abundant in onions (*Allium cepa*). Quercetin is significantly higher in red and yellow onions than in white onions (Del Rio et al., 2013).

Cauliflower, being a member of the Brassica family, is rich in glucosinolates, which possess the chemopreventive property (International Agency for Research on Cancer, 2004). It is also a source of choline, a nutrient essential for brain development and liver function.

Major Bioactive Compounds and Health Benefits Associated with Coloured Vegetables

Key Aspect	Details	Example
Bioactive Compounds	Allicin, Quercetin, Kaempferol, Glucosinolates, Inulin	Garlic, Onion, Cauliflower, Radish, Mushroom (white), French Bean
Health Benefits	Antimicrobial, cholesterol reduction, immune boost, anti-cancer	Broccoli, Brinjal

From Farm to Food Industry: Vegetable Pigments as Natural Colourants

The market for natural food colouring is expected to surpass USD 3.5 billion by 2028, with a compound annual growth rate (CAGR) of more than 7%. Growing consumer demand for clean-label products, stricter laws governing synthetic dyes, and increased knowledge of the health hazards associated with artificial food colouring are the major drivers.

Natural vegetable pigments are safe and these provide health advantages over synthetic dyes made from petroleum compounds. Beetroot extract (betanin, E162) is approved as a natural food colourant in India and is widely used in beverages, dairy products, ice cream etc. Chlorophyll and its derivatives (E140, E141) provide stable green colouring to the products ranging from pasta to chewing gum. Beta-carotene (E160a), whether extracted from carrots or synthesized biologically, is among the most widely used food colourants globally, found in margarine, dairy etc.

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A significant advantage of vegetable-derived colourants is that they can be marketed not just as colour agents but also as functional ingredients. A beverage coloured with beetroot extract carries the antioxidant, nitrate, and anti-inflammatory benefits. This is transforming how food manufacturers think about natural colours.

Eat the Rainbow: A Simple, Powerful Health Strategy

"Eat the rainbow" is among the most scientifically supported and practical dietary recommendations. Different colours present in various vegetables indicate phytochemicals, which provides many health benefits through distinct biological mechanisms. Since no single vegetable contains all of these beneficial compounds, consuming a diverse range of coloured vegetables is must for obtaining their nutritional and health-promoting benefits (Slavin & Lloyd, 2012; Del Rio et al., 2013).

People who consumed the maximum variety of differently colored fruits and vegetables had the lowest risk of mortality, according to a study published in the American Journal of Clinical Nutrition which examined over 65,000 people. The

protective effect was strongest in case of green, orange, and red vegetables. Importantly, the relationship was not only explained by total vegetable consumption; variety mattered independently of quantity.

Traditional Indian cuisine uses a wide variety of vegetable colours, such as tomatoes and red chillies in curries, carrots and turmeric in rice dishes, spinach and fenugreek in vegetables, and garlic and onion as basic aromatics in every recipe. However, these conventional eating habits are being undermined by urbanization and the trend towards processed foods. Thus, promoting the idea of vegetable colour variation is essential for both food culture preservation and nutrition education.

Conclusion

The vegetable colours are not random; they are the result of millions of years of biochemical evolution and represents most of the powerful natural medicines known to us, nicely packaged in tasty, reasonably priced foods. Each family of pigments, including chlorophyll, carotenoids, anthocyanins, betalains, flavonoids, and allicin, has a unique set of antioxidant, anti-inflammatory, cardioprotective, neuroprotective, and chemopreventive properties.

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Enhanced Production Technologies and Uses of Sesame (*Sesamum indicum* L.) in Punjab

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Sesame (*Sesamum indicum* L.) is a multipurpose crop used in food, nutrition, medicine, industry, and agriculture. Its seeds, oil, and plant biomass contribute to its economic value and sustainability. Because of its adaptability and diverse uses, sesame remains important for farm income, nutritional security, and sustainable agricultural systems. As an herbaceous annual oilseed crop in the family Pedaliaceae, it has been cultivated for edible seeds and high-quality oil for millennia (Britannica Encyclopaedia 2026).

Uses of Sesame (*Sesamum indicum* L.)

Nutritional and Food Applications: Sesame seeds contain 40-60% oil and 18-25% protein, along with essential amino acids, vitamins, and minerals, making them nutritionally dense. They are widely used in bakery products, confectionery, and traditional foods such as tahini and halva due to their flavour and energy value.

Health and Bioactive Properties: Sesame seeds are rich in lignans (sesamin, sesamol, sesamol), tocopherols, and phytosterols with strong antioxidant and cardioprotective effects. These bioactive compounds contribute to improved lipid metabolism and reduced oxidative stress, with potential benefits against cardiovascular and metabolic disorders (Ma et al., 2023).

Culinary, Industrial and Pharmaceutical Uses: Sesame oil is a high-quality edible oil with good oxidative stability and a favourable unsaturated fatty acid profile, widely used in cooking and food processing (Wei et al., 2022). It is also utilized in cosmetics, soaps, and pharmaceuticals due to its emollient and antioxidant properties (Oboulbiga et al., 2023).

Agricultural and environmental applications: Sesame residues are used for composting, mulching, and improving soil organic matter and nutrient cycling. Dried stalks are commonly used as domestic fuel and low-cost structural material in rural areas

Ethnobotanical and Therapeutic Uses

Sesame seeds and oil have long been used in traditional medicine for treating inflammation, wounds, and metabolic disorders. Various plant parts are employed in ethnopharmacological practices, highlighting the crop's therapeutic significance scoring its therapeutic value. Table 1 and Fig. 2 show its utilisation.



Fig 1: Sesame Plant and Seed (www.google.com Plant and Seed)



Fig 2: Sesame seed and Oil uses (www.Sesame seed and oil Use)

Varieties

Punjab Til No. 2: This variety yields 2.8 quintals per acre. It has profuse branching and dense capsule-bearing. Capsules arranged opposite to each other are long and non-hairy. Its seeds are white, bold, and have 49 per cent oil content. Seeds have less crude fibre, are soft and better in palatability. This variety is tolerant to phyllody and cercospora leaf blight. It matures in 90 days.

RT 346: This variety yields 2.6 quintals per acre. It has profuse branching, long, non-hairy capsules arranged alternately. It has white, bold seeds which contain 49 per cent oil. It is moderately resistant to Antigastra capsule borer. It matures in 87 days.

Agronomic Practices

Land Preparation: The crop requires a well-prepared seedbed. Two or three ploughings followed by planking.

Time of Sowing: First fortnight of July after receipt of adequate rain or with pre-sowing irrigation application. An early-sown crop in June suffers from phyllody disease.

Soil Type: It thrives best on well-drained, sandy-loam soils.

Seed Rate and Method of Sowing: The seed rate is 1 kg per acre. The row-to-row spacing should be 30 cm, and the seed should be sown at a depth of 4 to 5 cm with a pora or tube attached to the desi plough. After complete germination, extra plants should be thinned to maintain a spacing of 15 cm.

Time of Sowing: First fortnight of July, as an early-sown crop is more prone to phyllody disease. Remove phyllody-infected plants from time to time and bury them to check further spread of the disease.

Fertiliser Application: Apply 45 kg urea per acre before sowing and avoid excessive weed growth. One hoeing three weeks after sowing can reduce weeds.

Harvesting and Threshing: When plants turn yellow or reach maturity, and the capsules have just opened, harvest the crop to prevent seed shattering. Tie the plants into small bundles and stack them upright after harvesting. Two shakings of the bundles are enough to collect the entire produce.

Plant Protection

1. Insect Pests:

Sesame leaf webber and capsule borer: The larvae web and roll leaves or bore into capsules, feeding on developing seeds; early infestation may result in plant death. Timely sowing at the recommended period significantly reduces pest incidence.

Jassids: Jassids damage the crop by sap sucking and by transmitting mycoplasma, leading to inflorescence malformation. Early sowing in June should be avoided to minimise jassid infestation.

2. Diseases:

Phyllody: It is caused by a mycoplasma-like organism (MLO), phyllody transforms floral parts into leafy structures, preventing capsule formation. The disease is transmitted by the jassids (*Orosius albicinctus*); removal of infected plants and effective jassid management help limit its spread.

Blight (*Cercospora sesami*): The disease appears at flowering as dark brown angular lesions with grey centres on leaves, petioles, stems, and capsules, leading to defoliation. Avoid excessive nitrogen fertilisation and maintain field sanitation by removing weeds and crop debris.

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Overfishing Along the Southern Coast of Tamil Nadu: A Growing Marine Crisis

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Sesame (*Sesamum indicum* L.) is a multipurpose crop used in food, nutrition, medicine, industry, and agriculture. Its seeds, oil, and plant biomass contribute to its economic value and sustainability. Because of its adaptability and diverse uses, sesame remains important for farm income, nutritional security, and sustainable agricultural systems. As an herbaceous annual oilseed crop in the family Pedaliaceae, it has been cultivated for edible seeds and high-quality oil for millennia (Britannica Encyclopaedia 2026).

Abstract

The southern coast of Tamil Nadu, encompassing the Gulf of Mannar and Palk Bay, supports over one million coastal livelihoods and harbours more than 4,000 marine species, including endangered fauna, coral reefs, and seagrass beds. This ecologically sensitive region is currently facing severe fishing pressure due to a significant increase in fishing capacity. Between 2000 and 2020, the number of mechanized fishing vessels rose by **57%**, and motorized craft increased by **71%**. This heightened effort, coupled with destructive trawling, has led to substantial habitat degradation: live coral cover in the Gulf of Mannar has declined from 37% in 2005 to **27.3%** in 2021, and seagrass areas have shrunk by nearly **29%** (Kannan *et al*, 2019). Furthermore, non-selective gears are targeting young fish; in areas like Dhanushkodi and Thoothukudi, approximately **68%** of shore-seine landings consist of juveniles, resulting in an annual loss exceeding **₹44.6 crore** in potential yield. Consequently, catch-per-unit-effort has decreased, increasing economic instability among artisanal fishers. Achieving sustainability requires stricter regulation, investment in habitat restoration, and community-based fisheries governance to prevent irreversible ecological and economic collapse.

Keywords: Biodiversity, Gulf of Mannar, Juvenile Fish, Marine Protected Area, Overfishing.

Introduction

Tamil Nadu, situated on the south-eastern coast of India, possesses some of the nation's richest and most ecologically sensitive marine environments. The southern districts border the Gulf of Mannar and the Palk Bay, regions globally recognized for their immense biodiversity, harbouring over 4,000 marine species, including coral reefs, seagrass meadows, and endangered *dugongs* (ICSF, 2023). These ecosystems are vital, sustaining the livelihoods of over a million people engaged in fishing and related industries. However, overfishing has emerged as the primary threat, driven by technological advancements in fishing gear, rising demand, and inadequate regulation. This practice is rapidly depleting fish stocks and degrading critical habitats, posing an ecological and socio-economic emergency along the southern coast.

Drivers of Overexploitation

The current crisis is fuelled by three main factors: excessive fishing capacity, destructive gear, and juvenile fish harvest.

Increased Fishing Capacity and Destructive Gear: The sheer number of fishing vessels operating in the region has created unsustainable pressure on fish stocks. Between 2000 and 2020, mechanized fishing vessels (such as trawlers) and motorized craft increased by **57%** and **71%**, respectively, particularly in the Gulf of Mannar region (ICSF, 2023). This capacity expansion drives intense competition, often pushing fishers into sensitive nursery and reef zones.

A significant contributor to habitat damage and stock depletion is the widespread use of mechanized **bottom trawling**. These trawlers indiscriminately sweep the seafloor, causing irreparable damage to benthic habitats like coral reefs and seagrass beds. Bottom trawlers are highly non-selective, leading to substantial bycatch; one study found that over 70% of the bycatch in Tamil Nadu's trawl fisheries consisted of juveniles or non-commercial species (ICSF, 2023).

Habitat Degradation and Juvenile Harvesting: Critical habitats supporting fish recruitment seagrass beds and coral reefs have been severely degraded by destructive fishing practices. Live coral cover in the Gulf of Mannar has declined dramatically from **37% in 2005 to just 27.3% in 2021**. Similarly, seagrass beds, which serve as essential fish nurseries, have seen an estimated **29% reduction in area** over two decades (Kannan *et al*, 2019). The *dugong* a critically endangered species that relies heavily on seagrass for food, is particularly vulnerable to this habitat loss and accidental capture.

Furthermore, the harvest of juvenile fish is undermining future fishery yields. In key landing areas such as Dhanushkodi and Thoothukudi, non-selective nets like fine-meshed shore seines (karai valai or marukku valai) capture young fish before they have a chance to reproduce. This practice is severe; approximately **68% of shore-seine landings** were found to consist of juveniles (Surya *et al*, 2018). The economic impact of this loss is staggering, translating into an estimated **₹44.6 crore loss** in future fishery value. (Surya *et al*, 2018).

Impacts and Regulatory Gaps

The immediate consequences of overfishing are clear: declining catch rates and increased social conflict. Fishermen across Tamil Nadu report declining **catch per unit effort (CPUE)**. Traditional fishers, especially those dependent on nearshore resources, are the most affected. Many have been forced to migrate or invest in expensive offshore ventures, increasing economic vulnerability. Biodiversity loss is also evident, impacting non-target and ecologically important species.

The depletion of nearshore resources has also heightened conflicts:

1. Tensions between mechanized and artisanal fishers.
2. Cross-border fishing conflicts between Indian and Sri Lankan fishers in Palk Bay (Fig 1) (Daily Mirror Online, 2025).

The seizure of Indian fishing boats by the Sri Lanka Navy for alleged poaching in Sri Lankan waters near Mannar. This represents the serious geopolitical and economic tensions that arise from resource depletion in the shared maritime boundary (Daily Mirror Online, 2025). Although regulatory measures exist such as the seasonal fishing ban (typically 15 April to 14 June) for mechanized vessels and the restriction on mechanized vessels operating within 5 km of the shoreline **weak enforcement** remains a critical issue. Illegal trawling persists, even within protected zones like the Gulf of Mannar Marine National Park, undermining the conservation goals of these policies daily. Table 1 shows Key Indicators of Overfishing and Habitat Degradation in Southern TamilNadu (2000-2021) (Dineshbabu *et al*, 2019).

Efforts Towards Sustainability

Tamil Nadu has initiated several interventions to address the crisis (ICSF, 2023):

1. **Protected Areas and Restoration:** The Gulf of Mannar Marine National Park and Biosphere Reserve offer essential protection. Restoration projects, including artificial reef deployment and coral transplantation, have shown promising results in reviving fish stocks.
2. **Fishing Regulation and Policy:** The government has promoted the conversion of coastal trawlers into deep-sea longliners via subsidy programs, reducing pressure on coastal habitats. The Tamil Nadu Marine Fishing Regulation Act (TNMFRA, 1983; amended 2017) mandates minimum mesh-size limits and restricts mechanized vessels from operating within 5 km of the shoreline.
3. **Community Involvement:** Community-based fisheries management is being explored, enabling local fisher groups to participate actively in monitoring, enforcement, and conservation.

Conclusion

Overfishing on the southern coast of Tamil Nadu represents a critical ecological and socio-economic emergency. The rich biodiversity of the Gulf of Mannar is being severely threatened by uncontrolled exploitation, habitat destruction, and significant regulatory failures (ICSF, 2023). The combined pressure from a **71% increase** in motorized boat fleets and the use of non-selective gears has resulted in devastating outcomes. We now retain only **27.3% live coral cover** and have lost **29% of seagrass beds** in the Gulf of Mannar (Kannan *et al*, 2019). This irregular fishing is also devastating fish populations, with up to **68% of the harvest** being juvenile fish, costing the region over **₹44 crores** annually in lost potential yield (Surya *et al*, 2018). The impact extends to socio-economic stability, forcing traditional fishers into financially precarious offshore ventures, and destroying the habitat of critically endangered species like the *dugong*. Despite existing efforts, such as Marine Protected Areas and new regulations, success is limited due to a lack of strict enforcement, especially during critical breeding seasons (Dineshbabu *et al*, 2019). To reverse this trend, sustainable solutions are urgently required. These solutions must integrate **strict and consistent enforcement** of existing fishing regulations, substantial **investment in habitat restoration**, robust **support for alternative livelihoods**, and the genuine empowerment of coastal communities in fisheries governance. Without these comprehensive reforms, the collapse of these marine ecosystems may become irreversible, threatening both the region's unique biodiversity and the future of millions who depend on the sea.

Conflict of Interests

The authors declare no conflict of interests.

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Indicator	Baseline (pprox.. 2000-2005)	Current (pprox.. 2020-2021)	Change / Impact
Mechanized Vessels	-	-	57% increase (2000-2020)
Motorized Craft	-	-	71% increase (2000-2020)
Live Coral Cover	37% (2005)	27.3% (2021)	9.7%-point decline
Seagrass Area	-	-	Approx. 29% reduction over two decades
Juvenile Fish in Landings	-	68% of shore-seine landings	High rate of stock depletion
Lost Potential Yield	-	-	Annual loss exceeding ₹44.6 crore
Indicator	Baseline (pprox.. 2000-2005)	Current (pprox.. 2020-2021)	Change / Impact
Mechanized Vessels	-	-	57% increase (2000-2020)

Table 1: Key Indicators of Overfishing and Habitat Degradation in Southern Tamil Nadu (2000-2021) (Source: Dineshbabu et al, 2019)

26.01.2025

**DailyMirror
ONLINE**

NAVY SEIZES 03 INDIAN FISHING BOATS POACHING IN SRI LANKAN WATERS NORTH OF MANNAR

The Sri Lanka Navy and Coast Guard seized three Indian fishing boats and arrested 33 Indian fishermen while they were poaching in Sri Lankan waters, during special operations conducted in the sea area north of Mannar on 25 and 26 January.



Figure 1. Illustration of cross-border fishing conflicts in the Palk Bay. (Source: Daily Mirror Online, 2025).

Vegetables as Probiotic Powerhouses: Potential for Sustainable Health Promotion

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Vegetables are widely recognized for their nutritional value however their role as carriers of probiotics is gaining increasing attention in recent years. Probiotics are live microorganisms that provide health benefits when consumed in adequate amounts, particularly by improving gut health and immunity. Traditionally, dairy products have been the main sources of probiotics, but vegetable-based alternatives are emerging due to their affordability, accessibility and suitability for lactose intolerant and vegan populations. Recent studies highlight that fermented vegetables are rich in beneficial microbes and bioactive compounds that support both physical and mental health. Fermented vegetables such as cabbage, carrot, cucumber and radish serve as ideal substrates for beneficial microorganisms, particularly lactic acid bacteria like *Lactobacillus* and *Leuconostoc*. Additionally, vegetable-based probiotics contribute to sustainable food systems by reducing reliance on animal-based products.

Introduction

Vegetables form an essential part of the human diet, providing vital nutrients such as vitamin, mineral, fiber and antioxidant. In recent years, there has been increasing interest in functional foods that offer health benefits beyond basic nutrition. Among these, probiotics have gained prominence due to their role in improving digestive health, enhancing immunity and preventing various diseases. Probiotics are defined as live microorganisms which, when administered in adequate amounts, confer health benefits to the host. Traditionally, dairy-based products like yogurt and kefir have been the primary sources of probiotics. However, due to lactose intolerance, vegan dietary habits and sustainability concerns, plant-based alternatives are gaining popularity (Tamang *et al.*, 2020).

Vegetables particularly when fermented, provide an excellent medium for the growth of probiotic microorganisms. The fermentation process not only preserves vegetables but also enhances their nutritional and functional properties. Recent findings further confirm that fermented vegetables contain diverse bioactive compounds and beneficial microbial populations that enhance health outcomes (Wei *et al.*, 2025). Therefore, vegetables are increasingly being explored as cost-effective and sustainable probiotic sources.

Fermentation and Development of Probiotics in Vegetables

Fermentation is a natural metabolic process in which microorganisms convert carbohydrates into organic acids under anaerobic conditions. In vegetables, fermentation is mainly carried out by lactic acid bacteria (LAB), which are responsible for developing probiotic characteristics. During fermentation, LAB utilize sugars present in vegetables to produce lactic acid, leading to a reduction in pH and inhibition of pathogenic microorganisms. The most common probiotic bacteria found in fermented vegetables include *Lactobacillus plantarum*, *Lactobacillus fermentum* and *Leuconostoc mesenteroides* (Tamang *et al.*, 2020). Recent research emphasizes that fermented vegetables contain bioactive metabolites that contribute to improved gut microbiota and overall health. Products such as sauerkraut, kimchi and pickles are rich in probiotics and contribute to improved gut health and nutrient availability (Marco *et al.*, 2021).

Common Vegetables Used as Probiotic Sources

Various vegetables are suitable for probiotic fermentation due to their nutrient composition and natural microflora. Some commonly used vegetables include:

1. Cabbage - Used in sauerkraut and kimchi, rich in LAB
2. Carrot - Contains natural sugars that support fermentation
3. Cucumber - Commonly used in pickle
4. Radish - Widely used in traditional fermented foods
5. Beetroot - Rich in antioxidant and suitable for fermentation

These vegetables provide a favourable environment for microbial growth and enhance probiotic diversity.

Health Benefits of Vegetable-Based Probiotics

Vegetable-based probiotics offer numerous health benefits:

1. Improved Gut Health: Maintain intestinal microbial balance (FAO/WHO, 2002)
2. Enhanced Immunity: Strengthen immune response (Marco *et al.*, 2021)

3. Better Digestibility: Increase nutrient bioavailability (Di Cagno *et al.*, 2013)
4. Disease Prevention: Reduce risk of gastrointestinal disorders (Swain *et al.*, 2014)
5. Antioxidant Activity: Reduce oxidative stress (Tamang *et al.*, 2020)
6. Mental Health Benefits: Fermented vegetables may act as psychobiotics influencing the gut-brain axis (Shawky *et al.*, 2025)
7. Recent meta-analysis studies also confirm that fermented foods significantly improve gastrointestinal health and overall well-being.

Advantages of Vegetables as Probiotic Carriers

Vegetables provide several advantages over dairy-based probiotics:

1. Suitable for lactose-intolerant and vegan population
2. Cost-effective and easily accessible
3. Rich in nutrients and dietary fiber
4. Environmentally sustainable
5. Extended shelf life due to fermentation

Role in Sustainable Health Promotion

Vegetable-based fermented products can serve as effective carriers for probiotic delivery while maintaining nutritional and sensory quality. In developing countries, fermented vegetables serve as affordable probiotic sources and help improve public health outcomes.

Challenges and Future Prospects

Despite their benefits, certain challenges exist:

1. Lack of standardization in fermentation processes
2. Variability in microbial strains
3. Shelf-life limitations
4. Limited consumer awareness

Future research should focus on improving fermentation techniques, identifying new probiotic strains and enhancing commercialization.

Conclusion

Vegetables have emerged as promising probiotic powerhouses with immense potential for sustainable health promotion. Fermented vegetables not only provide essential nutrients but also deliver beneficial microorganisms that improve gut health, immunity and even mental well-being. Their affordability, accessibility and eco-friendly nature make them a suitable alternative to traditional probiotic sources. Thus, incorporating vegetable-based probiotics into daily diets can significantly contribute to improved health and sustainable nutrition.

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Digital Transformation of Agricultural Marketing in India

Article ID: 74085

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Introduction

Agriculture plays a vital role in the Indian economy by supporting rural livelihoods and contributing to economic development (FAO, 2019). However, inefficiencies in agricultural marketing continue to limit farmers' income and market performance (Kumar, 2021). Agricultural marketing includes activities such as grading, storage, transportation, pricing, financing, and distribution, linking farmers with consumers efficiently. An effective marketing system helps ensure fair prices for farmers, reduces post-harvest losses, and improves market competitiveness (Acharya & Agarwal, 2011).

Traditional agricultural marketing in India is dominated by multiple intermediaries, leading to high marketing costs, low transparency, and a smaller share of consumer prices reaching farmers (Chand, 2012). Small and marginal farmers often face challenges such as lack of market information, weak bargaining power, and limited market access (Birthal et al., 2015; Asha et al., 2022). In recent years, digital platforms have started transforming agricultural marketing by providing real-time price information, enabling direct farmer-buyer interactions, and reducing transaction costs (Pradeepkumara et al., 2020). Platforms such as National Agriculture Market (e-NAM) and AGMARKNET improve transparency and market efficiency through online trading and information services (Government of India, 2023; DMI, 2022). These digital initiatives reduce dependence on intermediaries, improve farmers' decision-making, and promote a more efficient and inclusive agricultural marketing system (World Bank, 2017).

Role of Digital Platforms in Enhancing Agricultural Marketing Efficiency

1. Market Access: Digital platforms have significantly enhanced market access by connecting farmers directly with buyers, reducing spatial and institutional barriers. Platforms enable participation in broader markets beyond local mandis, thus reducing dependency on intermediaries. Studies show that platform-based systems facilitate multi-sided interactions among farmers, traders, and consumers, enabling inclusive participation in agricultural markets (Marsaoly & Mahmud, 2026). Further, digital integration across regions improves equitable market participation, particularly for smallholders, by lowering entry barriers and transaction costs (Michael & Ogunsola, 2023). Evidence from India highlights that platforms such as e-NAM have expanded farmers' access to national markets and improved spatial market integration (Das et al., 2024). The digital platforms expand geographical reach, reduce market fragmentation, and enhance inclusivity in agricultural marketing systems.

2. Price Discovery: Efficient price discovery is a critical function of agricultural markets, and digital platforms improve this through real-time information dissemination. Agricultural Market Information Systems (AMIS) embedded in digital platforms provide timely data on prices, demand, and supply conditions, reducing information asymmetry (Singh & Dey, 2023). Platforms like e-NAM contribute to transparent price formation, enabling farmers to compare prices across markets and negotiate better deals. Empirical findings suggest improved price realization and stronger price integration across regions after digital platform adoption (Das et al., 2024). Moreover, improved access to reliable price information minimizes transaction uncertainty and curbs opportunistic behavior, thereby fostering more competitive and efficient markets (Singh & Dey, 2023). Overall, digital platforms enhance transparency and improve allocative efficiency through better price discovery mechanisms.

3. Supply Chain Efficiency: Digital platforms improve supply chain efficiency by enabling integration, coordination, and real-time information flow across value chain actors. Technologies such as IoT, blockchain, and AI enhance tracking, traceability, and logistics optimization, thereby minimizing post-harvest losses and improving overall efficiency (Fahmie & Solehan, 2026). Research highlights that digital platforms streamline logistics, optimize resource allocation, and improve coordination among producers, distributors, and retailers, thereby enhancing overall value chain performance (Michael & Ogunsola, 2023). Additionally, digital systems integrate information, financial, and physical flows, leading to faster response times and improved decision-making (MDPI Review, 2024). Thus, the literature demonstrates that digital platforms play a pivotal role in reducing inefficiencies, improving traceability, and enhancing supply chain resilience.

4. Farmer Empowerment: Digital platforms contribute to farmer empowerment by improving access to information, finance, and decision-support tools. Access to market intelligence, advisory support, and weather information empowers farmers to make well-informed decisions regarding production and marketing (Singh & Dey, 2023). Platforms also enhance farmers' bargaining power by reducing dependence on intermediaries and providing direct access to buyers (Marsaoly & Mahmud, 2026). Furthermore, digital ecosystems facilitate financial inclusion, enabling access to credit,

insurance, and digital payments, thereby improving livelihood resilience (Fahmie & Solehan, 2026). However, some studies caution that increasing platform dominance by large agribusiness firms may lead to dependency and unequal power structures (Sauvagerd et al., 2024). Overall, digital platforms are seen as tools for enhancing agency, income potential, and resilience, though outcomes depend on governance structures.

5. Digital Adoption Constraints: Despite their benefits, several constraints limit the adoption of digital platforms in agriculture. Key barriers include digital illiteracy, inadequate infrastructure, and affordability issues, especially in developing countries (Marsaoly & Mahmud, 2026). Institutional barriers including weak regulatory frameworks, fragmented policies, and low levels of trust continue to constrain widespread adoption (Michael & Ogunsola, 2023). In the Indian context, implementation challenges of platforms like e-NAM are often categorized into infrastructure, institutional, and information gaps, which affect their effectiveness (Gupta & Badal, 2020). Additionally, digital inequality and unequal access to technology continue to marginalize smallholders, limiting the inclusiveness of digital transformation (Fahmie & Solehan, 2026). Thus, the literature emphasizes that addressing these constraints is essential for realizing the full potential of digital agricultural platforms. A qualitative synthesis approach was adopted to evaluate the role of digital platforms in improving agricultural marketing efficiency.

Conclusion

Agricultural marketing plays a vital role in improving farmers' income, ensuring price stability, and strengthening rural development. However, traditional marketing systems are often characterized by inefficiencies, information asymmetry, and excessive dependence on intermediaries, which reduce farmers' share in consumer prices. The emergence of digital platforms has significantly transformed agricultural marketing by improving market access, enhancing price discovery, streamlining supply chains, and empowering farmers with timely information and financial inclusion. Despite these advantages, challenges such as digital illiteracy, inadequate infrastructure, and institutional constraints continue to hinder widespread adoption. Addressing these barriers is essential for achieving an efficient, inclusive, and sustainable agricultural marketing system.

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Production of Seedling Rootstocks Through Seeds in Temperate Fruit Crops

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Seedling rootstocks raised from seed remain essential to temperate fruit orcharding, particularly across rugged terrain and elevations where clonal rootstocks are impractical. Despite their importance, low germination, uneven emergence, and high seedling mortality are common and almost always traceable to three avoidable failures: inadequate stratification, retention of locule inhibitors on seed surfaces, and absence of GA3 pre-treatment. This article presents a concise, evidence-based protocol covering seed dormancy biology, extraction and inhibitor removal, cold-moist stratification, nursery bed management, post-emergence care, and tongue grafting and chip budding, drawing on the best available published research.

Keywords: seedling rootstock, seed dormancy, stratification, GA3, tongue grafting, chip budding, temperate fruit crops.

Introduction

Seedling rootstocks produced from seed provide deeper anchorage, greater adaptability to variable soils, and lower establishment costs than clonal alternatives, advantages that are particularly pronounced in areas with calcareous alkaline soils, complex terrain, and irrigation constraints. The entire commercial enterprise of temperate fruit nursery production, especially in apple, pear, and stone fruits, rests on the reliability of seedling rootstock supply. Yet seedling rootstock nurseries routinely deliver disappointing results. In most cases the fault lies not with the seed itself but with three correctable errors: (i) exposing seeds to sub-zero field temperatures and calling it stratification; (ii) failing to remove the potent germination inhibitor present in the fruit locule cavity; and (iii) omitting growth-regulator pre-treatment that can almost double germination percentage and triple seedling survival in difficult conditions. This article addresses all three systematically.

Biology of Seed Dormancy

Seeds of all commercially important temperate fruit crops, apple (*Malus domestica*), pear (*Pyrus* spp.), peach, plum, cherry, and almond, exhibit deep physiological embryonic dormancy. This is a state in which the embryo itself is biochemically inhibited from germinating regardless of external conditions. The inhibitory agent is abscisic acid (ABA), present at high concentrations within the embryo at fruit maturity; gibberellins (GA) and cytokinins, which promote radicle elongation and endosperm mobilisation, are correspondingly suppressed. Only prolonged, continuous exposure to temperatures of 1-7°C in the presence of adequate moisture, the process called after-ripening or cold-moist stratification, progressively shifts this hormonal balance towards germination competence.

A second, separate dormancy factor is the germination inhibitor present in the locule, the seed cavity of the fruit. Research has demonstrated that seeds after-ripened inside the fruit locule fail to germinate even after full stratification, while identical seeds stratified outside the fruit on moist paper germinate at 88-100 per cent. The inhibitor is water-soluble and is metabolised once the seed is separated from the locule; it is renewed as long as the seed remains in contact with locule tissue. This finding has direct practical implications: thorough washing of extracted seeds is not merely hygienic; it is a chemical necessity.

A third critical point is the temperature specificity of stratification. Temperatures at or below 0°C arrest the biochemical cascade of dormancy release; seeds exposed to freezing in open field beds are in frozen quiescence, not after-ripening. Temperatures above 7-10°C during stratification can induce secondary dormancy in partially after-ripened seeds. The practical consequence: a refrigerator at 3-5°C, verified with a thermometer, is not a luxury, it is the minimum requirement for reliable stratification.

Seed Collection, Extraction, and Viability Testing

1. Source Selection and Harvest Timing: Select seed parent trees that are vigorous, disease-free, and adapted to the target elevation and soil type. Harvest fruits at full physiological maturity, when seeds inside are fully brown, plump, and firm. Seeds from prematurely harvested fruits have incompletely developed embryos and give poor germination regardless of subsequent treatment. Fruits for seed extraction may be stored at 2-3°C for up to 4 months; this cold storage partly after-ripens seeds within the fruit, reducing subsequent stratification time required.

2. Extraction and Inhibitor Removal: Extract seeds from fruit within 2-3 days of harvest. Separate from all locule material immediately.

- Soak seeds in clean water for 3-4 days, changing water daily. This step leaches water-soluble locule inhibitors; germination increases in direct proportion to soaking duration.
- Rub seeds thoroughly between palms to remove all remaining pulp. Seeds must be completely pulp-free.
- Rinse under running water for 10 minutes. Surface-dry in shade for 24-36 hours.

3. Viability Testing: Before committing to a 12-15 week stratification cycle, test viability:

- Float test: discard seeds that float (empty or non-viable). Quick bulk screening.
- Cut test: bisect 30 seeds; firm cream-white embryo = viable. Proceed only if viability is 70 per cent or above.
- Tetrazolium (TZ) test: 0.5% TZ solution, 24 h at 25°C; viable tissue stains deep red. Most accurate method.

Cold-Moist Stratification: Methods and Protocols

1. Key Parameters:

Parameter	Recommended Value	Key Basis	Common Error
Temperature	3°C optimum; 1-7°C effective range	Suszk (1989); Górník et al. (2018)	Freezing field temps (< 0°C)
Duration – apple / crabapple	14-15 weeks (Malus sylvestris / M. baccata); 12-13 weeks for cultivar seeds	Suszk (1989)	Too short (< 8 weeks)
Duration – stone fruits	Peach/cherry: 8-16 weeks depending on species	Standard reference	Same as apple
GA3 pre-treatment	500 ppm / 40 h soak before stratification	Wani et al. (2014)	Omitted entirely
Medium	Moist sand : peat 1:1; or moist vermiculite	Suszk (1989)	Unclean, debris-laden media
Monitoring	Weekly: check moisture; remove germinants and decayed seeds; aerate	All sources	No monitoring for weeks

2. Refrigerator Stratification Protocol (Primary Method):

- Wash sand until clear; mix with peat 1:1; moisten until mixture forms a ball but does not drip.
- GA3 pre-soak (strongly recommended): dissolve 500 mg GA3 in 5 ml dilute NaOH, dilute to 1 litre (500 ppm). Soak viability-tested seeds 40 hours at 18-22°C. Rinse once in clean water.
- Mix seeds with medium (1 part seed : 3 parts medium). Fill polythene bags to two-thirds. Close loosely, seeds need gas exchange.
- Label: species, source, date, seed count. Place in refrigerator at 3-5°C. Verify temperature with thermometer at seed level.
- Check every 7 days: restore moisture if dry; remove seeds with radicle ≥3 mm; remove and record decayed seeds; aerate by briefly unpacking, mixing, and repacking.
- When 10-15 per cent of seeds show visible radicle, prepare beds. Allow bags to stand at room temperature for a few hours, separate seeds from medium gently, and sow immediately.

3. Role of GA3 in Improving Germination: GA3 counteracts ABA-mediated dormancy by stimulating hydrolytic enzymes that mobilise endosperm reserves. At 500 ppm/40 h pre-treatment in cold-arid conditions, germination increased from 54% (control) to 87%; seedling survival from 4/10 to 9.7/10; root length from 9.0 cm to 15.0 cm (Wani et al., 2014). In separate studies, stratification medium moistened with GA3 at 250 mg per litre increased germination of 'Ligol' apple by 100% and accelerated it by 5-10 days (Górník et al., 2018). GA3 is the single most cost-effective input available to seedling rootstock nurseries.

4. Field Trench Stratification (For Sites Where Temperatures Stay 1-7°C): Dig a 30 cm deep trench. Layer 2-3 cm clean moist sand; place seeds in a 2 cm layer; cover with 3 cm sand; fill with soil. Protect from rodents. This method is valid only where trench soil temperature remains in the 1-7°C range throughout winter. It must not be used where temperatures drop below 0°C. Direct field sowing in mid-winter at frost-prone elevations is not stratification, it is frozen quiescence and produces near-zero germination.

Nursery Bed Preparation and Sowing

1. Site and Bed Preparation: Choose a full-sun, well-drained site with reliable water. Avoid frost pockets and sites with replant disease history. Raise beds 15-20 cm above ground level (1 m wide × 3-4 m long) for drainage. Dig to 25-30 cm; incorporate well-composted organic matter at 5-8 kg per sq. metre. On calcareous alkaline soils (pH > 7.5), add elemental sulphur at 50-100 g per sq. metre to bring pH towards 6.0-6.5. Apply a preventive fungicide drench (thiram 0.2% or copper oxychloride 0.3%) 7-10 days before sowing.

2. Sowing Specifications: Sow when soil temperature at 5 cm depth reaches 10-15°C. Early spring sowing in the period of large day-night temperature fluctuation (cool nights 5-10°C, warm days 15-20°C) compresses germination from 6 weeks at constant 3°C to just 1-2 weeks, as the natural alternation mimics the optimal 3°C/20°C laboratory regime.

Specification	Value	Reason
Sowing depth	1.0-1.5 cm	Optimal warmth and moisture at radicle
Within-row spacing	7-10 cm	Light, air, and root space per plant
Row spacing	30 cm	Access for weeding, earthing-up, lifting
Working alley	30-40 cm after every 4-5 rows	Management without bed compaction
Mulch cover	2-3 cm straw or organic mulch	Moisture retention and temperature moderation

Post-Emergence Seedling Management

1. Irrigation, Weeding, and Earthing-Up: Apply light irrigation every 2-3 days, never waterlog. Weed as soon as weed seedlings appear; uproot before flowering. Combine weeding with earthing-up (drawing soil gently to plant bases) to stabilise stems and improve root architecture. These three operations done together save labour and time.

2. Hail and Frost Protection: Install anti-hail netting (50% shade, blue or green) before the hail season, at a height that allows management access beneath. Mesh aperture must be smaller than local hailstone size. Against frost: light pre-frost irrigation releases latent heat; polythene tunnels buffer late spring frosts; straw mulch at stem bases before winter prevents frost heaving of roots.

3. Damping-Off Prevention: Damping-off (Pythium, Fusarium, Rhizoctonia) can destroy 20-80 per cent of stands if beds are waterlogged. Apply thiram or captan (0.2%) as preventive spray every 10-14 days for the first 6 weeks. Irrigate in the morning so foliage dries during the day. Remove affected plants immediately; apply metalaxyl + mancozeb drench to affected zones.

4. Nutrient Management:

- Basal: single superphosphate 30-40 g per sq. metre incorporated at bed preparation.
- Nitrogen: urea 2-3 g per sq. metre dissolved in water at 3 and 6 weeks after emergence.
- Micronutrients: zinc sulphate (0.5%) + borax (0.1%) foliar spray at 4 and 8 weeks, critical on alkaline soils.

5. First-Year Growth Targets: End-of-season target: stem diameter 5-8 mm at 5 cm above the root collar; height 20-40 cm; well-developed fibrous root system. Plants meeting these targets are ready for grafting or budding in Year 2. Mulch stem bases before winter.

Grafting, Budding, and Plant Characteristics

1. Tongue Grafting (Primary Method – Year 2, January-February): Tongue (whip-and-tongue) grafting during the dormant season is the standard method for scion propagation onto seedling rootstocks. Match rootstock and scion diameters (7-10 mm). Make a smooth 3-4 cm oblique cut on both pieces, then a second interlocking tongue cut one-third from the top of the first cut. Align cambium layers on at least one side, wrap firmly with transparent polythene grafting tape. Maintain at 18-22°C for 10-14 days for callus formation, then harden progressively. Expected take: 70-85 per cent. One year after grafting the plant is ready for sale – completing the standard two-year nursery cycle.

2. Chip Budding (Salvage Method – May-July): When tongue grafting fails, chip budding during May-July recovers the rootstock plant within the same nursery year, avoiding the loss of the Year 1 investment. Select a plump vegetative bud from current-season scion wood. Remove a matching chip of bark and wood from the rootstock at the graft position. Insert the bud chip, align cambium, bind with polythene tape. Bud take is visible in 3-4 weeks as bud swelling begins.

3. Characteristics of Seedling Rootstock Plants: Vigour and adaptability: deep, extensive root systems; excellent adaptation to variable soils and elevations; long productive orchard life. Best suited to standard-density plantings and sites where clonal rootstock performance is unproven.

- Precocity:** Later bearing than clonal dwarfing rootstocks, typically 6-8 years to full production. Must be factored into orchard investment planning.
- Disease susceptibility:** No specific resistance to crown gall, woolly apple aphid, or Phytophthora root rot. Consistent nursery hygiene is essential.

4. Feathered Plants for High-Density Systems: Standard maiden plants from seedling rootstock nurseries (60-90 cm, 4-6 mm calliper) are unsuitable for vertical planner high-density systems. Feathering with 6-benzyladenine (6-BA) at 600-1000 ppm during the second nursery year, applied in 3-4 weekly sprays when the central shoot has 12-15 cm new growth, produces 6-14 lateral branches, plant height 1.6-1.9 m, and trunk calliper 12-15 mm – meeting high-density planting specifications and delivering marketable fruit in Year 2 of the orchard.

Integrated Protocol Summary

No.	Operation	Key Specifications	Timing
1	Fruit harvest	Full physiological maturity; brown plump seeds; record source and date	Late Sept-Oct
2	Extraction + wash	3-4 days water soak, daily change; rub pulp off; rinse 10 min; shade-dry 24-36 h	Oct
3	Viability test	Float + cut test or TZ test; proceed only if viability $\geq 70\%$	Oct
4	GA3 pre-soak	500 ppm GA3, 40 h at 18-22°C; rinse once after soak	Oct or Jan
5	Stratification	Moist sand:peat 1:1 in polythene bag; 3-5°C; 14-15 wks (crabapple), 12-13 wks (cultivar); weekly check	Oct-Feb/Mar
6	Bed preparation	Raised beds; FYM 5-8 kg/m ² ; pH correction; fungicide drench 7-10 days pre-sowing	Jan-Feb
7	Sowing	Soil 10-15°C; 7-10 cm $\times$ 30 cm; 1.0-1.5 cm deep; 30-40 cm alley per 4-5 rows; straw mulch	Late Feb-Mar
8	Irrigation + weeding	Every 2-3 days; weed + earth-up combined; no waterlogging; morning irrigation only	Mar-Oct
9	Hail/frost protection	Anti-hail net; pre-frost irrigation; polythene tunnel spring; winter stem mulch	As required
10	Disease + nutrition	Thiram 0.2% $\times$ 6 wks; urea at 3 and 6 wks; ZnSO ₄ + borax foliar at 4 and 8 wks	Mar-Sep
11	Tongue grafting	Dormant season; matched diameter 7-10 mm; cambium alignment; polythene tape; callus at 18-22°C	Jan-Feb Yr 2
12	Chip budding	Salvage for failed grafts; bark slipping; matched chip; polythene tape; take in 3-4 weeks	May-Jul Yr 2
13	Plant sale / HDP feathering	Sale 1 yr after grafting; or 6-BA 600-1000 ppm for feathered plant (HDP systems)	Oct-Nov Yr 3

Conclusion

The gap between common nursery practice and achievable results in seedling rootstock production is explained almost entirely by three correctable errors. First, freezing field temperatures do not stratify seeds, only 1-7°C with continuous moisture does, and this requires a functioning refrigerator at 3-5°C verified with a thermometer. Second, seeds must be extracted promptly from fruit and soaked for 3-4 days in water to leach the locule inhibitor that prevents germination even in fully stratified seeds. Third, GA3 at 500 ppm for 40 hours before stratification can nearly double germination percentage and more than double seedling survival, it is the single most impactful and affordable input available.

Apply these three corrections consistently, follow the sowing and nursery care specifications summarised above, and tongue-graft in the second dormant season with chip budding as salvage in May-July. The result is a reliable two-year nursery cycle that delivers high-quality seedling rootstock plants at 70-85 per cent grafting success, the foundation of productive, long-lived temperate fruit orchards.

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Farming Insects & Entomophagy in India

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Introduction

Entomophagy, the practice of consuming insects as food by human beings, has been followed for centuries in many parts of the world. The term is derived from the Greek words “entomon” meaning insect and “phagein” meaning to eat. In recent years, entomophagous insects have gained global attention due to their high nutritional value, environmental sustainability, and potential role in ensuring food security. According to the Food and Agriculture Organization (FAO), more than 2,000 insect species are consumed by people worldwide, especially in Asia, Africa, and Latin America.

The Greeks and Romans both ate insects. Records state that they ate locust and beetle larva. Aristotle wrote they tastes best between molts. (Insects Cambridge World History of Food). As early as 1813, Forbes had mentioned that termites are eaten by local tribes in Mysore and the Karnataka region.

Farming Insects

The consumption of insects as food is an ancient practice that remains widespread in many regions of Asia, Africa, Latin America, and Oceania. However, this tradition has largely disappeared in Western countries, where it is often met with aversion. Nutritionally, insects can contain up to 60-70% protein (dry weight), along with beneficial fats, minerals, and vitamins, making them comparable to commonly consumed protein sources.

Insects in tropical countries are predominantly harvested from nature, although that approach cannot be continued sustainably as the demand for edible insects grows. In Thailand, 20,000 cricket farms produced an average of 7,500 tonnes (16.5 million pounds) of insects per year in 1996-2011 for home consumption and for the market. In the Western world, insects are mainly farmed as pet food. However, some insect-rearing companies in the Netherlands have set up special production lines for human consumption; those insects are sold freeze-dried. A major challenge with such products is to bring down the cost to consumers, which are high because of labour costs.

Insect Species Consumed in India

Northeast India is one of the primary biodiversity hotspots in India, where a huge percentage of its flora and fauna uncharted. It comprises of seven sister states namely Arunachal Pradesh, Assam, Meghalaya, Manipur, Nagaland, Tripura and Sikkim. The Northeast India is native to many traditionally living indigenous tribes and communities who are in continual touch with nature. The use of edible insects a food is common among ethnic people of Northeast India.

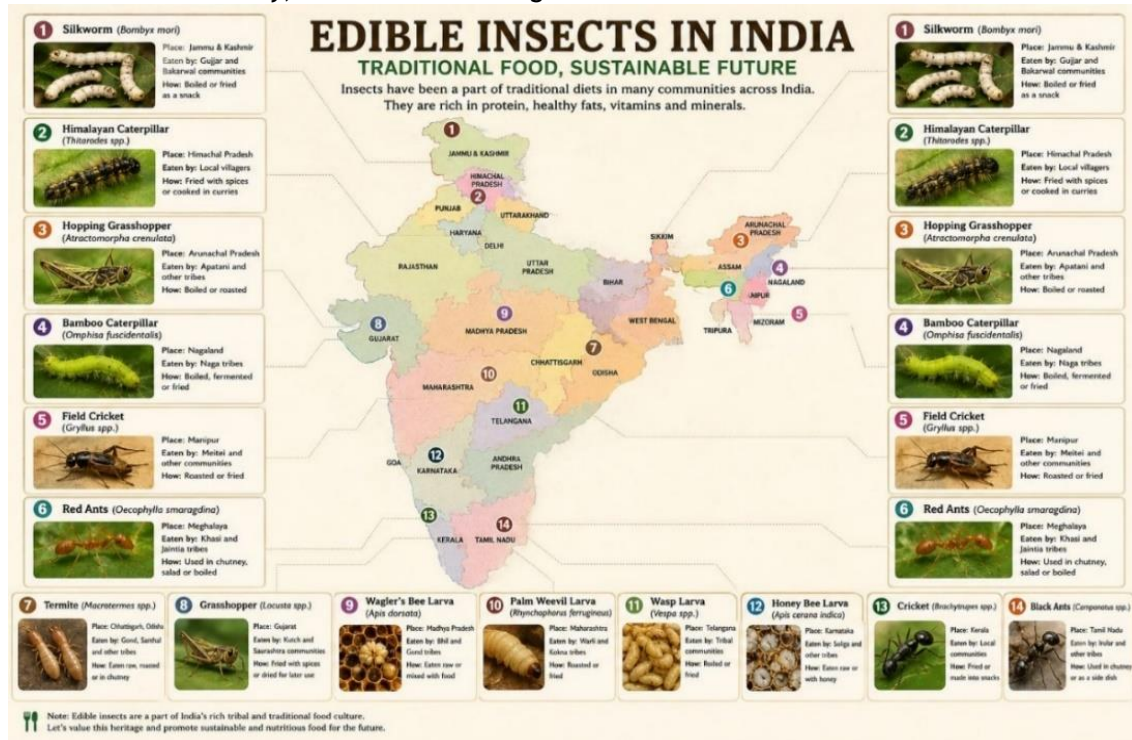
The food processed and prepared traditionally by its people is connected to their socio health. In Northeast India culture life and insects have been using in varied ways such as for edible, medicinal, industrial, cultural purposes. It was observed that various insects used by tribal people as a food it plays a vital role in retaining the nutritive value of food and cause significant impact on health.

A scientific study revealed that about 255 insect species are used as food by different tribes of India. Among the edible species of insects, consumption of coleopteran insects was highest constituting a bout (34%) followed by Orthoptera (24%), Hemiptera (17%), Hymenoptera (10%), Odonata (8%), Lepidoptera (4%), Isoptera (2%) and the least was Ephemeroptera (1%) (Chakravorty al., 2014). Edible insects are chosen by members of various tribes according to their traditional beliefs, taste, regional and seasonal availability of the insects. Depending on the species, only certain, but sometimes all, developmental stages are consumed. Preparation of the edible insects for consumption involves mainly drying, roasting and boiling. Sometimes spices are added to enhance the taste. This review focuses on Entomophagy practiced in different tribes of Northeast India.

Insects in Human Diet

Insects are included in the human diet in most parts of the world, with Europe and parts of North America being two exceptions (FAO, 2013). Edible insects contain high quality protein, fat, vitamins and minerals and are also considered tasty and even delicious by those accustomed to eating them. Insects have a comparatively efficient feed conversion, which in a rearing system limits the amount of land required for feed production. There is also evidence that insects emit the less greenhouse gases and ammonia compared with conventional livestock. Due to these benefits, rearing of

insects has been suggested as a promising alternative to conventional livestock production even in Western societies. For this to be a sustainable industry, much new knowledge is needed.



Insect Recipes in India

Chaprah (Red Weaver Ant Chutney) - Chhattisgarh and Odisha: The Bastar district of Chhattisgarh and the Mayurbhanj district of Odisha, tribal communities harvest red weaver ants and their eggs to make a sharp, citrusy chutney.

Eri Polu (silkworm) - Assam: In Assam and other parts of Northeast India, silkworm pupae are considered a major delicacy.

Fried Grasshoppers & Crickets - Nagaland & Arunachal Pradesh: Grasshoppers, Locusts, and field crickets are highly valued as rich protein source during their seasonal outbreaks.

Honey Bee Brood - Manipur & Assam: The larvae and pupae of honey bees are harvested from natural hives.

Giant Water Bugs - Manipur: In Manipur locally known as jebangkori, this insect is a seasonal delicacy.

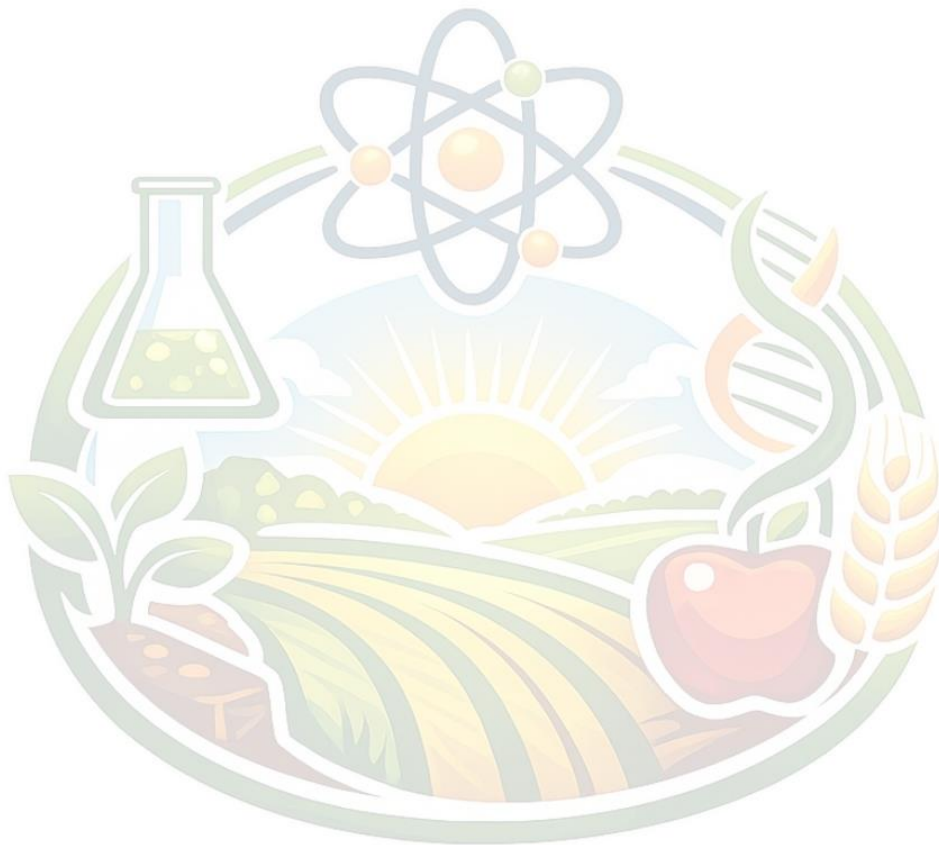


Conclusion

India being tropical country, the diversity and abundance of insects are greater. Therefore, India can be a potential land for insect bio-resource. While many get nervous at the thought of insect-tasting, they are the future of protein and there is a need to develop effective means to glamorize the consumption of these often-undervalued bio-resources. Edible insects can constitute an important part of the diet of Indians and other developing nations and help combat various global issues, predominantly malnutrition and food insecurity.

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Bio-Preservation: A Natural Approach to Extending Shelf Life of Fish

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Abstract

In present, people are more aware and concern about their health, which result in avoiding the use of chemical preservatives in food. As fish is one of the highly perishable food items, it also needs to preserve in such a technique which will keep fish fresh for longer period, less prone to spoilage as well as safe for human consumption. Biopreservation is a technique where non-pathogenic microbes are used as preservatives. Biopreservation is considered as safe because it uses non-pathogenic beneficial microbes which prevent other pathogenic/spoilage microbes to grow and make food safe and healthy for consumers. They mainly include LAB that produce bacteriocins and other metabolites which is antimicrobial peptide and have antimicrobial properties which have potential to prevent spoilage and increase shelf life. This review mainly focusses on the Biopreservation method and its application in fisheries products.

Introduction

Fresh fish spoils very quickly compared to other foods, partly because it travels so far from where it is caught to where we buy it. Additionally, the time between catching the fish and getting it to shore is often significantly longer than the time it spends in the shop, so fishermen are largely responsible for ensuring the fish is as fresh as possible when it reaches to us. When fish is not fresh, it often becomes less valuable in the market. This usually happens because its hygiene might not be maintained as well. Fishermen are particularly concerned about keeping fish fresh right now, because well-preserved products usually command higher prices at the market, which translates to better profits for the fishing industry. It becomes difficult for producers of food and the seller community to keep food safe for human consumption. This problem is more complicated for some products, including fish, which may have microbial contamination that speeds up the flesh's breakdown and reduces its shelf life. As a result of this, the meat's qualities alter, which may lower the product's shelf life or result in customer disapproval. New methods of conservation and preservation must be created in order to reduce these risks. According to Leyva *et al.* (2017), Biopreservation is the process in which we use innate or controlled microbes and their microbicide to improve both the shelf life and microbiological safety of food. It is an environmentally friendly solution to the food preservation issue that is receiving more attention recently.

Biopreservation through lactic acid bacteria (LAB), primarily *Lactobacillus* species, creates bacteriocin compounds, which prevent *Salmonella*, *Escherichia coli*, *Listeria monocytogenes*, and *Staphylococcus aureus* growth and prevent food from getting spoiled. An alternative to synthetic preservatives that are harmful to health is a Biopreservative. Due to their ease of digestion by the human digestive system, bacteriocins received major interest in recent years for their potential application as harmless food preservatives (Mills *et al.*, 2011).

Lactic Acid Bacteria-The genus that comes under LAB are *Lactococcus*, *Streptococcus*, *Lactobacillus*, and *Weissella*. *Carnobacterium*, *Aerococcus*, *Oenococcus*, *Pediococcus*, *Leuconostoc*, *Enterococcus*, *Tetragenococcus*, *Vagococcus* (Adams, 1999) The role play by this microbe is to maintain the nutritional value of the raw material hence extending shelf life and inhibiting bacteria that causes spoilage. Many strains of LAB act as probiotics, which alter the microbiota fauna and they are used to regulate the proliferation of unwanted microorganisms in different food products (Barcenilla *et al.*, 2022).

Natural Antimicrobials for Bio-Preservation

Organism	Antimicrobial agent	Origin	Preservation method
Bacterial cell	Organic acid (carboxylic acid)	The major final output of fermentation	Form a selective barrier over non-acidophiles by reducing the pH of the surrounding Environment By interfering with the membrane potential and breaking the cytoplasmic membrane, lactic acid has an antibacterial effect.
	CO ₂	Heterofermentative LAB release CO ₂ as a byproduct of glucose fermentation.	Releasing carbonic acid and making an anaerobic environment, therefore having

			antagonistic effects only for aerobic bacteria.
	Diacetyl (2,3 butanedione)	Metabolic activity results in LAB production.	Antimicrobial action toward, <i>Aeromonas listeria E. coli</i> .
	Hydrogen peroxide	Oxygen and activity of flavoprotein oxidases or NADH peroxidases by LAB.	Antimicrobial action by increasing membrane Permeability and oxidatively disrupting proteins.
	Reutrine	<i>Lactobacillus reuteri</i>	Antimicrobial action by inhibiting DNA synthesis in bacteria, yeasts, and molds.

Bacteriocin Production by LAB

The majority of LAB strains that produce bacteriocins, which act as antimicrobial proteins that are highly potent against microbes. Bacteria that produce bacteriocins, which are antimicrobial peptides, act on spoilage and disease-causing bacteria. (Vallejo, 2021) Bacteriocins are cytotoxic substances, inactive for eukaryotic cells, which are inactivated by digestive juices (proteases) and have an effect on the intestinal microbes. They have microbicidal and bacterial suppression activity, which generally acts on the cytoplasmic membrane of bacteria. Bacteriocins are mainly classified into 3 class, which include Class I lantibiotics (e.g., nisin), Class II (non-lantibiotic) pediocin-like peptides and Class III Thermolabile and that have important extracellular enzymes which act as bacteriocins. (e.g., Helveticin j) Class I are excellent heat-stable, and low pH, while Class II Have resistant towards *Listeria monocytogenes* in refrigerated storage. (Drider *et al.*, 2006; Silva *et al.*, 2018). Other class VI, include cyclic peptides mainly reuterin 6 and Class V have structured circular peptides which are Enterokine AS-48, Gaseicin A.

Demand and Guidelines for Bacteriocins

Criteria for selecting bacteriocin-producing bacteria are-

1. Generally recognized as safe (GRAS) must.
2. Do not alter quality and taste
3. Heat tolerance
4. High degree of effectiveness and efficacy.

Use of Bacteriocin-Producing Microbes in Fish

The main causative agents of fish spoilage are bacteria which are mostly gram negative in nature. In vacuum-packed fresh and seafood, *Clostridium botulinum* and *Listeria monocytogenes* cause problems. Adding a live bacteriocin-producing culture or a condensed bacteriocin preparation should be an effective method. Nisin and Microgard together lowered the overall oxygen depended bacterial populations in salmon, and enhance its shelf life, and prevent the development *Listeria* species in frozen and thawed salmon. (Zuckerman *et al.*, 2002). The species *Carnobacterium divergens* inhibits the growth of *Listeria monocytogenes*.

The Important Bacteriocins are Used as Biopreservatives in Food

1. **Nisin**- it is important bacteriocin. According to Chatzidaki *et al.*, (2019), nisin-carrying nanoparticles increase the antibacterial activity of *Listeria monocytogenes*, *Bacillus cereus*, *Staphylococcus aureus*, and *Lactococcus lactis* by microemulsion formation.
2. **Pediocins**- This is a protein product which is thermal stable derived from *Pediococcus acidilactici* and *Pediococcus pentosaceus*. This cause pore into membrane and kill the target microbes.
3. **Lacticin** - They are released by some bacteria. They have a wide spectrum of antimicrobial activities against food borne pathogen and many spoilage bacteria.
4. **Reuterin**- This is non proteinaceous low weight compound mainly secreted by *Lactobacillus reuteri*.
5. **Bacteriophages and Endolysins**- A bacteriophage is a virus that causes lysis in bacteria and they also produce protein which increase antimicrobial properties. (Martinez *et al.*, 2019).

Microorganism Responsible for Biopreservation in Fish Products are

Fish product	Microbes (lab)	Kpi (performance indicator)	References
Salmon (cold smoked)	<i>Carnobacteria divergens</i>	Salt- resistant Shelf life +6 days Dissuasion;75%	(Tahiri <i>et al.</i> , 2009)

Peeled, deveined and cooked shrimp	<i>Lactococcus piscium</i>	Refrigeration stable Shelf life+4days Dissuasion;82%	(Fall <i>et al.</i> , 2012)
Pacific oysters	<i>Lactobacillus delbrueckii</i> , <i>Lactobacillus casei</i> , <i>Lactobacillus gasseri</i>	No change in sensory quality. Dissuasion;78%	(Khouadja <i>et al.</i> , 2017)
Filletts (fresh salmon)	<i>Lactobacillus pentosus</i>	Surface adhesion increases Shelf life +5 days. Dissuasion;85%	(Anacarso <i>et al.</i> , 2014)
Salmon (cold smoked and vacuum packed)	<i>Lactobacillus casei</i> , <i>Lactobacillus plantarum</i>	no sensory alteration Shelf life +7days Dissuasion;90%	(Reinemann <i>et al.</i> , 2006)
Sea bass	Mixture of LAB	Effect on mesophilic aerobic bacteria. Coliform yeast molds etc.	(Boulares <i>et al.</i> , 2018)
White leg shrimp	LAB (<i>Pediococcus pentosaceus</i> LJR1)	Have strong inhibition Toward Staphylococcus typhi listeria species	(Ladha <i>et al.</i> , 2020)
Horse mackerel fillet	<i>Lactobacillus sakei</i> , <i>Lactobacillus plantarum</i> .	Reduce, Staphylococcus species count.	(Nath <i>et al.</i> , 2017)
Fish paste	LAB (<i>Enterococcus mundtii</i>)	Show resistivity towards gram positive bacteria Listeria species.	(Delcarlo <i>et al.</i> , 2019)

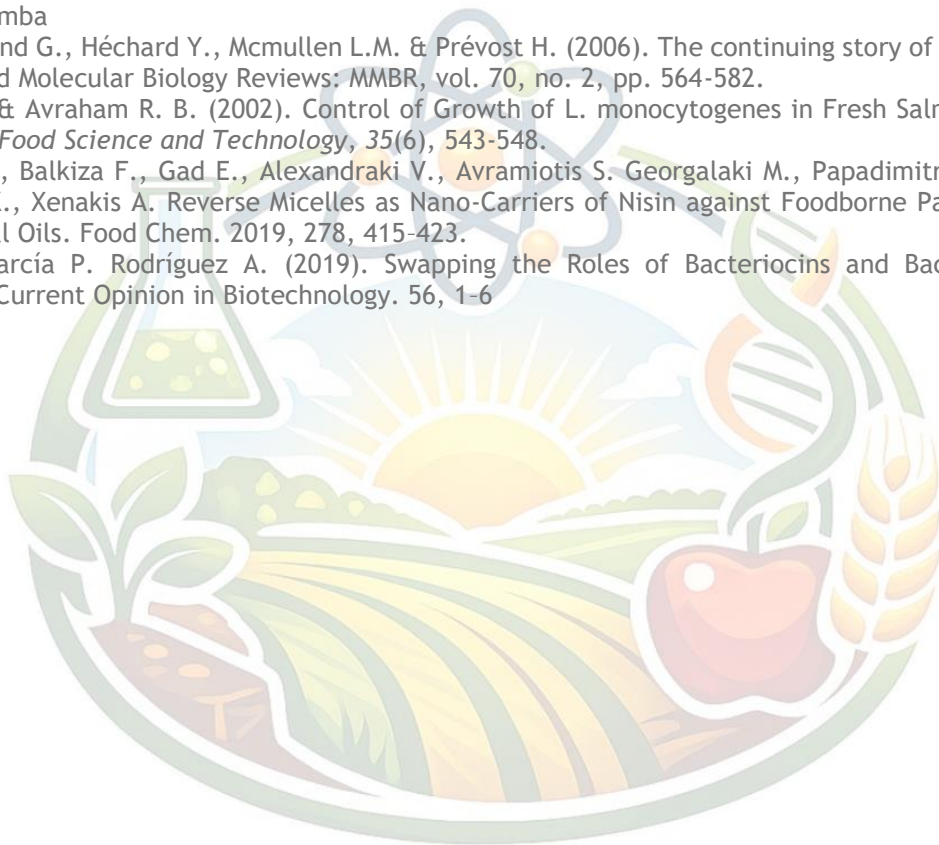
Conclusion

Biopreservation, which uses natural microbes and their metabolites, is a sustainable and efficient way to prolong food's shelf life while preserving its safety and quality. In order to satisfy customer demand for clean-label and minimally processed foods, it helps limit spoilage and harmful bacteria without excessively depending on chemical preservatives. All things considered, Biopreservation presents a viable and environmentally friendly method of enhancing food safety, lowering losses, and assisting contemporary food preservation methods. Exploiting marine LAB's capacity to regulate the security and efficacy of marine goods is the goal of an expanding number of analyses. This technology is unable to replace proper hygiene measures; rather, it must be utilized as an extra barrier to stop the growth of unwanted microbe.

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Bioethanol: A Sustainable Renewable Fuel for the Future

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Introduction

Bioethanol is a renewable, liquid biofuel produced through the biochemical breakdown and microbial fermentation of sugars and starches derived from organic biomass. As global economies actively combat climate change, volatile fossil fuel markets, and greenhouse gas (GHG) emission, bioethanol serves as a mature, immediate replacement for petroleum-derived transportation fuels.

When blended into commercial gasoline (such as E10 or E20), bioethanol adds oxygen to the fuel mixture, promoting complete combustion, reducing tailpipe carbon monoxide emissions, and curtails crude oil import dependency. Major agricultural economies, including the United States, Brazil, and India, have deployed nationwide ethanol blending targets to revitalize rural farming sectors while lowering their national carbon footprints.

Chemical Profile and Basic Synthesis

Chemically, bioethanol is ethyl alcohol, produced by fermenting simple hexose sugars, primarily glucose using specialized yeast or bacterial strains.

Following fermentation, the dilute crude product is systematically concentrated and purified via multi-stage fractional distillation and molecular sieve dehydration to reach fuel-grade anhydrous purity ($\geq 99.5\%$).

Feedstock Classifications by Generation

First-Generation (1G) Bioethanol: Feedstocks: Sucrose-rich crops (sugarcane, sugar beet, sweet sorghum) and starch-dense grains (corn/maize, wheat, cassava).

Status: Mature, highly efficient industrial-scale operation.

Primary Drawback: Ignites a "food versus fuel" dilemma by competing for arable land and freshwater resources.

Second-Generation (2G) Bioethanol:

Feedstocks: Non-edible lignocellulosic residues (agricultural straws, corn stover, sugarcane bagasse, forestry waste).

Status: Scaled commercially; demands rigorous physical, chemical, or biological pretreatment.

Primary Advantage: Promotes a circular bioeconomy by diverting agricultural waste away from open-field burning without compromising food security.

Third-Generation (3G) Bioethanol:

Feedstocks: Autotrophic microalgae and macroalgae cultures.

Status: Scaling phase; currently bottlenecked by high cultivation, harvesting, and dewatering expenses.

Primary Advantage: Offers rapid biomass productivity with minimal land requirements while acting as a direct carbon capture system.

Industrial Production Workflow

Step 1: Feedstock Processing: The collected biomass undergoes mechanical milling, crushing, or grinding to reduce its particle size and maximize the surface area exposed to downstream reactions.

Step 2: Pretreatment (essential for 2G Lignocellulose): Lignocellulosic material contains a dense, protective matrix of lignin, cellulose, and hemicellulose. Pretreatment breaks this matrix apart to expose the carbohydrate polymers. Common industrial methods include:

- Physical: Steam explosion or mechanical milling.
- Chemical: Dilute acid processing, alkaline extraction, or organic solvent treatment.
- Biological: Enzymatic degradation.

Step 3: Enzymatic Hydrolysis (Saccharification): Complex carbohydrate polymers are broken down into fermentable monomeric sugars using tailored enzyme groups:

Enzyme Family	Primary Target Substrate	Specific Catalytic Function
α-Amylase	Gelatinized Starch	Cleaves internal α -1,4-glucosidic bonds during liquefaction
Glucoamylase	Dextrins & Malto-oligosaccharides	Exogenously releases glucose units from non-reducing ends
Cellulases	Crystalline Cellulose Polymers	Synergistically breaks down cellulose fibres into glucose
Xylanases	Hemicellulose Heteropolymers	Hydrolyses the complex xylan backbone into pentose sugars
Pectinase	Structural Pectin Matrices	Breaks down pectin to lower viscosity and improve sugar yields

Step 4: Fermentation: The liberated sugars are mixed with fermenting microorganisms inside anaerobic bioreactors. The yeast *Saccharomyces cerevisiae*, remains the industrial standard due to its high tolerance to ethanol and osmotic pressure.

Step 5: Product Recovery: The finished fermentation mash undergoes fractional distillation to isolate an azeotropic ethanol-water blend (~95%). This mixture is subsequently passed through vapor-phase molecular sieve dehydration beds to remove remaining water molecules, yielding fuel-grade anhydrous bioethanol (>99.5%).

Environmental and Macroeconomic Impacts

Global Carbon Mitigation: Bioethanol significantly lowers net greenhouse gas output. The carbon dioxide emitted during fuel combustion is offset by the carbon captured via photosynthesis during the biomass growth cycle.

Energy Self-Reliance: By substituting imported petroleum with locally manufactured biofuels, countries can reduce their vulnerability to geopolitical energy disruptions and strengthen domestic fuel supply chains.

Multi-Enzyme Cocktail Integration: Modern biorefineries are shifting away from single-enzyme treatments toward tailored multifunctional enzyme cocktails. Combining amylases, cellulases, xylanases, and pectinases allows facilities to extract sugars both from primary starches, but also from the fibrous husks of grains like maize and cassava. This technical refinement dramatically boosts final ethanol yields per ton of raw material.

Future Horizons: The bioethanol sector is working toward fully integrated biorefinery models capable of converting all fractions of biomass into valuable products. Key research areas include engineering multi-stress tolerant yeast strains, developing consolidated bioprocessing (CBP) methods where a single microbe handles both enzyme production and fermentation, and scaling up sustainable 2G lignocellulosic facilities. These advancements will continue to establish bioethanol as a foundation of the global transition to renewable energy.

Moringa: A Climate-Resilient Crop for Sustainable Farming in the North-Eastern Region of India

Article ID: 74090

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Introduction

In the fragile yet fertile landscapes of North-East India, agriculture stands at a crossroads. Erratic rainfall, shifting monsoon patterns, soil erosion in hill slopes, and shrinking landholdings are steadily challenging traditional farming systems. For smallholder farmers who form the backbone of the region's agrarian economy, the need of the hour is not just higher productivity, but resilience. Crops must withstand climate variability, require minimal external inputs, and offer reliable income alongside nutritional security. Under these conditions, *Moringa oleifera*, widely known as drumstick or the "miracle tree," is gaining recognition as a promising solution. Native to the Indian subcontinent and well-adapted to diverse climates, moringa is valued for its remarkable versatility. Its leaves, pods, seeds, and even flowers are edible and nutritionally dense, rich in vitamins, minerals, high-quality protein, and antioxidants. Beyond nutrition, the crop has medicinal, cosmetic, and industrial applications, creating opportunities for value addition and rural entrepreneurship. What makes moringa particularly attractive to North-East India is its adaptability to diverse agro-climatic conditions from the humid Brahmaputra valley to moderately dry upland pockets.



Unlike many horticultural crops that demand intensive care and irrigation, moringa thrives under low-input conditions. It tolerates drought, performs reasonably well in marginal soils, and responds positively to pruning and coppicing, enabling multiple harvests in a year. For smallholder farmers cultivating fragmented plots on hill terraces, such flexibility can translate into year-round green biomass, supplementary income, and improved household nutrition. As climate change continues to influence agricultural productivity across the region, integrating resilient crops like moringa into existing farming systems offers a pathway toward sustainable intensification. Its compatibility with intercropping systems, kitchen gardens, agroforestry models, and organic production practices further enhances its appeal. With growing domestic and global demand for plant-based nutraceuticals and functional foods, moringa also aligns well with emerging market trends.

Moringa (*Moringa oleifera*) is native to tropical and subtropical regions and thrives across a wide range of soils and rainfall patterns. It grows rapidly from seed, can be coppiced to produce regular leaf harvests within months, and tolerates temperatures as high as 40-48°C and a broad rainfall window (roughly 250-1,500 mm annually). These traits make it a particularly flexible match for the variable microclimates of the North-East, where elevation, monsoon patterns and local soil types change from valley to ridge. Moringa is valued not only for its hardiness but also for its ability to integrate seamlessly into diverse farming systems. During the early stages of growth, it can be intercropped with vegetables and pulses, and as the trees mature, they offer shade and protection from strong winds. This multifunctional

role is especially beneficial for smallholder farmers striving to meet household food needs, provide fodder for livestock, and generate additional income from the same land.

Drought Tolerance

Drought tolerance is one of the most valuable attributes of moringa, particularly for resource-poor farmers in drought-prone regions. Its exceptional resilience to water scarcity is the result of several complementary anatomical and physiological adaptations. A deep and extensive taproot system enables the plant to access moisture from deeper soil layers, while its water-efficient leaves help reduce transpiration losses. In addition, the accumulation of antioxidants and osmoprotectants protects cellular structures during periods of water deficit, allowing the plant to maintain essential physiological functions. These adaptive mechanisms enable moringa to survive prolonged dry spells and continue producing harvestable leaves even when many annual crops experience severe yield reductions or complete failure. The drought resilience of moringa has been demonstrated not only under experimental conditions but also through successful field-based cultivation in several water-limited regions of India. Development programmes have promoted the crop as a reliable and low-risk horticultural option because of its consistent performance under moisture-stressed environments.

This resilience is particularly relevant for the North-Eastern region of India, where climate change has increased the frequency of erratic monsoon rainfall and prolonged dry periods. Under such conditions, moringa serves as a dependable climate-resilient crop by providing stable yields even during less favourable growing seasons. Its rapid regrowth following the return of rainfall further enhances its value, ensuring a continuous supply of nutritious leaves for household consumption, livestock fodder, and local markets. By reducing the risk of crop failure and diversifying farm production, moringa contributes to improved food security, livelihood resilience, and sustainable farming systems in the region.

Nutrition, Health and Local Diets

Moringa are widely recognized as one of the most nutrient-rich leafy vegetables, making it an important resource for improving dietary quality and nutritional security. They are rich in provitamin A carotenoids, vitamin C, calcium, iron, essential amino acids, and high-quality protein, often surpassing many commonly consumed leafy vegetables in nutrient density. This exceptional nutritional profile has earned moringa the status of a "superfood" and highlighted its potential in addressing micronutrient deficiencies. In many rural communities, malnutrition is driven not only by inadequate calorie intake but also by a lack of essential vitamins and minerals, a condition often referred to as "hidden hunger." Incorporating fresh or dried moringa leaves into daily diets can significantly enhance the intake of these critical nutrients, particularly among vulnerable groups such as pregnant and lactating women, infants, and school-aged children. Regular consumption of moringa has the potential to improve dietary diversity and contribute to better maternal and child health outcomes.

	Leaves	Leaves powder	Pod	Seed
				
 Moisture (%)	75.6	6.8	88.2	8.7
 Protein (%)	6.7	27.1	2.6	24.8
 Fat (%)	1.2	5.2	0.4	5.6
 Carbohydrate (%)	13.4	46.2	7.6	55.1
 Dietary fiber (%)	2.6	15.6	2.1	6.4
 Ash (%)	0.5	5.3	1.1	3.0
 Calcium (mg/100 g)	440	2,003	66	134
 Iron (mg/100 g)	6.7	28.2	1.5	5.9
 Magnesium (mg/100 g)	70	368	30	138
 Potassium (mg/100 g)	259	1,321	189	648
 Phosphorus (mg/100 g)	110	204	44	410
 Zinc (mg/100 g)	1.1	3.2	0.6	2.4
 Vitamin A (µg/100 g)	6,184	16,290	112	7
 Vitamin C (mg/100 g)	220	17.3	45	2

Figure 1: Nutritional Composition of Moringa leaves, leaves powder, pod and seed

The nutritional value of moringa also provides a strong foundation for its wider adoption through community and institutional programmes. Its inclusion in school nutrition gardens, mid-day meal schemes, Integrated Child Development Services (ICDS), maternal and child health programmes, and community nutrition initiatives can help improve food quality while creating awareness of its health benefits. Beyond household consumption, the promotion of moringa

cultivation can support nutrition-sensitive agriculture by linking agricultural production with improved public health and sustainable rural livelihoods.

Smallholder Economics

Moringa is not only nutritionally valuable but also economically attractive for smallholder farmers because it requires relatively low initial investment and modest production inputs. The crop performs well under low-input conditions, requiring fewer synthetic fertilizers and pesticides than many conventional crops, making it suitable for resource-constrained farming systems. In addition, its ability to produce multiple marketable products throughout the year provides farmers with diverse income opportunities and reduces dependence on a single commodity.

1. **Fresh leaves:** sold to local markets or dried into leaf powder for longer shelf life.
2. **Pods (drumsticks):** a seasonal vegetable with ready local demand.
3. **Seeds:** source of oil (moringa oil has culinary and cosmetic uses) and can be processed for water-clarifying proteins.
4. **Biomass:** used as high-protein fodder or compost feedstock.

Diversifying production across these different products enables farmers to spread market risks and improve the overall profitability of moringa cultivation. Studies on moringa value chains have shown that farmers can substantially increase their returns by integrating primary production with simple value-addition activities, such as drying leaves and producing leaf powder. Community-based processing units equipped with affordable solar dryers and basic packaging facilities can extend product shelf life, improve product quality, and facilitate access to urban retail outlets, institutional buyers, and nutraceutical markets. Such collective approaches also strengthen farmers' bargaining power, reduce post-harvest losses, and create additional employment opportunities, particularly for rural women and youth. Development programmes across India have further demonstrated that these technologies can be successfully implemented at the village level through farmer groups, self-help groups, and producer organizations, thereby enhancing rural livelihoods and supporting sustainable agribusiness development.

On-Farm Practices that Work for Smallholders

To make moringa productive and accessible to smallholders, extension and farmer groups emphasize simple, low-risk practices:

1. **Rapid vegetative propagation** for uniform orchards (stakes or rooted cuttings) and seed propagation for less uniform, lower-cost establishment.
2. **High-density planting and staggered harvesting** so farmers obtain continuous leaf harvests rather than one-off crops.
3. **Intercropping with short-duration crops** during the tree's early life to maximize land use.
4. **Use of solar dryers** or shade-drying racks to convert surplus leaves into powder - a high-value, low-volume product that's easier to store and sell.
5. **Local training on quality standards and packaging**, often organized by producer groups or NGOs, to meet urban market expectations.

These methods keep cash outlays low, reduce labor peaks, and improve reliability - essential attributes for family farms in remote areas.

Barriers and Realistic Cautions

No crop is a universal solution. For moringa to contribute meaningfully to livelihoods, several challenges must be addressed:

1. **Post-harvest handling:** poor drying and packaging cause quality loss and market rejection. Investment in community drying and cleaning facilities is often necessary.
2. **Market linkages:** while local demand for fresh leaves exists, higher-value buyers for dried powder or oil require aggregation, quality assurance and brand development. Value-chain facilitation is where many projects falter.
3. **Policy and extension support:** targeted subsidies, planting material distribution and training significantly increase adoption rates. Successful state pilots (e.g., drumstick promotion in drought-prone mandals) show how coordinated public action can unlock scale.

To scale moringa's benefits sustainably across the North-East, action is needed at three levels:

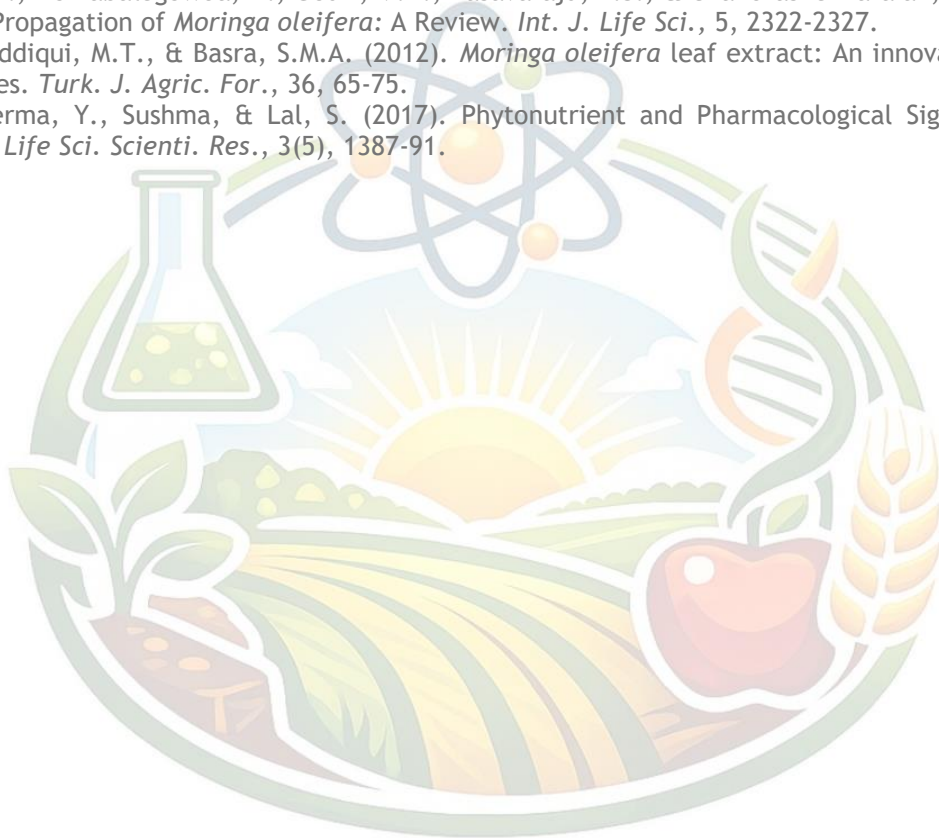
- a. **Seed and sapling systems:** ensure affordable, disease-free planting material via nurseries and farmer-producer organizations.
- b. **Technical extension and training:** focus on post-harvest, quality control, and product diversification (powder, oil, cosmetic ingredients). Partnerships with development agencies can accelerate these efforts.
- c. **Market facilitation and standards:** support producer groups with market intelligence, clustering for logistics, and branding assistance so they can compete beyond local wet markets.

Conclusion

For the smallholders of North-East India, moringa offers more than a cash crop; it's a flexible, nutrient-rich hedge against climate uncertainty and market volatility. With simple agronomic practices, community processing, and smart market linkages, moringa can help families secure food, improve nutrition, and open pathways to income diversification. The technical evidence for its resilience is strong, and pilot programs across India already demonstrate the socioeconomic payoff when farmers and supportive institutions work together. If the region wants climate-resilient, smallholder-friendly options that deliver both nutrition and livelihoods, moringa deserves a front-row seat.

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Persimmon as a High-Value Fruit Crop for North-East India: Opportunities and Future Prospects

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Introduction

The North-East region of India is widely recognised for its rich biodiversity, varied topography, fertile soils, and favourable climatic conditions, making it one of the most promising areas for horticultural development in the country. Comprising the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura, the region possesses agro-climatic zones ranging from tropical plains to temperate hill ecosystems. Such diversity offers tremendous scope for cultivating a wide range of fruit crops. In recent years, crops such as kiwifruit, orange, pineapple, and passion fruit have gained popularity in the region. However, several underutilised fruit crops remain unexplored, among which persimmon is emerging as a highly promising option. Persimmon (*Diospyros kaki*), commonly known as Japanese or Oriental persimmon, is a deciduous fruit tree valued for its attractive fruits, excellent taste, nutritional richness, and adaptability to subtropical and temperate climates. With its favourable climate and rich natural resources, the North-East region is ideally suited for persimmon cultivation, offering a sustainable avenue for enhancing farmers' livelihoods and promoting horticultural entrepreneurship.

Persimmon is native to China and has been cultivated for centuries in Japan, Korea, and other East Asian countries. It is now grown commercially in countries such as Spain, Italy, Brazil, the United States, and Australia. In India, persimmon is cultivated on a limited scale in Himachal Pradesh, Uttarakhand, Jammu and Kashmir, and some parts of the North-East. The fruit is highly favoured for its bright orange-to-reddish skin, sweet flavour, soft texture, and pleasant aroma. Persimmon varieties are broadly classified into astringent and non-astringent types. Astringent varieties contain tannins and need full ripening before consumption, whereas non-astringent varieties can be eaten while still firm. Popular non-astringent cultivars such as Fuyu and Jiro are particularly suitable for fresh fruit markets because of their consumer-friendly taste and storage quality.

Nutrient composition of persimmon fruit

(per 100 g edible portion)

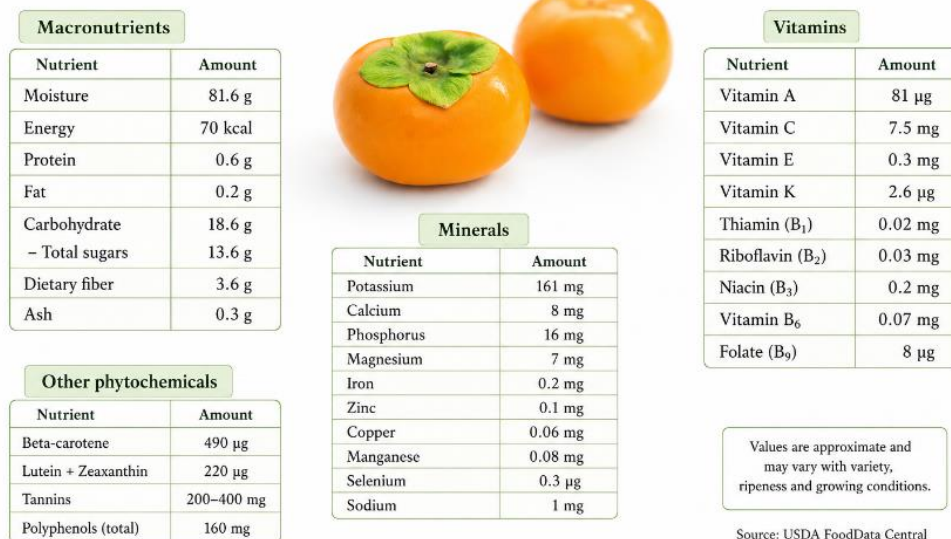


Figure 1: Nutritional composition of Persimmon fruit

The nutritional importance of the persimmon significantly increases its commercial potential. The fruit is rich in vitamins A and C, dietary fibre, potassium, calcium, phosphorus, and natural sugars. It also contains bioactive compounds, including carotenoids, flavonoids, tannins, and polyphenols, which possess antioxidant properties. These nutrients make persimmons beneficial for improving digestion, boosting immunity, promoting cardiovascular health, enhancing skin health, and reducing oxidative stress. As modern consumers increasingly prefer functional foods and health-promoting

fruits, persimmon has strong market prospects in domestic and international markets. Its unique taste and high nutritional value make it attractive to urban consumers, health-conscious households, and premium fruit retailers.

The agro-climatic conditions of North-East India provide an ideal environment for persimmon cultivation. The crop is well adapted to subtropical and temperate climates characterized by cool winters and moderate summers. It performs best in regions receiving 1,000-2,500 mm of annual rainfall, provided the soils are well drained. Persimmon also thrives at elevations between 800 and 2,200 m above mean sea level, making the hill and mid-hill landscapes of the region particularly suitable for its cultivation. Many areas across Arunachal Pradesh, Nagaland, Meghalaya, Sikkim, Mizoram, and Manipur fall within this favourable altitude range, offering considerable scope for expanding commercial production. The fertile, loamy soils rich in organic matter, coupled with the relatively low use of synthetic chemicals in many traditional farming systems, further enhance the region's suitability for high-quality persimmon production.

Among the North-Eastern states, Arunachal Pradesh holds exceptional potential for persimmon cultivation due to its vast mountainous terrain, cool climate, and expanding horticultural sector. Districts such as Tawang, West Kameng, Lower Subansiri, the Siang region, and Dibang Valley offer highly favourable conditions. The successful adoption of kiwifruit in the state demonstrates the capacity of farmers to embrace new high-value fruit crops, and persimmon can similarly be integrated into existing orchard systems. Nagaland also offers promising conditions, especially in districts such as Kohima, Phek, Mokokchung, and Wokha. The regions of Khasi and Jaintia Hills in Meghalaya have a climate conducive to persimmon production. And Sikkim, known for its organic agriculture model, can capitalise on premium organic persimmon markets. The hill areas of Manipur and Mizoram also possess good potential for small-scale cultivation.

The economic prospects of persimmon cultivation in the North-East region are substantial. Since persimmons are still relatively scarce in Indian markets, growers can obtain premium prices due to limited supply and novelty value. Increasing demand for imported and exotic fruits in metropolitan cities creates an opportunity for locally grown persimmons to substitute for imports. Unlike seasonal field crops, persimmon orchards provide a stable and sustained source of income over the long term, making them an attractive option for farmers seeking to diversify and enhance their livelihoods. The region's strategic proximity to neighbouring countries, including Bangladesh, Bhutan, Myanmar, and Nepal, further strengthens its market potential by opening avenues for cross-border trade. With investments in quality planting material, scientific orchard management, grading, packaging, branding, and cold-chain infrastructure, persimmons produced in North-East India can successfully compete in premium domestic markets while also establishing a foothold in export destinations.

Persimmon also offers significant scope for value addition and agro-processing. The fruit can be transformed into a wide range of products, including dried slices, pulp, juice, jam, jelly, wine, candy, vinegar, bakery fillings, and frozen desserts. Such processing not only extends the fruit's shelf life but also minimises post-harvest losses and enhances its market value, thereby creating additional revenue streams for farmers and rural entrepreneurs. Establishment of small-scale processing units in producing areas can generate employment in harvesting, sorting, packaging, transportation, and marketing. Women and youth can especially benefit from cottage-scale enterprises based on persimmon processing.

From a sustainability perspective, persimmon cultivation is well-suited to the ecological conditions of North-East India. Being a perennial tree crop, persimmon helps reduce soil erosion on hill slopes, improves soil structure, and enhances moisture conservation. Its long-lived canopy also contributes to carbon sequestration, supporting efforts to mitigate climate change. Persimmon can be effectively integrated into mixed farming and agroforestry systems alongside crops such as kiwi, citrus, pear, plum, peach, walnut, and various spices, thereby promoting on-farm biodiversity, improving resource-use efficiency, and strengthening the resilience of farming systems. Moreover, its relatively low requirement for chemical inputs makes it highly compatible with environmentally sustainable and organic production practices, aligning well with the growing demand for eco-friendly agriculture.

Despite this considerable potential, certain challenges need to be addressed for the successful expansion of persimmon cultivation in the region, such as limited awareness among farmers regarding improved production technologies, scarcity of quality grafted planting material, inadequate post-harvest infrastructure, weak market linkages, and poor transportation facilities, which hinder efficient marketing and distribution of the fruit. Some astringent varieties may face low consumer acceptance if marketed before attaining proper ripeness. There is also a need for region-specific research to identify suitable cultivars and optimize production practices, including pruning, nutrient management, pest and disease management, and post-harvest storage techniques, to ensure sustainable and profitable cultivation.

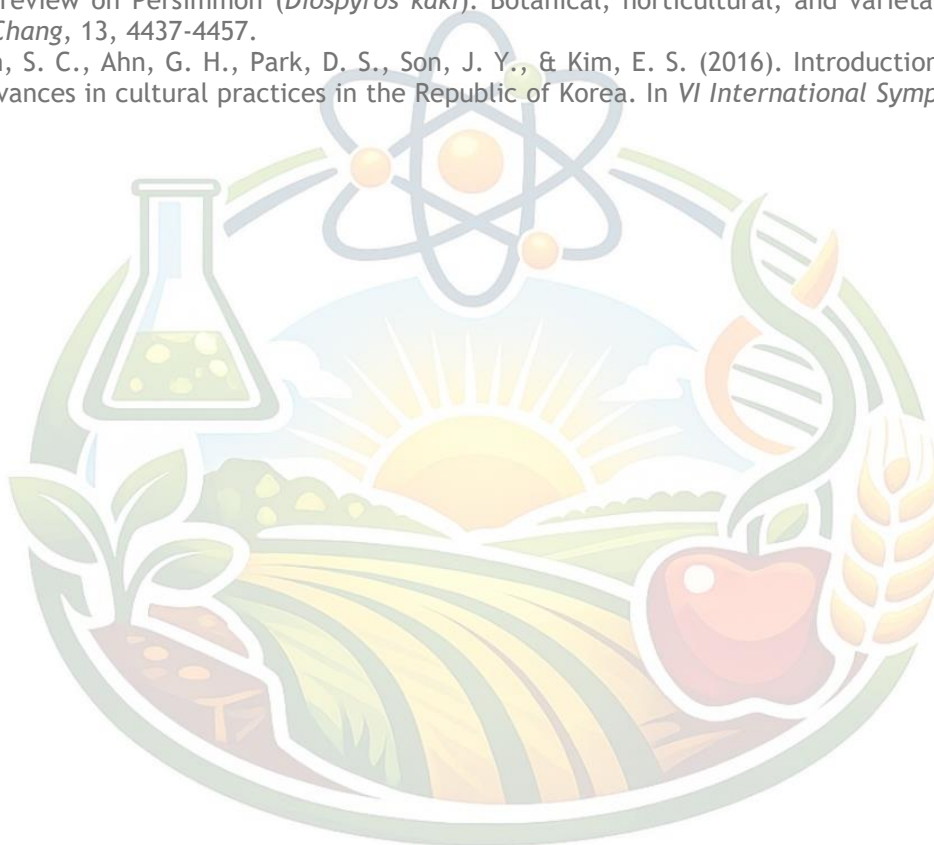
To unlock the full potential of persimmon in North-East India, coordinated efforts from government agencies, research institutions, and private stakeholders are essential. Agricultural universities and ICAR institutes should undertake multilocation trials to identify suitable cultivars and develop production packages for local conditions. The establishment of certified nurseries is essential to ensure a reliable supply of quality grafted planting material. Capacity-building programmes should equip farmers with improved knowledge and skills in orchard management, harvesting, grading, post-harvest handling, and marketing. Simultaneously, investments in cold storage facilities, pack houses, efficient transportation systems, and value chain infrastructure, along with regional branding and market promotion, will strengthen market access, enhance product identity, and enable farmers to obtain premium prices for their produce.

Conclusion

Persimmon cultivation represents a highly promising sustainable horticultural opportunity for the North-East region of India. The region's favourable climate, suitable altitudes, fertile soils, and organic farming traditions provide ideal conditions for its successful cultivation. Persimmon offers multiple benefits in terms of nutrition, farm income, ecological sustainability, employment generation, and export potential. With timely investment in research, planting material, infrastructure, and market development, persimmon can emerge as the next high-value fruit crop of North-East India. For states such as Arunachal Pradesh, Nagaland, Meghalaya, and Sikkim, the crop has the potential to transform hill agriculture and strengthen rural livelihoods in the years ahead.

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Artificial Intelligence in Plant Breeding: A New Era of Crop Improvement

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Summary

AI is redefining plant breeding, replacing traditional and lengthy methods of breeding with much faster data-driven digital plant breeding. Combining genomic selection with high-throughput phenotyping, machine learning, and AI-supported gene editing enables breeders to develop better crop varieties faster that yield more than current crops while bearing less disease burden, tolerating abiotic stressors such as heat or drought, and improving food quality. The ability to predict how plants will perform in different climates can further allow researchers to develop thriving, climate-resilient crops. Despite persisting issues such as difficulties in collecting data, paucity of sufficient computational resources and lack of technical knowhow, digital plant breeding is revolutionizing modern agriculture by enabling high precision, efficiency and sustainability in crop improvement.

Introduction

Digital agriculture is not a notion anymore, but a reality that is changing the way we breed, grow and manage crops. A major part of this revolution is the introduction of artificial intelligence (AI). AI is reinventing plant breeding, transforming a sluggish and laborious process into a vibrant, data-driven discipline. With the worldwide demand for food rising and the effects of climate change becoming increasingly evident, AI-powered plant breeding represents a crucial tool in maintaining the sustainability and resilience of our agricultural systems. (FAO, 2023). This revolutionary technique not only makes breeding easier, but also improves our ability to forecast and address the difficulties of a rapidly changing environment, making AI a key ally in protecting our agricultural future.

From Fields to Algorithms: A New Era Begins

Traditional plant breeding depended on extensive field trials, prolonged observation periods, and the intuition of breeders. Although this method proved effective, it was notably time-intensive. The advent of artificial intelligence has significantly expedited this process.

Machine learning models can analyse thousands of genotypes and environmental scenarios simultaneously, identifying the best breeding candidates in a fraction of the time (Varshney et al., 2021). Instead of waiting for multiple growing seasons, breeders can run simulations, test hypotheses virtually, and predict the outcomes before a seed is even sown. This fusion of biology and computation is the essence of digital plant breeding.

Genomic Selection: Predicting the Future of a Seed

One of the most groundbreaking advancements in AI-driven breeding is genomic selection (GS). Using genome-wide markers, AI models predict the performance of plants for traits such as yield, drought tolerance, disease resistance, and grain quality (Meuwissen et al., 2001). What once took several years can now be done in months.

For example, GS has significantly accelerated breeding cycles in crops like maize, wheat, rice, and chickpea (Crossa et al., 2017). By combining genomic information with machine learning algorithms, breeders can identify superior varieties with unprecedented accuracy.

Phenotyping: Turning Images into Insights

High-throughput phenotyping (HTP) is another revolution. Drones, sensors, and automated imaging platforms capture detailed plant traits – leaf area, canopy temperature, growth rate, and stress responses. AI algorithms then convert these images into meaningful biological data (Fiorani & Schurr, 2013). This enables breeders to evaluate thousands of plants objectively and rapidly, eliminating human error and bias. Many institutes across India, including ICAR, have already integrated AI-based phenotyping platforms into breeding programs for rice, pulses, and millets.

Climate-Smart Breeding With AI

Climate change has increased the frequency of droughts, heatwaves, floods, and pest outbreaks. Breeding climate-resilient crops is now a global priority.

AI models can predict how a variety will perform under different climate scenarios, helping breeders design crops that can withstand extreme environments (Zhao et al., 2021). Combined with environmental datasets, soil information, and weather models, AI offers a comprehensive tool for future-proofing agriculture.

AI + CRISPR: A New Genetic Frontier

AI does not stop at prediction – it is also improving gene editing. Machine learning tools now help identify ideal gene targets for CRISPR edits, increasing the efficiency and precision of genome editing in crops (Crawford & Whitworth, 2021).

This marriage of CRISPR and AI unlocks new possibilities:

- a. Engineering disease-resistant varieties
- b. Enhancing nutrient content
- c. Improving stress tolerance
- d. Shortening breeding cycles for perennial crops

The next decade may see AI-guided genetic improvement as a routine practice in plant breeding labs worldwide.

Challenges Ahead: The Road Is Promising but Complex. Despite its potential, digital plant breeding faces challenges:

- a. Lack of high-quality datasets
- b. Need for interdisciplinary expertise (biology + data science)
- c. Limited access to advanced computing tools for small institutions
- d. Data privacy and intellectual property concerns

However, global research investments and collaborations are rapidly addressing these gaps (OECD, 2022).

The Future: Smart Breeding for a Smarter Planet

People who work in plant breeding are not being replaced by artificial intelligence; rather, they are being empowered by it. The convergence of genetics, computing, and data science is resulting in the development of a new generation of breeding programs that are more efficient, more accurate, and more resistant to the difficulties that society faces on a global scale. The birth of digital plant breeding marks the beginning of a smarter agricultural era, one in which every seed is supported by science, data, and prediction. This transition is being brought about by the ongoing development of artificial intelligence.

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The Power of Omics: Integrating Genomics and Proteomics for Precision Crop Improvement

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Introduction

Global food production faces unprecedented challenges due to rapid population growth, climate change, shrinking arable land, and the emergence of new pests and diseases. Conventional plant breeding has played a significant role in developing improved crop varieties; however, it primarily relies on phenotypic selection, which is time-consuming and often requires multiple generations to improve complex quantitative traits such as yield, drought tolerance, disease resistance, and nutritional quality. Furthermore, the expression of these traits is influenced by complex interactions between genetic makeup and environmental conditions, making phenotypic selection alone insufficient for achieving rapid genetic gain.

Advances in genomic technologies have revolutionized crop improvement by enabling the identification of genes, quantitative trait loci (QTLs), and molecular markers associated with economically important traits. High-throughput sequencing platforms, genome-wide association studies (GWAS), genomic selection (GS), and CRISPR/Cas-mediated genome editing have significantly accelerated the discovery and manipulation of genes controlling desirable agronomic characteristics. Nevertheless, the genome represents only the genetic blueprint of an organism and does not fully explain how genes are translated into functional traits. Gene expression is regulated at multiple levels, including transcription, translation, protein modification, and protein degradation, resulting in substantial differences between gene expression and protein abundance.

Proteomics complements genomics by providing a comprehensive analysis of the proteins that are actively expressed under specific developmental stages or environmental conditions. Modern proteomic techniques enable the identification of protein abundance, post-translational modifications, protein-protein interactions, and signaling pathways that regulate plant growth, development, and stress adaptation. Integrating genomic and proteomic information bridges the gap between genotype and phenotype, providing a systems-level understanding of plant biology. Such multi-omics approaches have become indispensable for precision breeding, enabling the development of climate-resilient, disease-resistant, nutrient-rich, and high-yielding crop varieties capable of ensuring sustainable agricultural productivity and global food security.

Genomic Tools for Crop Improvement

Genomics has revolutionized modern plant breeding by providing a comprehensive understanding of the genetic basis of economically important traits. The development of high-throughput sequencing technologies and advanced molecular breeding approaches has enabled researchers to identify genes, molecular markers, and genomic regions associated with yield, quality, nutritional value, and tolerance to biotic and abiotic stresses. These genomic tools have significantly accelerated breeding programs by increasing selection accuracy and reducing the time required to develop improved crop varieties.

Next-generation sequencing (NGS) technologies, including Illumina, Pacific Biosciences (PacBio), and Oxford Nanopore Technologies, have transformed genome analysis by enabling rapid, high-throughput sequencing of whole genomes, exomes, and transcriptomes (RNA-Seq). Illumina sequencing offers high accuracy and depth for detecting single nucleotide polymorphisms (SNPs) and small insertions or deletions, whereas PacBio and Oxford Nanopore generate long sequencing reads that facilitate genome assembly, structural variant detection, haplotype phasing, and characterization of repetitive genomic regions. These technologies have greatly enhanced gene discovery and comparative genomics, particularly in complex crop genomes.

Genome-wide association studies (GWAS) utilize naturally occurring genetic variation across diverse germplasm collections to identify statistical associations between SNP markers and phenotypic traits. Compared with conventional biparental QTL mapping, GWAS provides higher mapping resolution and enables the discovery of novel alleles controlling complex quantitative traits such as grain yield, drought tolerance, disease resistance, flowering time, and nutrient-use efficiency. The identified genomic regions serve as valuable targets for molecular breeding and functional genomics studies.

Marker-assisted selection (MAS) and genomic selection (GS) have substantially improved breeding efficiency by enabling early and accurate selection of superior genotypes. MAS uses DNA markers closely linked to target genes or QTLs for selecting desirable individuals, while GS employs genome-wide marker information and statistical prediction

models to estimate breeding values for complex polygenic traits. These approaches reduce breeding cycles, increase genetic gain, and improve selection efficiency, especially for traits with low heritability.

The emergence of **CRISPR/Cas9 genome-editing** technology has further transformed precision crop improvement by enabling targeted modification of specific genes without introducing undesirable genetic backgrounds associated with conventional breeding. More recent innovations, including base editing and prime editing, allow precise nucleotide substitutions and small insertions or deletions without generating double-stranded DNA breaks. These technologies have been successfully applied to develop crop varieties with enhanced disease resistance, improved drought and salinity tolerance, increased nutritional quality, herbicide resistance, and higher yield potential. Collectively, modern genomic tools provide the foundation for precision breeding by integrating genetic information with advanced breeding strategies to accelerate the development of climate-resilient and high-performing crop varieties.

Proteomic Tools for Crop Improvement

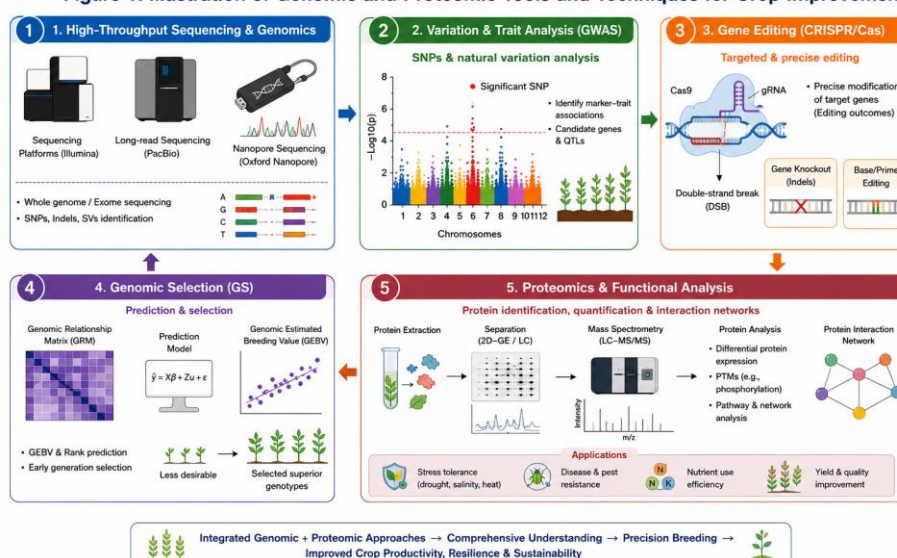
While genomics provides the genetic blueprint of an organism, proteomics offers a functional understanding of how genetic information is translated into proteins that regulate cellular processes. Since proteins are the primary functional molecules responsible for plant growth, development, metabolism, and responses to environmental stimuli, proteomics provides valuable insights into the molecular mechanisms underlying complex agronomic traits. Unlike the relatively static genome, the proteome is highly dynamic and varies according to tissue type, developmental stage, and environmental conditions. Therefore, proteomic analysis complements genomic studies by revealing changes in protein abundance, post-translational modifications (PTMs), and protein-protein interactions that cannot be predicted solely from DNA or RNA sequence information.

High-resolution mass spectrometry (MS) is the cornerstone of modern proteomics and is widely used for large-scale protein identification and quantification. Proteins are enzymatically digested into peptides, ionized using techniques such as electrospray ionization (ESI) or matrix-assisted laser desorption/ionization (MALDI), and analysed based on their mass-to-charge (m/z) ratios. Advanced instruments, including Orbitrap and time-of-flight (TOF) mass spectrometers, provide high sensitivity, mass accuracy, and resolution, enabling the identification of thousands of proteins in a single experiment. Quantitative proteomic approaches such as stable isotope labeling by amino acids in cell culture (SILAC), isobaric tags for relative and absolute quantification (iTRAQ), tandem mass tags (TMT), and label-free quantification facilitate comparative analyses of protein abundance under different physiological or stress conditions.

Two-dimensional gel electrophoresis (2DGE) remains an effective technique for separating complex protein mixtures. In the first dimension, proteins are separated according to their isoelectric point through isoelectric focusing, while in the second dimension they are resolved by molecular weight using SDS-PAGE. This approach enables the visualization of protein isoforms, post-translationally modified proteins, and differentially expressed proteins, which can subsequently be identified using mass spectrometry.

Post-translational modifications, particularly protein phosphorylation, play critical roles in regulating enzyme activity, signal transduction, protein stability, and stress adaptation. Phosphoproteomics combines selective phosphopeptide enrichment methods, such as immobilized metal affinity chromatography (IMAC) or titanium dioxide (TiO_2) chromatography, with high-resolution mass spectrometry to identify phosphorylation sites and characterize phosphorylation-mediated signaling pathways. These analyses provide important insights into regulatory networks involved in drought tolerance, disease resistance, hormone signaling, and other adaptive responses.

Figure 1. Illustration of Genomic and Proteomic Tools and Techniques for Crop Improvement



Understanding how proteins interact within the cell is equally important for deciphering biological processes. Protein-protein interaction (PPI) studies employ techniques such as yeast two-hybrid (Y2H) analysis, co-immunoprecipitation (Co-IP), bimolecular fluorescence complementation (BiFC), and affinity purification coupled with mass spectrometry (AP-MS) to identify interacting protein partners and construct cellular interaction networks. These approaches have been instrumental in identifying key regulatory proteins involved in plant immunity, hormone signaling, developmental processes, and responses to biotic and abiotic stresses. Collectively, modern proteomic technologies provide a comprehensive understanding of protein function and regulation, making them indispensable tools for identifying biomarkers, validating candidate genes, and supporting precision crop improvement through multi-omics integration.

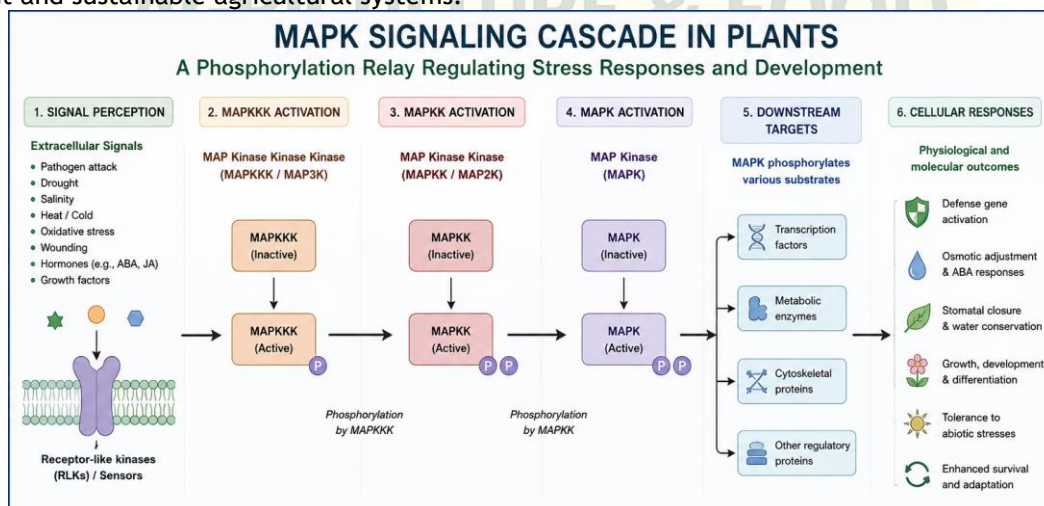
Signal Transduction and Multi-Omics Integration

Plants are continuously exposed to a wide range of biotic and abiotic stresses, including drought, salinity, extreme temperatures, nutrient deficiency, and pathogen infection. To perceive and respond effectively to these environmental cues, plants rely on highly coordinated signal transduction pathways that convert external stimuli into appropriate cellular responses. Among these, reversible **protein phosphorylation** is one of the most important post-translational modifications, regulating protein activity, stability, localization, and interactions. Protein kinases and phosphatases function together to activate or deactivate signaling pathways, enabling plants to rapidly adapt to changing environmental conditions.

One of the best-characterized signaling pathways is the Mitogen-Activated Protein Kinase (MAPK) cascade, which acts as a highly conserved phosphorylation relay system in eukaryotes. The cascade consists of three sequentially activated protein kinases: MAP kinase kinase kinase (MAPKKK or MAP3K), MAP kinase kinase (MAPKK or MAP2K), and MAP kinase (MAPK). Upon perception of external signals such as pathogen attack, drought, salinity, heat stress, or oxidative stress, MAPKKKs become activated and phosphorylate MAPKKs, which subsequently activate MAPKs through dual phosphorylation. Activated MAPKs phosphorylate various downstream substrates, including transcription factors, enzymes, and regulatory proteins, resulting in extensive transcriptional reprogramming and physiological adaptations. These responses include activation of defense-related genes, reactive oxygen species (ROS) detoxification, hormone signaling, cell division, phototropism, and regulation of the circadian clock.

Another major signaling pathway involved in stress adaptation is the abscisic acid (ABA)-mediated SnRK2 signaling pathway, which plays a central role in plant responses to drought and osmotic stress. Under water-deficit conditions, ABA accumulates rapidly and activates SNF1-related protein kinase 2 (SnRK2) family members through interactions with ABA receptors (PYR/PYL/RCAR) and PP2C phosphatases. Activated SnRK2 kinases phosphorylate downstream targets that regulate stomatal closure, osmotic adjustment, antioxidant defense, and stress-responsive gene expression, thereby enhancing drought tolerance and water-use efficiency.

The integration of genomic and proteomic datasets has greatly improved our understanding of these complex signaling networks. Genomic approaches, including genome-wide association studies (GWAS), quantitative trait locus (QTL) mapping, and transcriptome sequencing, identify candidate genes associated with stress-responsive traits, while proteomic and phosphoproteomic analyses validate the corresponding proteins, phosphorylation events, and protein-protein interactions involved in these pathways. Such multi-omics integration enables the identification of key regulatory genes, signaling hubs, and molecular biomarkers that can be exploited through marker-assisted breeding, genomic selection, and CRISPR/Cas-mediated genome editing. These integrated approaches have contributed significantly to improving drought tolerance, disease resistance, nutrient-use efficiency, and yield stability in major crops such as rice, maize, wheat, soybean, tomato, and other economically important species, thereby supporting the development of climate-resilient and sustainable agricultural systems.



Future Perspectives and Conclusion

Future crop improvement will increasingly rely on single-cell omics, artificial intelligence, and machine learning for integrating genomic, transcriptomic, proteomic, and metabolomic datasets. These approaches will improve prediction of complex traits and facilitate precision breeding. By combining the static genomic blueprint with the dynamic proteome, multi-omics technologies provide an integrated understanding of plant biology and accelerate the development of resilient, nutritionally enhanced, and climate-smart crop varieties capable of supporting global food security.

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Date Seed Powder as a Natural Decaffeinated Coffee Alternative for Pregnant Women

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Introduction

For many people, starting the day with a cup of coffee is a cherished routine. While coffee is known for improving alertness and reducing fatigue, these effects come from caffeine, a natural stimulant that should be consumed cautiously during pregnancy. Research has shown that caffeine passes freely through the placenta, yet the developing fetus lacks the enzymes needed to metabolize it efficiently. As pregnancy progresses, the mother's ability to break down caffeine also slows, increasing the duration of fetal exposure.



Excessive caffeine intake has been linked to an increased risk of miscarriage, low birth weight, restricted fetal growth, and preterm birth. As a result, pregnant women are generally advised to limit their daily caffeine intake. However, giving up coffee completely can be difficult, especially for women who enjoy its taste and comforting ritual. This has encouraged researchers and food scientists to search for natural alternatives that mimic coffee without containing caffeine.

Roasted date seed powder has recently attracted attention as one such alternative. The beverage not only resembles coffee in appearance and flavor but also provides valuable nutrients that may contribute to maternal health.

Date Seeds: From Agricultural Waste to Functional Food

Date fruits are cultivated extensively in many regions of the Middle East, North Africa, and parts of Asia. Although the fruit is highly valued for its sweetness and nutritional content, the seeds are often discarded during processing. These seeds account for nearly 10-15% of the fruit's total weight and have long been considered waste.

Recent studies have changed this perception by demonstrating that date seeds contain significant amounts of dietary fiber, healthy fats, proteins, minerals, and natural antioxidants. These findings have encouraged their use in the development of functional foods and beverages. After roasting and grinding, date seeds produce a dark powder that can be brewed much like coffee, offering a pleasant roasted aroma with mild nutty and chocolate-like notes.

Nutritional Value of Date Seed Powder

Date seed powder is rich in several nutrients that make it an attractive functional ingredient. It contains a high concentration of dietary fiber, which supports digestive health and promotes satiety. The seeds also provide moderate amounts of protein and healthy lipids, along with minerals such as potassium, magnesium, calcium, and iron.

Another notable feature of date seed powder is its abundance of polyphenols and other antioxidant compounds. These bioactive substances help protect cells against oxidative stress by neutralizing free radicals. Unlike conventional coffee, date seed powder is naturally free from caffeine, making it suitable for individuals who need or prefer to avoid stimulants.

Why Pregnant Women Need Caffeine-Free Alternatives

Pregnancy brings about several physiological changes that affect the way caffeine is processed in the body. The metabolism of caffeine becomes progressively slower, meaning that both the mother and the fetus remain exposed to it for longer periods. Since the fetal liver is not fully developed, it cannot efficiently eliminate caffeine from the body.

Several studies have suggested that high caffeine intake during pregnancy may increase the risk of adverse outcomes, including miscarriage, low birth weight, and impaired fetal growth. Caffeine may also contribute to maternal symptoms such as anxiety, sleep disturbances, and heart palpitations. Consequently, many international health organizations recommend limiting caffeine intake to no more than 200 mg per day during pregnancy.

Although decaffeinated coffee contains much less caffeine than regular coffee, it is not completely caffeine-free. Therefore, naturally caffeine-free beverages such as roasted date seed coffee represent an appealing alternative.

Health Benefits of Date Seed Coffee During Pregnancy

One of the most important advantages of date seed coffee is that it allows pregnant women to continue enjoying a warm, comforting beverage without consuming caffeine. This simple substitution may help reduce caffeine intake while maintaining familiar dietary habits.

The high antioxidant content of date seeds may also help reduce oxidative stress, which has been associated with several pregnancy-related complications. Additionally, the substantial amount of dietary fiber present in date seed powder can support digestive health and help relieve constipation, a common complaint during pregnancy.

Essential minerals such as potassium and magnesium contribute to normal muscle and nerve function, while calcium and iron support maternal nutrition and fetal development. Because date seed coffee is generally less acidic than conventional coffee, it may also be more comfortable for women experiencing heartburn or gastric irritation during pregnancy.

Preparation of Date Seed Coffee

Producing date seed coffee is a relatively simple process. Fresh date seeds are first separated from the fruit, thoroughly washed, and dried to remove moisture. They are then roasted at high temperatures until they develop a dark brown color and characteristic roasted aroma. During roasting, Maillard reactions generate the compounds responsible for the beverage's coffee-like flavor. Once cooled, the roasted seeds are finely ground into powder. The powder can then be brewed using methods similar to those employed for conventional coffee, including filter brewing, French press, or boiling with hot water. Depending on personal preference, milk, plant-based beverages, or natural sweeteners may be added to improve flavor.



Consumer Acceptance and Future Opportunities

The popularity of plant-based and functional beverages has increased considerably in recent years, creating opportunities for products such as date seed coffee. Consumers are becoming more interested in foods that provide health benefits while supporting environmental sustainability.

Since date seeds are usually discarded during fruit processing, converting them into a valuable beverage contributes to waste reduction and promotes the circular economy.

Despite its promising characteristics, date seed coffee is still relatively new in commercial markets. Further research is needed to optimize processing techniques, improve sensory quality, evaluate long-term safety during pregnancy, and investigate its nutritional benefits through well-designed clinical studies.

Conclusion

Roasted date seed powder represents an innovative and sustainable alternative to conventional coffee, particularly for pregnant women who wish to reduce or eliminate caffeine from their diet. Beyond providing a pleasant coffee-like flavor and aroma, it offers dietary fiber, antioxidants, and essential minerals that may contribute to overall maternal health. Its utilization also supports sustainable food production by transforming an underutilized agricultural by-product into a nutritious functional beverage. Although more clinical evidence is required to confirm all of its health benefits, current research suggests that date seed coffee has considerable potential as a safe, healthy, and environmentally friendly beverage for pregnancy and other caffeine-sensitive populations.

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High Starch Maize Cultivars: An Emerging Crop for Bioethanol Production

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Maize is an important cereal crop used as food, feeds and various industrial uses (Duo et al. 2026). There has been a significant increase in maize production from 2016-17 to 2024-25, that is, the total (*kharif* + *Rabi* + summer) production in 2016-17 was 25.90 million tonnes, which increased in 2024-25 to 43.41 million tonnes (UPAg, 2025). Maize grains, commonly known as kernels, are the edible part of the plant and mainly contains 8.0-11.5 % protein, 68-74 % starch, and 4.0-5.5 % fat (Narpinder Singh et al., 2014), which makes it a good source of nutrition. Apart from human consumption, maize is also used as a feedstock for bioethanol production through hydrolysis and fermentation (Stefan Schwietzke et al., 2009). Maize with high starch content is used for bioethanol production (Stefan Schwietzke et al., 2009). During ethanol production, starch is hydrolysed into glucose, which is subsequently fermented by yeast to produce ethanol (Stefan Schwietzke et al., 2009). Therefore, the starch characteristics of maize kernels play a crucial role in determining their suitability for bioethanol production.

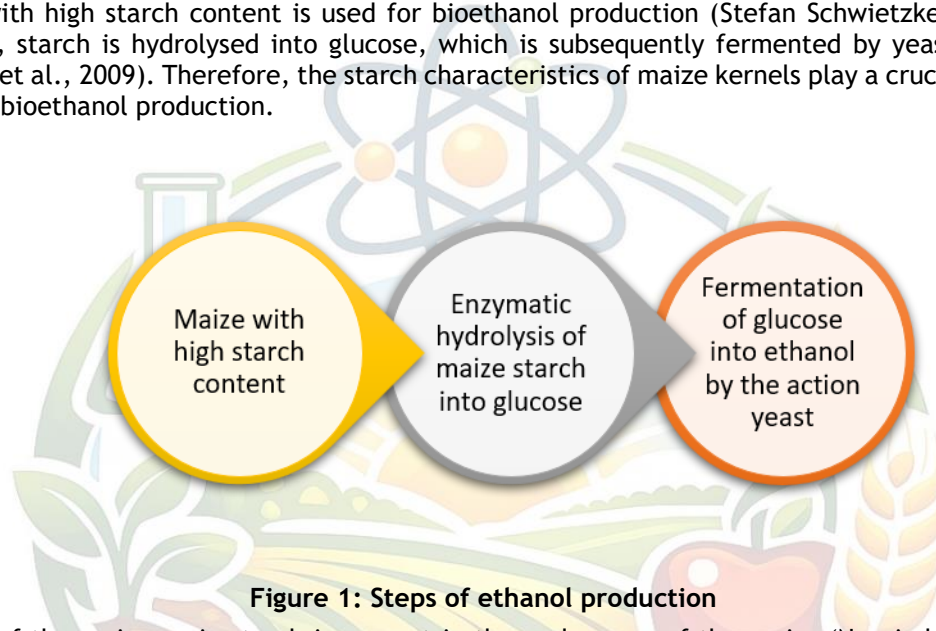


Figure 1: Steps of ethanol production

The major portion of the maize grain starch is present in the endosperm of the grains (Narpinder Singh et al., 2014). Based on starch distribution, maize endosperm can be classified into two types, namely floury endosperm and horny endosperm. The floury endosperm has loosely packed starch granules, while the horny endosperm has tightly packed small starch granules (Narpinder Singh et al., 2014). The size of starch granules also affects the kernel waxiness, viscosity, and physicochemical properties (Na Liu et al., 2018). Normal maize starch contains about 25% amylose and about 75% amylopectin, whereas waxy corn contains about 99% amylopectin and < 1% amylose (Narpinder Singh et al., 2014). Amylopectin is a branched structure with α 1-4 glycosidic linkage and α 1-6 glycosidic branch linkage, while amylose is a linear structure with α 1-4 glycosidic linkage (Cathie Martin et al., 1995). The viscous property of amylopectin makes it suitable for adhesive, paper, and textile industries (Firoz et al., 2022). The starch of waxy maize is more readily hydrolysed than that of normal maize; therefore, waxy maize is considered more suitable for ethanol production (Hanyu Yancheng et al., 2012). Since starch composition is genetically controlled, understanding the genes governing starch biosynthesis is essential for developing maize cultivars with enhanced industrial value. The starch content in the endosperm is mediated by various genes. Mutant (*su1*) and wild (*Su1*) genes give rise to two types of endosperms, i.e., sugary and starchy endosperm, respectively (James W. Cameron, 1947). The sugary endosperm kernels impart a glassy, wrinkled, and translucent phenotypic appearance due to low accumulation of starch, while the starchy endosperm kernels impart a starchy, smooth, and opaque appearance due to high accumulation of starch (James W. Cameron, 1947). Another important gene, waxy1 (*wx1*) regulates starch composition by promoting the accumulation of amylopectin that gives the kernels a dull and waxy appearance (Firoz et al., 2022). Mangelsdorf (1947) reported two genes, dull (*du*) and amylaceous sugary (*su^{am}*), that also affect the carbohydrate properties of maize endosperm (James W. Cameron, 1947). The genes *su1* and *du* interact with each other to increase the amylose content in endosperm to 65% (Cameron, 1947), which is higher than the normal amylose content of 25 %. Vineyard and Bear (1952) reported a mutation called amylose extender (*ae*), which is the first mutation to increase amylose content without reducing the total starch content in the endosperm (Roy g. Creech, 1968). A gene mutation called shrunken1 (*sh1*) was reported by Hutchinson (1921) responsible for a significant reduction in the starch content of endosperm, giving rise to a shrunken or collapsed kernel phenotype (Roy g. Creech, 1968). Among these genes, the waxy1 (*wx1*) gene has received special attention because of its direct influence on amylopectin accumulation.

Collins (1909) discovered the waxy gene (*wx1*) in a maize cultivar introduced from China to the USA, and located it on the short arm of chromosome 9. The wild type (nonwaxy, *Wx1*) gene encodes for starch granule-bound NDP glucose starch glucosyltransferase enzyme (Granule-bound starch synthase1, GBSS1), which is responsible for the synthesis of amylose (Chia-Yin Tsai, 1973). The mutant waxy (*wx1*) gene produces no bound glucosyltransferase enzyme, due to which there is no synthesis of amylose (Chia-Yin Tsai, 1973) in a cultivar with genotype *wx1wx1*, and nearly complete amylopectin is found in its endosperm; therefore, it is called waxy (sticky) maize. It was assumed that amylopectin was produced by converting amylose by the action of Q-enzyme, but it was later found that the recessive *waxy1* (*wx1*) gene produces amylopectin exclusively (Chia-Yin Tsai, 1973). The mutant *wx1* gene codes for the synthesis of amylopectin in both endosperm and pollen tissues, allowing pollen to be used for determining the presence of *wx1* gene in a cultivar, for its utilization in the development of waxy maize hybrids (Zahirul A. Talukder et al., 2022). The unique starch composition of waxy maize influences both its nutritional properties and its industrial applications.

The starch-ethanol conversion efficiency of normal and waxy corn shows significant differences. Normal corn starch undergoes incomplete hydrolysis into glucose units, leading to lower fermentation and ultimately lower ethanol production (Hanyu Yancheng et al., 2012). Waxy corn starch undergoes greater hydrolysis than normal corn, thus producing more glucose units, leading to higher fermentation and higher production of ethanol (Hanyu Yancheng et al., 2012). Under a cold-fermentation process, waxy and normal corn exhibit starch-to-ethanol conversion efficiencies of 93.0% and 88.2%, respectively (Hanyu Yancheng et al., 2012). In normal corn starch, the amylose content has a significant effect on raw-starch hydrolysis and starch ethanol conversion efficiency, whereas in waxy corn, the amylopectin branch-chain length has a significant effect on hydrolysis and starch-ethanol conversion efficiency (Hanyu Yancheng et al., 2012). So, the amylose content in normal corn and the amylopectin branch-chain length in waxy corn can be used to predict the starch-ethanol conversion efficiency. (Hanyu Yancheng et al., 2012).

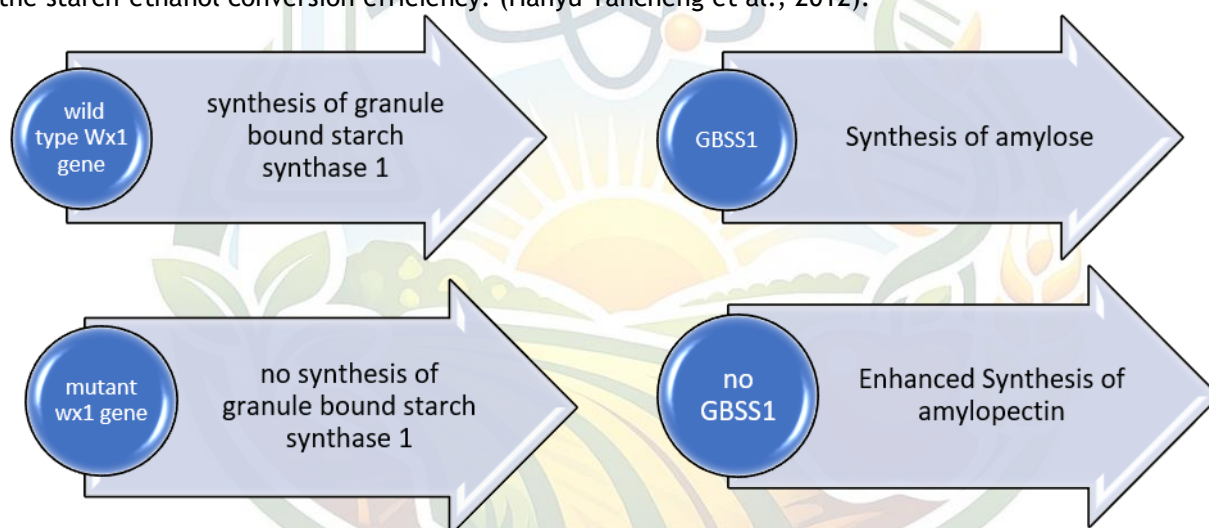


Figure 2: Effects of wild-type and mutant allele of *wx1* gene

Maize is not only an important food and feed crop but also a promising industrial crop for bioethanol production. The starch composition of maize kernels, particularly the proportion of amylopectin and amylose, plays a crucial role in determining ethanol conversion efficiency. The *waxy1* (*wx1*) gene, through its effect on amylopectin accumulation, offers a valuable genetic resource for developing high-starch, high-ethanol-yielding maize cultivars. Therefore, breeding programs focusing on waxy maize and other starch-modifying genes can contribute significantly to sustainable biofuel production in the future.

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Status of Agroforestry in Jharkhand: Current Status, Opportunities and Scope under a Climate Change Perspective using Remote Sensing

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Abstract

Agroforestry - the deliberate integration of trees with crops and livestock on the same unit of land - is increasingly recognised as a nature-based solution reconciling rural livelihoods, land restoration and climate resilience in Jharkhand, a forest-rich, predominantly tribal and rain-fed state in eastern India. This article synthesizes the current extent and spatial distribution of agroforestry in the state, reviews the remote sensing (RS) and geographic information system (GIS) based methodologies used to map and assess its suitability, and examines its role from a climate change adaptation and mitigation perspective.

Keywords: Agroforestry; GIS; climate change; carbon sequestration; trees outside forest.

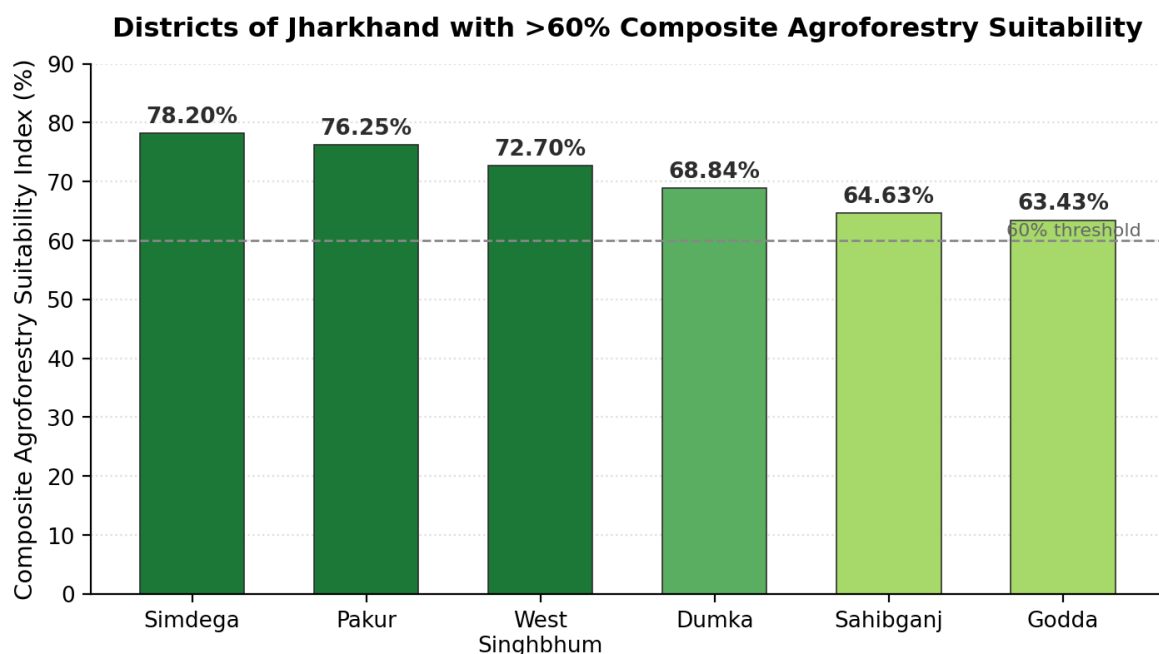
Introduction

Jharkhand, which was carved out of southern Bihar in 2000, is one of India's most forested and tribal-dominated states, with 17 of its 24 districts classified as tribal, and a large share of its population continuing to depend on rainfed, subsistence agriculture (Forest Survey of India [FSI], 2019). According to the India State of Forest Report (ISFR) 2023 (FSI, 2023), the state had a forest cover of 23,765.78 km², or 29.81% of its geographical area. (but conventional rainfed agriculture is hampered by small and fragmented landholdings, declining soil fertility and recurrent rainfall variability (Sarkar et al., 2017; Turkey et al., 2018). Under these conditions, agroforestry, practiced for generations in the form of homestead gardens and farm-boundary trees by tribal communities such as the Santhal, Munda, Oraon and Ho, offers a low-cost means to diversify income, rehabilitate degraded land and cushion climate shocks (Sarkar et al., 2017; Kumari et al., 2018). With the growing recognition of the value of agroforestry as a nature-based climate solution, satellite remote sensing and GIS have become essential tools for mapping the extent, modelling land suitability and monitoring change over time at scales that conventional ground surveys cannot match (FSI, 2020). The present status of agroforestry in Jharkhand, the methodology adopted for its assessment using RS/GIS and the opportunities and scope available in the background of changing regional climate is described in this article.

Current Status of Agroforestry in Jharkhand

1. Traditional Systems and Extent: Agroforestry in Jharkhand is mainly practiced in the form of agrisilviculture and multi-strata home-garden systems. A survey of four panchayats of Namkum block in Ranchi district revealed that the dominant land-use practices were agrisilviculture (37.50%) and pure agriculture (36.87%) followed by agri-horticulture (18.75%) and horti-silviculture (6.87%) (Kumari et al., 2018). Home gardens generally have a canopy of fruit trees like jackfruit, litchi and mango, a sub-canopy of banana, citrus and papaya and a ground layer of vegetables. Farm bunds and boundaries are increasingly being planted with fast growing species like gamhar, bakain, karanj and khair (Sarkar et al., 2017). Agroforestry is rising in importance as a livelihood enhancer. The ISFR 2023 assigns 1,27,590 km² of tree cover and 1,292 million m³ of growing stock to agroforestry at the national level.

2. Spatial Suitability: Evidence from GIS-Based Mapping: A GIS based multi-criteria suitability assessment incorporating climate (temperature, precipitation), topography (slope, elevation), ecology (NDVI, percent tree cover) and socio-economic indicators (poverty rate, tribal dominance) identified six districts- Simdega (78.20%), Pakur (76.25%), West Singhbhum (72.70%), Dumka (68.84%), Sahibganj (64.63%) and Godda (63.43%) - with composite agroforestry suitability greater than 60% (Figure 1). It also identified 513 of the state's 32,620 villages as highly suitable (suitability of 80% or more) (Ahmad et al., 2022). The same study found that nearly 8.58% of Jharkhand's total geographical area, is classified as wasteland with strong potential for agroforestry-based restoration. Climatic suitability alone exceeds 60% across nearly 41% of the state, peaking in Simdega (82.32%) and Pakur (80.31%) (Ahmad et al., 2022).



Data source: Ahmad et al. (2022), *Regional Sustainability* 3(3): 254–268 (GIS-based suitability modelling: climate, topography, NDVI/tree cover, socio-economic indices)

Figure 1. Districts of Jharkhand with composite agroforestry suitability exceeding 60%, derived from GIS multi-criteria modelling of climate, topography, ecology and socio-economic indicators (Ahmad et al., 2022).

Methodology: Remote Sensing and GIS-Based Assessment

Since 2007, the Forest Survey of India, the World Agroforestry Centre (ICRAF), the Central Agroforestry Research Institute (CAFRI) of the Indian Council of Agricultural Research (ICAR) and the National Remote Sensing Centre have collaborated to develop medium- and high-resolution RS techniques to map agroforestry and trees outside forest (TOF) across (FSI, 2020). The generalised workflow followed in recent Jharkhand-focused and comparable Indian studies, consists of four main stages. First, multi-temporal optical satellite imagery (Sentinel-2, Landsat) and gridded climate data (TerraClimate, India Meteorological Department records) are obtained, often using the cloud-based Google Earth Engine platform that allows for planetary-scale geospatial computation without the need for local data storage or processing limitations (Gorelick et al., 2017). Second, ecological suitability proxies are derived as vegetation indices; principally the Normalised Difference Vegetation Index (NDVI) and percent tree-cover layers (Ahmad et al., 2022). Third, topographic layers such as slope and elevation are derived from digital elevation models. Fourth, these climatic, topographic, ecological and socio-economic layers are combined in a GIS environment, typically by means of Analytic Hierarchy Process (AHP) weighting, into a composite suitability index at district and village scale (Ahmad et al., 2022).

Agroforestry Under a Climate Change Perspective

Jharkhand's agriculture is largely rainfed and therefore highly vulnerable to climate variability. A long-term analysis of 71 stations over the state (1984–2014) indicated a general decline in rainfall and increase in summer days and consecutive dry days during the monsoon, in addition to an increasing frequency of heat-wave events, resulting in delays in transplanting and decline in kharif rice yields (Tirkey et al., 2018). In a more recent district-level drought-vulnerability assessment based on a combination of TerraClimate and MODIS NDVI data in an Analytic Hierarchy Process framework, it was found that about 32% of the geographical area of the state is highly to very-highly vulnerable to agricultural drought (Koley & Jeganathan, 2023).

So, agroforestry in this situation is both a strategy for adaptation and mitigation. Tree components buffer microclimate extremes, improve soil-moisture retention and diversify farm income away from single-season rainfed cropping, while also acting as a measurable carbon sink: reported sequestration potential across Indian agroforestry systems ranges from 0.25–76.55 Mg C ha⁻¹ yr⁻¹ in above-ground tree biomass, 0.01–0.60 Mg C ha⁻¹ yr⁻¹ in crop components, and 0.003–3.98 Mg C ha⁻¹ yr⁻¹ in soil carbon, depending on species, system design and site conditions (Panwar et al., 2022). At the Jharkhand scale, converting suitable wasteland to agroforestry has been estimated to sequester around 637 tonnes of additional carbon annually, alongside local economic co-benefits (Ahmad et al., 2022). The Jharkhand State Action Plan on Climate Change clearly recognises tree-based farming as an adaptation strategy for drought-prone, rainfed tracts (Government of Jharkhand, 2014). RS-derived vulnerability layers – rainfall trend, NDVI anomaly, drought frequency – can directly be overlaid on agroforestry suitability maps to prioritise interventions where climate risk and restoration potential coincide.

Opportunities, Goals and Scope

There is room for scaling agroforestry in Jharkhand through several converging policy instruments. The National Agroforestry Policy, 2014 - the first of its kind in the world - relaxed rules on tree felling and transit in farmland, upgraded the earlier National Research Centre for Agroforestry to CAFRI, and a separate Sub-Mission on Agroforestry (2016) offering performance-based subsidies (Government of India, 2014). In the high-suitability districts of Jharkhand, the expansion of agroforestry has been associated with progress on as many as nine of the Sustainable Development Goals including poverty alleviation, food and nutrition security, gender equity, clean water, affordable energy, responsible production, climate action and land restoration (Ahmad et al., 2022).

Agroforestry and other trees-outside-forest resources already meet an estimated 85% of India's industrial wood demand nationally, demonstrating significant economic potential for raw-material self-sufficiency if Jharkhand's suitable wasteland and fallow land are converted to tree-crop systems. Methodologically, there is significant scope to move from periodic, biennial state-level inventory (ISFR) to more frequent, finer-resolution RS-based monitoring - integrating Sentinel-2 time series, object-based classification and machine-learning classifiers - strengthening the evidence base for targeted implementation of the Sub-Mission on Agroforestry and for prioritising the 513 villages already identified as highly suitable (Ahmad et al., 2022; Chaitanya et al., 2024).

Challenges

However, there are real constraints to expansion: residual regulatory friction around tree felling and transit despite policy liberalisation, limited availability of quality planting material, an unorganised market for agroforestry produce, and the lack of a standardised, periodic national system for assessing agroforestry extent - resulting in widely varying area estimates across studies (Government of India, 2014). Cloud cover, mixed pixel effects on fragmented smallholdings, and the spectral similarity between scattered farm trees and surrounding forest patches also continue to limit the accuracy of medium resolution RS-based mapping in heterogeneous tribal landscapes (Kumari et al., 2018; Chaitanya et al., 2024).

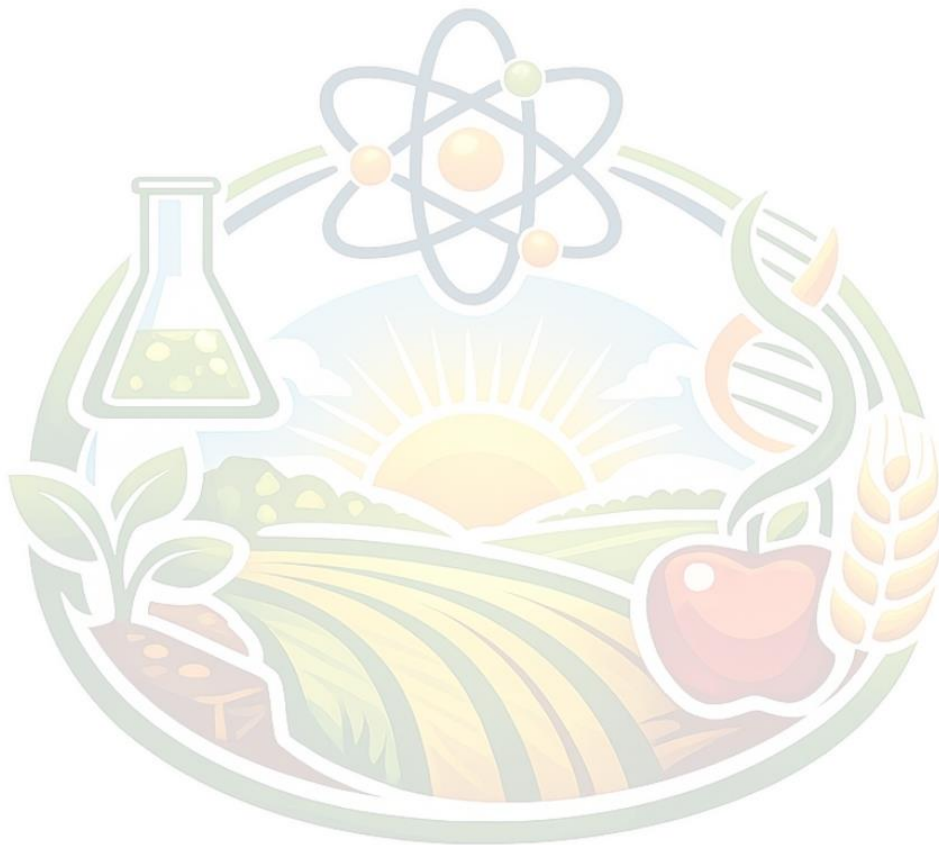
Conclusion

Jharkhand has a strong traditional base of tree-based farming and a considerable, untapped biophysical potential for agroforestry expansion, particularly in its southern and eastern districts. Remote sensing and GIS-based multi-criteria assessment provides a scalable, repeatable way to map this potential and monitor change in the face of declining rainfall reliability and increasing drought risk. A practical pathway to transform Jharkhand's high-potential fallow and wasteland into a climate-resilient, livelihood-generating tree-crop landscape and contribute measurably to India's forestry-sector carbon-sink commitments under its Nationally Determined Contributions is to align policy instruments like the National Agroforestry Policy and the Sub-Mission on Agroforestry with satellite-derived suitability and vulnerability maps.

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Sustainable Solutions for Virus Vector Management Beyond Insecticides

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Abstract

The management of plant viral diseases has historically relied heavily on the prophylactic application of chemical insecticides to control hemipteran vectors. However, accelerating insecticide resistance, severe off-target ecological impacts, and the paradoxical increase in viral transmission rates under sub-lethal chemical stress necessitate a critical paradigm shift. This article synthesizes recent advancements in non-chemical, sustainable strategies for uncoupling the plant-vector-virus transmission cycle. We evaluate the integration of cutting-edge molecular tools specifically topical RNA interference (RNAi) targeting essential vector feeding genes with advanced biological control frameworks utilizing entomopathogenic fungi and highly specific parasitoids. Furthermore, we explore the applied chemical ecology of volatile organic compounds (VOCs) to disrupt host-finding behaviours and pull vector populations toward strategically deployed trap crops. By transitioning from eradication-focused chemical models to holistic Integrated Pest and Disease Management (IPDM) frameworks, these diverse strategies offer robust, environmentally sound solutions for ensuring global food security and sustainable horticulture production in a post-insecticide era.

Keywords: Integrated pest management, RNA interference, biological control, vector competence, virus-vector management.

Introduction

The intensification of global agriculture has historically relied on the heavy application of synthetic insecticides to manage insect vectors and the debilitating plant viruses they transmit. However, the ecological and economic costs of this traditional reliance are becoming unsustainable. Prolonged chemical control has driven the rapid evolution of insecticide resistance in primary vector species, decimated non-target beneficial insect populations, and led to the accumulation of toxic residues in agricultural soils and water systems (Wamonje *et al.*, 2020). Beyond these environmental externalities, the economic burden on farmers is compounding, as the efficacy of available chemical interventions continues to wane.

Vector-borne plant viruses remain among the most difficult crop diseases to manage because control depends not only on suppressing the pathogen but also on interrupting acquisition and inoculation by highly mobile insect vectors such as aphids, whiteflies, leafhoppers, planthoppers, and thrips (Kanakala & Ghanim, 2016; Chandi, 2020). Heavy reliance on conventional insecticides has imposed ecological and economic costs, including repeated spray expenses, selection for resistance, disruption of natural enemies, and limited protection against viruses transmitted during very brief feeding probes (Hooks & Fereres, 2006).

The mode of virus transmission explains much of this failure. Crucially, from a virological perspective, chemical control is fundamentally mismatched with the mechanics of certain viral transmission pathways. Plant viruses are generally categorized by their transmission mechanics: persistent (circulative or propagative, taking hours to days to be acquired and transmitted) and non-persistent (stylet-borne, acquired and transmitted in a matter of seconds to minutes) (Chandi, 2020).

Non-persistent viruses are typically acquired and inoculated during brief epidermal or mesophyll probes and are retained only transiently on vector mouthparts, which means vectors can infect plants before lethal insecticide exposure occurs (Ng & Falk, 2006). By contrast, persistent and circulative relationships involve longer acquisition and latent periods, often with virus movement through the insect body, creating more opportunity for vector suppression to reduce secondary spread, though not necessarily primary infection from immigrating viruliferous insects (Kanakala & Ghanim, 2016). Semi-persistent transmission occupies an intermediate position, with virus retention associated with foregut structures and inoculation mechanisms that remain incompletely resolved (Catto *et al.*, 2022; J. C. Ng & Zhou, 2015).

These biological realities shift management away from a purely toxicological model toward integrated pest and disease management (IPDM), where success depends on reducing vector pressure, altering vector behavior, protecting crop susceptibility windows, and lowering vector competence rather than expecting insecticides alone to stop rapid inoculation (Hooks & Fereres, 2006).

Next-Generation Biological Control Agents

As the limitations of synthetic chemistries become apparent, next-generation Biological Control Agents (BCAs) offer a sustainable alternative, capitalizing on complex trophic interactions to suppress vector populations.

Entomopathogenic fungi (EPF), such as *Beauveria bassiana* and *Metarhizium anisopliae*, represent a powerful tool for vector suppression (Liu *et al.*, 2023). These fungi operate through contact pathogenesis, where conidia adhere to the insect cuticle, germinate, and penetrate the hemocoel using a combination of mechanical pressure and cuticle-degrading enzymes (Zhang *et al.*, 2010). Unlike chemical insecticides, which require ingestion or target specific neural receptors prone to mutation, entomopathogenic fungi present a multifaceted mode of action that significantly reduces the likelihood of resistance. Advanced formulations, including oil-based dispersions and UV-protectant adjuvants, are expanding the environmental persistence of these fungi, making them viable for both controlled greenhouse environments and open-field horticulture.



Figure: Parasitized Aphid Mummies. Source: Koppert

Parasitoid wasps are highly specialized BCAs that offer precise, host-specific vector management. Species such as *Aphidius colemani* and *Encarsia formosa* are highly effective against aphid and whitefly populations, respectively (Prado *et al.*, 2015). Female parasitoids oviposit directly into the host nymph; the developing larva consumes the vector from the inside, eventually leaving behind a mummified husk. These wasps are highly compatible with horticultural systems, particularly in greenhouses where populations can be introduced and maintained through banker plant systems (Payton Miller & Rebek, 2018). Because parasitoids actively forage for hosts, they provide a continuous, self-replicating pressure on vector populations that chemical applications cannot replicate.

The major operational lesson is compatibility. EPF and parasitoids perform best when embedded in programs that minimize harmful residues, use economic thresholds for persistent-virus vectors, and emphasize conservation biological control alongside inoculative releases where appropriate (Chandi, 2020).

Genetic and Molecular Interventions

The frontier of vector management lies in precision molecular biology, targeting the genetic machinery of the vectors and their competence to transmit viruses.

RNA interference (RNAi) has emerged as one of the most targeted molecular tools for vector management because carefully designed double-stranded RNA can silence essential genes with sequence-specific precision (Ricci *et al.*, 2021). For virus-vector systems, the most attractive targets include genes associated with stylet function, salivary secretions, gut uptake, cuticle-associated retention sites, neural regulation of probing, and pathways tied to survival or fecundity (Choudry *et al.*, 2024).

RNAi is emerging as a revolutionary, highly targeted biopesticide (Zhang *et al.*, 2022). By utilizing double-stranded RNA (dsRNA) engineered to match specific essential genes in the insect vector, RNAi triggers the degradation of the corresponding messenger RNA (mRNA), silencing gene expression and causing mortality or functional impairment. Two primary delivery methods are currently under development. Host-Induced Gene Silencing (HIGS) involves creating transgenic crop lines that express the dsRNA, effectively turning the plant itself into a targeted control agent (Zhang *et al.*, 2022). Alternatively, Spray-Induced Gene Silencing (SIGS) offers a non-transgenic approach where synthetic dsRNA is applied topically to the crop (Chen *et al.*, 2025). A particularly promising application of RNAi in virology involves targeting the vector's stylet mechanics, gut receptors, or salivary gland proteins, explicitly disabling the cytological and molecular pathways required for viral acquisition and inoculation.

A related frontier involves insect-specific viruses (ISVs), which are viruses restricted to insects and unable to replicate in vertebrates (Bolling *et al.*, 2015). Most evidence currently comes from mosquito systems, where ISVs can alter replication of co-infecting pathogens and modify vector competence, making them attractive conceptual analogues for future agricultural biocontrol in pest insects (Öhlund *et al.*, 2019). For crop protection, the translational opportunity lies in discovering or engineering insect-restricted viral symbionts that reduce vector competence or impose fitness costs on

agricultural pests without harming pollinators, parasitoids, or vertebrates; however, field-ready examples in major horticultural vectors remain limited (Carvalho & Long, 2021).

Chemical Ecology and Behavioural Manipulation

Manipulating the chemical dialogue between plants and insects provides a non-toxic method to protect cash crops through spatial and behavioural control.

1. Push-Pull Strategies The "Push-Pull" strategy is a cornerstone of applied chemical ecology (Cook *et al.*, 2007). This framework utilizes repellent Volatile Organic Compounds (VOCs)—the "push"—emitted by intercropped or border plants to drive vectors away from the primary cash crop. Simultaneously, highly attractive trap crops—the "pull"—are planted on the perimeter to isolate and concentrate the vectors, where they can be eliminated using localized BCA releases or highly targeted biological sprays. In horticulture, tailoring these plant combinations to specific vector species can drastically reduce viral inoculation rates.

2. Disrupting Viral Manipulation of Plant Scents Recent advances in plant virology have revealed that many plant viruses actively alter their host's volatile profile to enhance their own transmission. For instance, plants infected with the Cucumber mosaic virus (CMV) often emit unique volatile blends that deceive aphids, drawing them to diseased plants (Mauck *et al.*, 2010). Once the aphid feeds and acquires the virus, the poor nutritional quality of the infected plant triggers the aphid to disperse, carrying the non-persistent virus to healthy plants. Understanding these complex semiochemical interactions opens the door to disrupting this viral manipulation. By deploying synthetic volatile dispensers that mask attractive scents or utilizing elicitors to prime plant defenses before viral infection occurs, growers can sever the chemical cues that facilitate the vector-pathogen relationship.

Synthesizing the IPDM Framework

The efficacy of modern horticulture relies on moving away from single-tactic solutions and toward a synthesized, multilayered IPDM framework. Developing practical, field-ready protocols requires integrating molecular, biological, and ecological strategies. For example, a commercial greenhouse protocol might combine the genetic resistance of HIGS-enabled crops with the ecological foundation of a push-pull border system. Within this environment, prophylactic releases of parasitoid wasps can maintain a low baseline vector population, while SIGS or entomopathogenic fungi are held in reserve for targeted application during sudden pest spikes. This layered approach ensures that if a vector bypasses the chemical ecology deterrents, its transmission competence is compromised by molecular interventions, and its reproductive potential is suppressed by BCAs.

Conclusion & Future Perspectives

The shift away from total reliance on synthetic chemical control is not merely an environmental preference but a biological necessity for sustainable horticulture. By integrating biological control agents, RNAi technologies, and chemical ecology, we can achieve durable suppression of both vectors and the plant viruses they carry.

However, realizing this future requires navigating significant hurdles. The regulatory landscape for novel molecular tools, particularly RNAi and SIGS, remains fragmented. Policymakers must establish clear, science-based frameworks that evaluate the unprecedented target specificity of these biopesticides compared to legacy chemicals. Furthermore, as climate change alters the geographic distribution and phenology of both insect vectors and plant viruses, our IPDM frameworks must remain dynamic. Future research must prioritize the development of climate-resilient management strategies, ensuring that molecular and biological tools maintain their efficacy under increasing abiotic stress, ultimately safeguarding global horticultural production for the decades to come.

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Mulching Organic Matter Protects Soil Organic Carbon Accumulation

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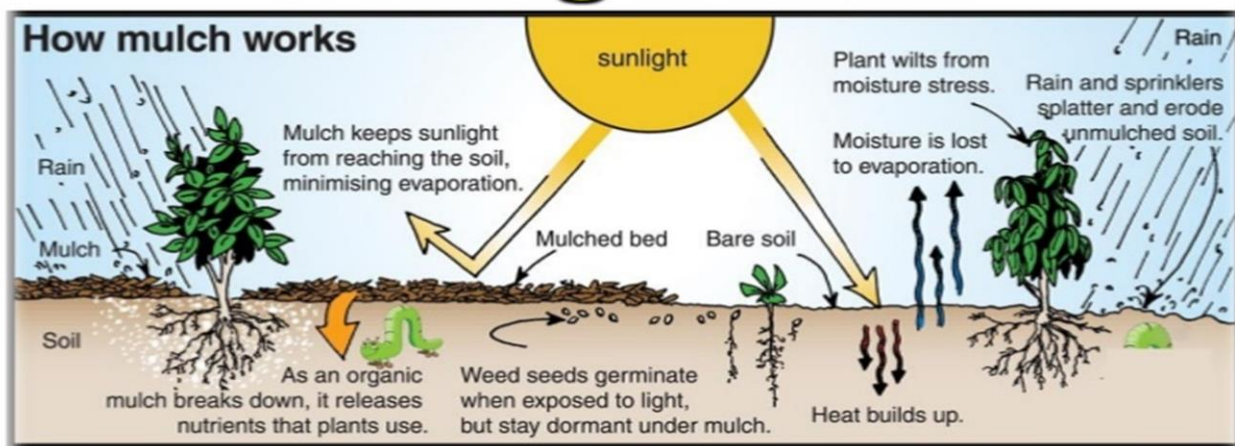
Mulching can indeed protect soil organic carbon accumulation when applied correctly. Soil organic carbon is an essential component of healthy soil, as it improves soil structure, fertility, and overall soil health. Here's how mulching can contribute to soil organic matter accumulation:

The rhizosphere is a special ecological interface that connects root systems and soil and is strongly influenced by the plant root system and microbial activity. Nutrient cycling and energy conversion are more rapid in the rhizosphere than in bulk soil. The physical, chemical, and biological properties of the rhizosphere and bulk soil differ after nutrient. As an important site for plant-soil microorganism interactions, the combination of the rhizosphere and the bulk soil environments may provide an important window in understanding the mechanism of soil-plant interactions. Accordingly, we tested changes in the soil organic matter fractions in the rhizosphere and bulk soil after four organic matter treatments over a period of 1 year. We measured the carbon content in the plant fine roots, leaves, and organic mulch, as well as several soil physico-chemical properties, to analyse the relationships between soil organic matter fractions and the measured variables.

1. Organic matter would significantly affect soil organic matter fractions and that dissolved organic matter would be the most variable carbon fraction.

2. With the decomposition of the organic mulch, the carbon input through the production and turnover of fine roots should increase because of improvements in the soil properties and plant growth, which will then increase rhizosphere deposition and protect soil organic matter storage.

Working of Mulch



1. Organic Matter Input: Organic Matter Input: Mulch is typically made from organic materials such as leaves, straw, wood chips, or compost. When mulch is applied to the soil surface, it provides a continuous source of organic matter. As this organic matter breaks down over time, it contributes to SOC accumulation. Soil microorganisms decompose the mulch material, converting it into stable forms of carbon that become part of the soil's organic carbon pool.

2. Reduced Erosion: Mulch helps protect the soil surface from erosion caused by wind and water. Erosion can lead to the loss of topsoil, which contains significant amounts of organic carbon. By preventing erosion, mulch helps retain the soil and the organic carbon it contains.

3. Temperature and Moisture Regulation: Mulch helps regulate soil temperature by insulating it from extreme temperature fluctuations. This moderates the microbial activity in the soil, reducing the rate at which organic matter decomposes. Additionally, mulch retains moisture in the soil, which creates favorable conditions for soil organisms responsible for decomposing organic matter. Slower decomposition rates lead to increased SOC.

4. Microbial Activity: Mulch provides a habitat for soil microorganisms. These microorganisms play a crucial role in breaking down organic matter and converting it into stable organic carbon forms. A healthy microbial community in mulched soils can enhance SOC accumulation.

5. Weed Suppression: Many mulches also help suppress weed growth. By reducing competition from weeds, plants in the mulched area can grow more vigorously and produce more organic matter through root exudates and plant residues, which contribute to SOC accumulation.

Studies have shown that mulching can change the soil hydrothermal environment in farmland but it also significantly increases the carbon emissions due to soil respiration. Due to the possible increases in crop yields and the carbon turnover rate, studies have considered the sustainability of farmland ecosystems under long-term coverage. Soil organic carbon (SOC) is a core indicator that reflects the quality and sustainability of cultivated land, and it can significantly affect the productivity of crops. Previous studies have obtained inconsistent results regarding the effects of plastic film mulching measures on SOC storage because of differences in the climate conditions, soil types, and initial organic carbon contents. In addition, SOC has a long turnover time as a “slow variable”, so it is very difficult to systematically study the effects of different mulching measures on SOC based on limited point testing experiments in the field. Therefore, it is necessary to model the response of the SOC storage to cover in the context of climate change. The De Nitrification-DeComposition (DNDC) model based on carbon and nitrogen cycling in agro-ecosystems has advantages for simulating SOC and it has been verified in many studies (Zhang *et al.*, 2018). In the last 30 years, various studies have simulated the effects of farmland cover measures on the SOC contents and crop yields. These simulations often considered a single mulching method (Zhang *et al.*, 2018) and they did not aim to predict future trends thereby preventing comparisons of the changes in maize yields and SOC storage under different mulching practices in future scenarios.

Conclusion

Mulching is an effective agricultural and gardening practice that can promote soil organic carbon (SOC) accumulation. By providing a continuous source of organic matter, reducing erosion, regulating temperature and moisture, fostering microbial activity, and suppressing weeds, mulching contributes to the enhancement of soil health and the buildup of SOC. However, the effectiveness of mulching may vary depending on various factors, and it should be applied carefully and in accordance with specific site conditions to maximize its benefits for SOC accumulation and overall soil fertility.

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Organic Farming: New Way of Agriculture

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Organic farming is the form of agriculture that relies on crop rotation, green manure, compost, biological pest control, organically approved pesticide application and control pest, strictly limiting the use of synthetic fertilizers and synthetic pesticides, plant growth regulators, livestock and genetically modified organisms.

Concept and Meaning

Chemicals such as artificial fertilizers, herbicides, insecticides, fungicides, animal drenches are not used on an organic farm. The term ‘organic’ was first used in relation to farming by Northbourne (1940) in the book Look to the Land: ‘the farm itself must have a biological completeness; it must be a living 2 entity, it must be a unit which has within itself a balanced organic life’.



According to Lampkin, Organic Farming is a production system which avoids or largely excludes the use of synthetically compounded fertilizers, growth regulators and livestock feed additives. Our fathers and forefathers, who were traditional farmers, were the pioneers of organic farming. Today organic farming is looked upon as the answer to these problems posed by technical farming. Many farmers are now returning to organic methods of farming that are similar to their traditional methods but now, with more knowledge attached, organic farming can prove to be more successful as, if not more than conventional framing.



Principles of Organic Agriculture

1. Principle of health: Health is the wholeness and integrity of living systems. It is not simply the absence of illness, but the maintenance of physical, mental, social and ecological well-being. Immunity, resilience and regeneration are key characteristics of health. Organic Agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible. The role of organic agriculture, whether in farming, processing, distribution, or consumption, is to sustain and enhance the health of ecosystems and organisms from the smallest in the soil to human beings. Organic agriculture is intended to produce high quality, nutritious food that contributes to preventive health care and well-being. In view of this it should avoid the use of fertilizers, pesticides, animal drugs and food additives that may have adverse health effects.

2. Principle of ecology: Organic Agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them. It states that production is to be based on ecological processes, and e recycling. These cycles are universal but their operation is site-specific. Organic management must be adapted to local conditions, ecology, culture and scale. Inputs should be reduced by reuse, recycling and efficient management of materials and energy in order to maintain and improve environmental quality and conserve resources. Organic agriculture should attain ecological balance through the design of farming systems, establishment of habitats and maintenance of genetic and agricultural diversity. Those who produce, process, trade, or consume organic products should protect and benefit the common environment including landscapes, climate, habitats, biodiversity, air and water.

3. Principle of fairness: Fairness is characterized by equity, respect, justice and stewardship of the shared world (among people and in their relations to other living beings). This principle emphasizes to ensure fairness at all levels and to all parties (farmers, workers, processors, distributors, traders and consumers) with regard to the common environment and life opportunities. Organic agriculture should provide everyone involved with a good quality of life, and contribute to food sovereignty and reduction of poverty. It aims to produce a sufficient supply of good quality food and other products. This principle also insists that animals should be provided with the conditions and opportunities of life that accord with their physiology, natural behavior and well-being. Fairness requires systems of production, distribution and trade that are open and equitable.

4. Principle of care: Precaution and responsibility are the key concerns in management, development and technology choices in organic agriculture. Organic Agriculture should be managed in a precautionary and responsible Manner to protect the health and well-being of current and future and the environment. New technologies need to be assessed And existing methods reviewed. Science is necessary to ensure that Organic agriculture is healthy, safe and ecologically sound. However, Scientific knowledge alone is not sufficient. Practical experience, Accumulated wisdom and traditional and indigenous.

Advantages of Organic Farming

1. Organic manures produce optimal conditions in the soil for high yields and good quality crops.
2. They supply all the nutrients required by the plant (NPK, secondary and micronutrients).
3. Most of the organic manures are waste or byproducts which accumulate may lead to pollution. By way of utilizing them for organic farming, pollution is minimized.
4. Organic fertilizers are considered as complete plant food. Organic matter restores the pH of the soil which may become acidic due to continuous application of chemical fertilizers.

Objectives of Organic Farming

1. To produce food of high nutritional quality in sufficient quantity.
2. To maintain and increase the long term fertility of soils.
3. To work with natural systems rather than seeking to dominate them.

Essential Characteristics of Organic Farming

1. Maximal but sustainable use of local resources.
2. Minimal use of purchased inputs, only as complementary to local resources.
3. Ensuring the basic biological functions of soil-water-nutrients-human continuum.

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Climate Change and Agricultural Productivity in Haryana: Challenges, Climate-Resilient Adaptation and Future Perspectives

Article ID: 74100

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Abstract

Climate change is becoming an imminent threat to the sustainability of agriculture in Haryana, which is one of India's main producers of food grains. Rising temperature, unpredictable rainfall, heat waves, falling groundwater levels, and extreme weather are impacting the productivity, health of soil, and availability of water. Wheat suffers from terminal heat stress, while rice production is facing problems due to falling levels of groundwater and monsoon unpredictability. Crops like cotton, mustard, and horticultural crops are witnessing higher cases of drought, heat stress, pests, diseases, resulting in lower productivity and profitability of farms. Climate change also results in rapid degradation of soils and water scarcity that make future agricultural sustainability difficult. Climate-smart agriculture, conservation agriculture, crop diversification, precision agriculture, efficient water management, and stress-tolerant varieties provide viable adaptation strategies. In the future, the survival of agriculture in Haryana will require the adoption of new technology in agriculture such as artificial intelligence, digital agro-advisory service, etc.

Keywords: Adaptation, climate change, climate-smart agriculture, heat stress, precision farming.

Introduction

Agriculture is highly dependent on climatic factors such as temperature, rainfall, humidity, solar radiation, and atmospheric carbon dioxide concentration. Small changes in these factors may have substantial effects on plant growth and development, water and nutrient availability, and other physiological activities and the output produced by agriculture. Over the last century, due to growing greenhouse gas emissions, there have been considerable changes in the climatic pattern of the world, which include warming, erratic rains, long periods of drought, heavy rains, and heat waves. India's vulnerability to climate change is very high because agriculture has an important role to play in securing food and livelihood security and development of the economy. The rise in temperatures, irregularity in rainfalls, and occurrences of extreme weather conditions have increasingly become threats to agriculture, resources, and farmers' incomes. Haryana, being an important contributor in terms of wheat and rice yield from India due to the Green Revolution, has been successful in increasing productivity because of intensive farming, irrigation, mechanization, and improved crop varieties. However, its resource-intensive crop production system of rice and wheat is becoming vulnerable to climatic changes and stress. Increase in temperature, exhaustion of groundwater resources, monsoon unpredictability, and occurrence of heat waves have decreased crop yield and increased environmental degradation. Climate change affects crop life span, decreases photosynthesis and grain filling, causes increase in evapotranspiration, and creates drought, floods, and soil erosion. It also affects pests and diseases, soil fertility, and biodiversity.

Climate Change Scenario in Haryana

Haryana, located in northwestern India, covers approximately 44,212 km² and encompasses diverse agro-climatic regions ranging from the Shivalik foothills to semi-arid plains. Agriculture occupies nearly 80% of the state's geographical area, with rice-wheat, cotton-wheat, pearl millet-mustard, sugarcane, and horticultural systems dominating agricultural production. The state's climate is characterized by hot summers, cool winters, and highly seasonal rainfall. Nearly 70-80% of annual rainfall is received during the southwest monsoon, while the remainder occurs during winter due to western disturbances. Consequently, agricultural production is highly sensitive to variations in rainfall distribution and seasonal temperature. Meteorological observations during recent decades reveal a significant warming trend across Haryana. Maximum temperatures have increased by approximately 0.5°C, while minimum temperatures have risen by nearly 1.0°C since the early 2000s. Heat waves have become more frequent during March and April, coinciding with the reproductive and grain-filling stages of wheat. These conditions accelerate crop maturity, shorten grain development, and reduce both grain quality and yield (Fig 1.).

Rainfall variability has also increased considerably. Although total annual rainfall has not declined uniformly, its distribution has become increasingly erratic. Delayed monsoon onset, prolonged dry spells, fewer rainy days, and high-intensity rainfall events have increased both drought and flood risks. Historic droughts in 2002, 2009, and 2019 caused substantial agricultural losses, while unseasonal rainfall and hailstorms have damaged wheat, mustard, vegetables, and fruit crops during critical growth stages witnessed during 2025. Groundwater depletion represents one of the most serious environmental challenges facing Haryana. Intensive rice cultivation depends heavily on tube-well irrigation, particularly in central and eastern districts. Rising temperatures increase crop evapotranspiration and irrigation demand, resulting

in excessive groundwater extraction. In several districts, groundwater levels continue to decline annually, threatening the long-term sustainability of irrigated agriculture. Climate projections suggest that Haryana will experience further increases in temperature, greater rainfall uncertainty, higher evapotranspiration, and more frequent extreme weather events during the coming decades. These changes necessitate a transition towards climate-resilient agricultural systems capable of sustaining productivity while conserving natural resources.

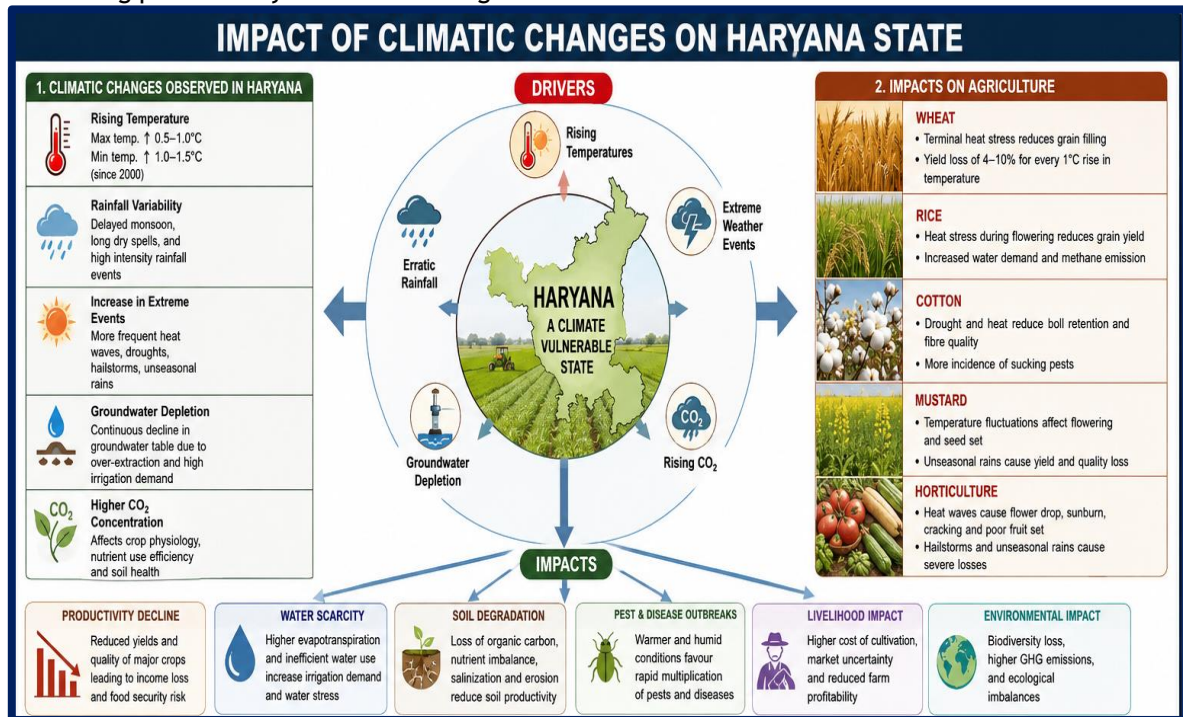


Fig. 1. Impact of climate change on Haryana agriculture

Impact of Climate Change on Agricultural Productivity

Climate change affects agricultural productivity through direct and indirect mechanisms. Rising temperatures, irregular rainfall, declining groundwater availability, and increasing atmospheric carbon dioxide influence crop physiology, water-use efficiency, nutrient uptake, and reproductive development. Simultaneously, climate variability increases pest outbreaks, disease incidence, weed competition, and soil degradation, thereby reducing the resilience of farming systems. The rice-wheat production system, which dominates Haryana agriculture, is particularly vulnerable because of its high dependence on groundwater irrigation and narrow climatic requirements for optimum crop growth. Simulation studies indicate that, without effective adaptation strategies, climate change could substantially reduce crop yields and farm incomes during the coming decades.

Crop-Wise Impact of Climate Change on Agricultural Productivity in Haryana

Climate change has become a major constraint to agricultural productivity in Haryana by adversely affecting crop growth, phenology, water-use efficiency, nutrient dynamics, and yield stability. Rising temperatures, erratic rainfall, groundwater depletion, and frequent extreme weather events have impacted both cereal and non-cereal cropping systems, with effects varying across crop species, growth stages, and agro-climatic zones. Crop-specific impacts of climate change are summarized in Table 1, while its effects on soil health, water resources, and biotic stresses are presented in Table 2. Major climate-resilient adaptation strategies for sustainable agricultural development in Haryana are outlined in Table 3.

Table 1. Crop-wise impact of climate change on major crops in Haryana:

Crop	Major climatic stresses	Effects on productivity and quality	Suggested adaptation measures
Wheat	Terminal heat stress at flowering and grain filling; temperatures >30–32 °C	Accelerated leaf senescence, reduced chlorophyll and photosynthesis, shortened grain filling, lower grain weight and yield; 1 °C rise may reduce productivity by 4-10%; deterioration in grain quality due to reduced starch and protein synthesis	Timely sowing, heat-tolerant cultivars, improved crop management
Rice	High temperature, irregular monsoon rainfall,	Reduced photosynthetic efficiency and grain filling, poor spikelet fertility, disrupted	Direct-seeded rice, alternate wetting and

	groundwater depletion, increased pest incidence	nursery raising and transplanting, increased irrigation dependence and cultivation costs	drying, drought-tolerant varieties
Cotton	Drought, heat stress, climate-induced pest outbreaks	Reduced boll retention and fibre quality, lower lint yield, increased incidence of whitefly, aphids, jassids, fungal diseases, and boll rot; higher production risks and costs	Drought-resilient hybrids, integrated pest management, efficient irrigation
Mustard	Temperature fluctuations, untimely rainfall, frost	Reduced flowering duration and seed weight, lodging and silique shattering, poor seed quality, lower biomass and yield in rainfed areas	Climate-resilient varieties, timely sowing, moisture conservation practices
Horticultural crops	Heat waves, unseasonal rainfall, hailstorms, high humidity	Reduced fruit set, flower drop, pollen damage, fruit cracking, blossom-end rot, sunburn, premature ripening, severe losses in tomato, onion, potato, mango, guava, and kinnow; increased fungal diseases and pesticide use	Protected cultivation, climate-smart horticulture, disease management, weather-based advisories

Table 2. Effects of climate change on soil health, water resources, and biotic stresses in Haryana:

Component	Climate-induced changes	Impacts on agriculture
Soil health	Rising temperature, erratic rainfall, prolonged drought	Decline in soil organic carbon, nutrient availability, microbial activity, and water-holding capacity; increased erosion, nutrient leaching, salinity, and alkalinity
Water resources	Increased evapotranspiration, reduced monsoon recharge, excessive groundwater extraction	Rapid groundwater depletion, increased irrigation demand, water scarcity, and reduced crop productivity
Pest dynamics	Higher temperatures and climatic variability	Faster insect development, multiple pest generations, and increased infestations of whitefly, aphids, stem borers, brown plant hopper, armyworms, and leaf folders
Disease incidence	High humidity and intermittent rainfall	Increased occurrence of rusts, sheath blight, powdery mildew, Alternaria blight, and leaf spot diseases
Weed dynamics	Elevated atmospheric CO ₂ and warmer climate	Enhanced weed competitiveness, increased herbicide dependence, pesticide resistance, and production costs
Overall impact	Combined climatic and ecological stresses	Reduced crop productivity, declining soil fertility, environmental degradation, and lower agricultural sustainability

Future Scenario of Agriculture in Haryana

The future of agriculture in Haryana will depend on its capacity to adapt to climate change while ensuring sustainable management of natural resources. Climate projections indicate a 1.5-2.5°C rise in temperature by the 2050s, accompanied by erratic rainfall, frequent heat waves, prolonged droughts, and extreme weather events. These changes are expected to increase crop water demand, accelerate groundwater depletion, and threaten the sustainability of the rice-wheat production system. Consequently, crop diversification towards maize, millets, pulses, oilseeds, fodder, and horticultural crops will be essential for improving water-use efficiency, soil health, and farm profitability.

Technological advancements, including artificial intelligence (AI), machine learning, remote sensing, drones, robotics, Internet of Things (IoT), and precision agriculture, will play a pivotal role in optimizing irrigation, nutrient management, pest surveillance, and yield forecasting. Sustainable water management through micro-irrigation, rainwater harvesting, groundwater recharge, and treated wastewater reuse will further enhance water security. Future crop improvement programmes should focus on developing high-yielding cultivars with tolerance to heat, drought, salinity, and emerging pests using genomics, biotechnology, and gene-editing tools (Fig. 2). In addition, conservation agriculture, integrated nutrient management, agroforestry, and carbon sequestration practices will improve soil health and climate resilience. Strong policy support, digital extension services, climate-smart villages, renewable energy adoption, and stakeholder collaboration will be critical for achieving a knowledge-based, climate-resilient, and environmentally sustainable agricultural system in Haryana, ensuring long-term food security and improved farmer livelihoods.

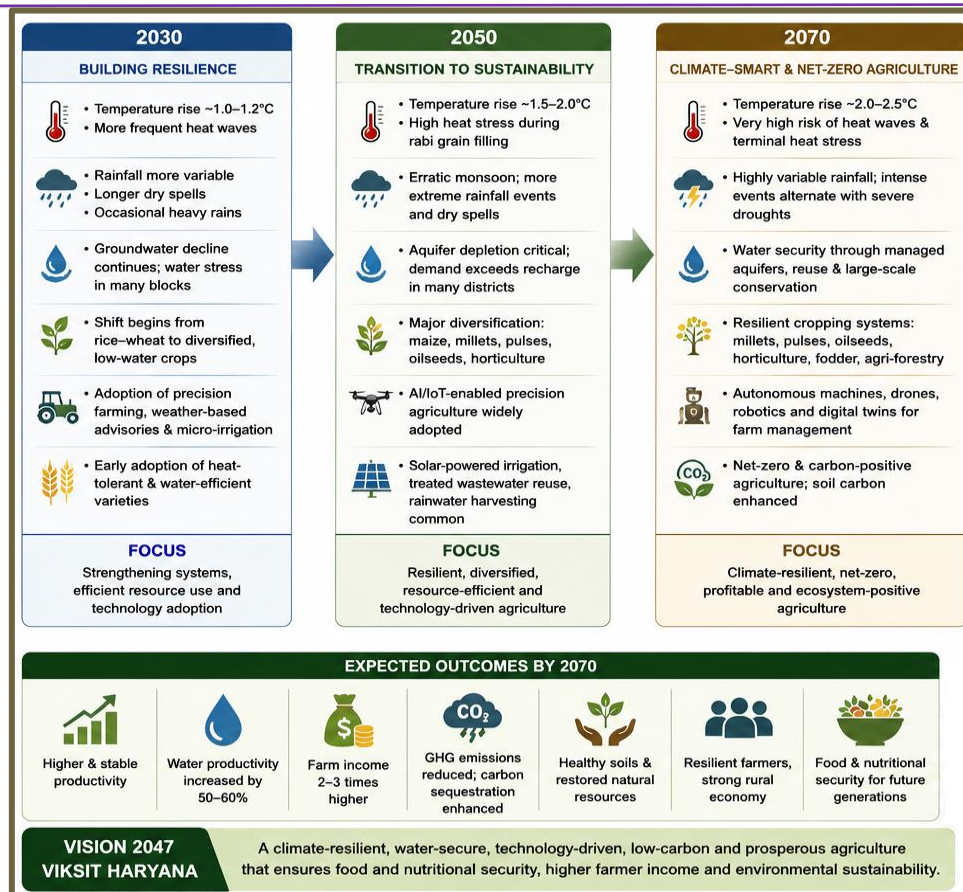
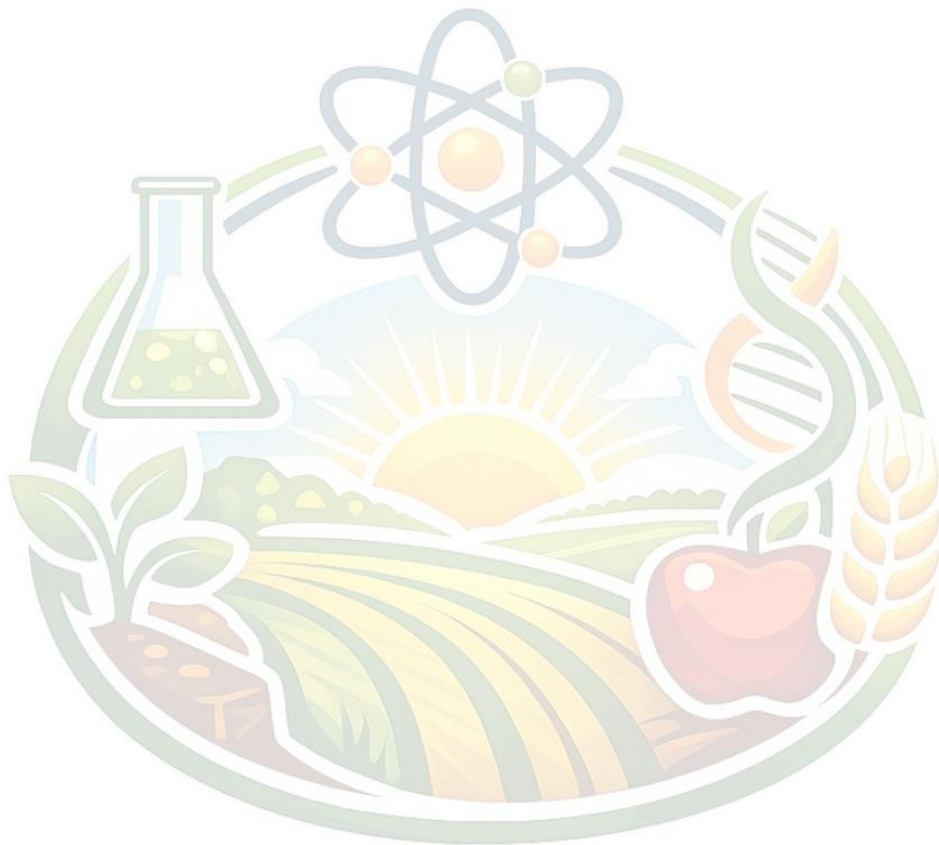


Fig. 2. Future outlook of Haryana agriculture towards climate resilient smart and sustainable agriculture

Conclusion

Climate change poses a serious threat to agricultural sustainability in Haryana by increasing production risks, water scarcity, and climatic uncertainties. Ensuring future agricultural resilience requires the adoption of climate-smart practices, sustainable water management, climate-resilient crop varieties, precision agriculture, renewable energy, and digital technologies. Strengthened policy support, farmer capacity building, and continued research are essential for accelerating the adoption of resilient farming systems. An integrated approach combining scientific innovation, natural resource conservation, and stakeholder participation will be crucial for enhancing agricultural productivity, ensuring food security, improving rural livelihoods, and achieving sustainable agricultural development under future climate scenarios.



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