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Tea Tourism and Agritainment

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Abstract

Tea tourism and "agritainment" have emerged as innovative and experiential models transforming tea-producing regions into dynamic tourism destinations. This article explores global examples-from Darjeeling, Assam and Kerala in India to Indonesia, China, South Korea and Sri Lanka and analyses economic impact, community engagement, sustainability and visitor satisfaction. Data show substantial economic benefits: US $68 M in Suzhou's Biluochun tea tourism and significant income diversification in Pagilaran (Indonesia). Agritainment elements like tea plucking, factory tours, homestays, digital storytelling and creative marketing which enhances visitor experience and community livelihood, though challenges such as infrastructure, equity and environmental sustainability remain. The article proposes best practices for integrating agritainment, ensuring inclusivity and balancing conservation with tourism development.

Keywords: Tea Agritainment**,** Sustainable Tourism**,** Community-Based Tourism**,** Tea Heritage**,** Agrotourism Innovation and Cultural Preservation.

1. Introduction

Tea tourism is also known as tea agritainment which is the fusion of agricultural production and tourism, where visitors engage deeply with tea culture, cultivation, processing and lifestyle. Moving beyond mere sightseeing, agritainment integrates hands-on experiences like tea plucking, factory tours and local cuisine, aiming to promote sustainability, cultural heritage and community livelihoods. This review emphasizes original published data and regional case studies to evaluate the benefits, models and challenges of tea tourism worldwide.

2. Economic Impacts of Tea Tourism

2.1 Biluochun Tea, Suzhou (China)

Feng in 2012, used travel cost and contingent valuation methods in Dongting Mountain, Suzhou, finding tea tourism's total economic benefit at **¥678.95 million** (approximately US $96 M) with ~¥656.75 M attributable to usage and ¥22.19 M to non-use values. This large valuation underscores the strong tourism-driven economic potential of tea landscapes.

2.2 Pagilaran Tea Plantation (Indonesia)

Researchers evaluated Pagilaran's agrotourism model involving penta-helix collaboration among academia, government, communities, corporations and media. Activities such as tea walk, factory visits and cultural performances-augmented by educational dimensions-bolstered sustainable livelihood outcomes.

3. Agritainment Experiences & Visitor Satisfaction

3.1 Hands-On Tea Engagement

Rungruang studied tourists in Chiang Rai's tea/coffee communities (N=384), showing that perceived novelty and social value, alongside creative tourism marketing skills, significantly influenced visitation intentions. Malaysia's BOH Plantation analysis (2022) highlighted that activities, cleanliness, English signage and security drive memorable experiences and loyalty; hands-on lessons in tea-picking and brewing were key to visitor satisfaction.

3.2 Community Integration & Cultural Exposure

In China's Anhui region, a livelihood-sustainability study found increased income diversity but growing income gaps due to uneven tourism participation. Assam's tea tourism circuit includes heritage bungalow stays, cultural festivals and weaving displays, but challenges remain: poor infrastructure, inequality and seasonal constraints.

4. Agritainment Infrastructure & Hospitality Models

4.1 Homestays & Factory-Turned-Hotels

Makaibari (Darjeeling) offers homestays hosted by Gorkha workers, enabling guests to experience tea cultivation and village life first-hand; it also supports community income through heritage stays. Sri Lanka's Heritance Tea Factory converted a colonial tea factory into a boutique hotel, preserving heritage architecture and enhancing tourism appeal.

4.2 Museums and Brand Experiences

O'Sulloc Tea Museum on Jeju Island attracts 1.5 M annual visitors, showcasing Korean tea history and processing-and is recognized globally for its design and marketing. East Frisian tea culture in Germany, honoured by UNESCO, integrates museum exhibits into regional tourism branding, reinforcing local cultural identity.

5. Digital Innovation & Agritainment

Virtual Tours & Digital Marketing

In Munnar (Kerala), digital technology-virtual tours, mobile apps and social media which enhances heritage preservation and visitor engagement. These innovations have helped market the region's tea estates to global audiences.

Technology & Heritage Storytelling

Technology-enabled tours in Munnar help educate tourists, raise awareness of tea heritage, and support conservation-a model increasingly used in agritainment.

6. Sustainability and Community Empowerment

6.1 Community Engagement & Benefit-Sharing

Active community participation in decision-making ensures local ownership over tourism practices. Tripura's "Tea Boutique" and museum initiatives by the Tea Board of India and TTDC demonstrate how government-driven agritainment can strengthen local identity and economy.

6.2 Inclusive Community Uplift

Assam government's Swadesh Darshan scheme, Tea Festival and tribe welfare initiatives link tourism with social uplift; however, they face issues such as poor connectivity and seasonal limitations. In China, tourism improved livelihoods for some but also widened income disparities, underscoring the need for inclusive strategies.

7. Challenges and Mitigation Strategies

7.1 Infrastructure & Seasonality

Remote estates often lack roads, accommodations and digital connectivity-limiting visitor access. Monsoon seasons in Assam reduce tourism flow and revenues.

7.2 Equity & Access

Unequal community participation can lead to widening income gaps. Ensuring benefits reach tea tribes requires inclusive planning and small-scale tourism initiatives.

7.3 Environmental and Cultural Constraints

Environmental impacts, crowding and cultural commodification need monitoring. BOH Plantation noted overcrowding on weekends.

8. Best Practices for Sustainable Tea Agritainment

1. **Diversify Experiences:** Combine factory tours, plucking experiences, tea tasting, cooking workshops, birdwatching, yoga, etc.
2. **Promote Digital Engagement:** Use apps, virtual reality and social media to build brand and reach global tourists.
3. **Empower Communities:** Ensure locals are decision-makers, hosts and service providers; preserve cultural traditions.
4. **Invest in Infrastructure:** Improve roads, accommodations, safety, English signage and hygiene to boost satisfaction and repeat visits.
5. **Seasonal Planning:** Offset monsoon slowdowns in Assam with festivals, wellness retreats, or indoor museum experiences.
6. **Monitor and Evaluate:** Adopt visitor surveys, economic tracking and environmental assessments to adapt and scale.

9. Conclusion

Tea tourism and agritainment are transforming traditional tea landscapes into vibrant, community-led tourism destinations. With economic influxes reaching tens of millions of dollars, transformational community development and elevated visitor experiences, the model holds great promise. Yet success hinges on inclusive participation, environmental stewardship, equitable benefit-sharing and robust infrastructure. By adopting this best practice- technology integration, hands-on agritainment, community homes and supportive policies-tea agritainment can balance cultural preservation, environmental sustainability and economic empowerment in global tea regions.

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Climate-Resilient Coffee Varieties

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Abstract

Climate change threatens the global coffee sector-especially *Coffea arabica*, which is highly sensitive to heat, drought, pests and reduced suitable growing area. To safeguard supply and livelihoods, researchers and breeders are developing climate-resilient varieties through interspecies hybrids (e.g., *C. arabica* × *C. canephora*), F1 hybrid cultivars like Starmaya and rediscovery or utilization of wild species such as *C. stenophylla*, *C. excelsa*, *C. liberica* and *C. racemosa*. These varieties offer traits including rust resistance, drought tolerance, heat resilience and wider elevational adaptability while maintaining quality. This article reviews key breeding programs, varietal performance, challenges and future directions based on scientific and field data.

Keywords: Climate change, Coffee breeding, F1 hybrids, Wild coffee species, Coffee leaf rust, Drought tolerance and Starmaya

Introduction

Coffee faces unprecedented climate-driven pressures. Global warming is reducing suitable land: studies estimate that by 2050 the area for *C. arabica* could decline by 50 per cent or more worldwide. Rising temperatures and drought accelerate the spread of pests like coffee berry borer and coffee leaf rust into formerly safe zones. Effective strategies include deploying existing durable varieties (e.g., Robusta), accelerating breeding of F_1 hybrid Arabicas and reintroducing wild, climate-adapted species. These approaches aim to secure productivity, cup quality and producer resilience as climates shift.

1. Arabica × Robusta and F1 Hybrids

1.1 Traditional Varieties: Robusta and S795

Robusta (*C. canephora*) inherently tolerates higher temperatures (22-26 °C), drought and pests, making it more climate-resilient than Arabica-though with altered flavour and lower cup grade In India, S795 (a hybrid of *C. arabica* and *C. liberica*) was developed in the 1960s to combine rust resistance, high yield and acceptable quality. Today, it covers 25-30 per cent of India's Arabica acreage and is used in specialty coffees.

1.2 F_1 Hybrid Varieties: Centroamericano, Starmaya Others

F_1 hybrids combine hybrid vigour with desired traits like yield, disease resistance and cup quality. Centroamericano (Arabica Hybrid H_1) was developed by crossbreeding Sarchimor (a CLR-resistant cultivar) with wild *Rume Sudan*. Released in 2016, it offers high rust resistance, climate adaptation and quality comparable to Arabica standards.

Starmaya, developed by CIRAD and ECOM, is the first F_1 hybrid reproducible by seed (*via* male-sterile lines), dramatically lowering cost and increasing scalability. It shows 30 per cent higher yield than parental cultivars, greater stability, lower rust susceptibility than standard lines and cupping scores around 82-83, solid specialty level. Field trials under rainfall reduction conditions also show Starmaya maintains taller canopy and good yield under moisture stress compared with other cultivars. Worldwide, World Coffee Research has advanced F_1 hybrids across countries like E_l Salvador, Costa Rica, Rwanda. Among 43 crosses in 2015, 4 finalists increased yield by approximately 28 per cent and achieved cup-quality scores above 84 in trials by 2022.

2. Wild Climate-Adapted Coffee Species

2.1 *Coffea stenophylla, C. excelsa, C. liberica, C. racemosa*

Over 100 wild coffee species exist with traits valuable in a warming climate. Kew Gardens and CCRI in India have prioritized several species with built-in heat and drought resilience:

1. *C. stenophylla* is naturally heat-tolerant (survives 6-7 °C higher temperatures than Arabica), has an Arabica-like taste (sweet, acidic) and grows at low elevations (~150 m). Though not yet commercially scaled, interest is growing due to its sensory appeal and resilience. (*C. excelsa*, cultivated in Uganda and South Sudan, shows

strong drought and heat tolerance, pest resistance and is being exported commercially (~5.5 tonnes from India), though still <1% of market share.

2. *C. liberica*, historically overlooked, is now appreciated for resilience and unique cup profile. It grows in low-elevation warmer zones and is being trailed by farmers and specialty roasters.
3. *C. racemosa*, along with the above, is part of Kew and CCRI's prioritized set, valued for climate hardiness.

2.2 Genetic Diversity & Conservation Importance

Genomic studies (39 Arabica varieties sequenced) reveal low genetic diversity due to historic inbreeding, increasing vulnerability to disease and climate stress. Sequencing of wild relatives offers new gene pools for breeding.

Protecting wild populations is urgent, as many species are threatened by deforestation and monoculture farming.

3. Performance in Climate Stress: Field Evidence

3.1 Drought & High-Temperature Tolerance

Multi-site trials under simulated drought conditions show F1 hybrids like Mundo Maya outperform traditional cultivars under rainfall reduction, maintaining higher yields, leaf area, and physiological resilience. Robusta performs well up to approximately 26 °C but declines above that; Arabica is optimal between 18-23 °C and shows quality degradation above 23-24 °C, prompting altitude range shifts in Brazil and elsewhere.

3.2 Disease Resistance-Rust & Borer

Coffee leaf rust (CLR) has become more prevalent in warmer climates. Varieties like Starmaya, Centroamericano, Catimor, Castillo and S795 exhibit CLR resistance ranging from reduced susceptibility to major tolerance. Berry borer populations increase approximately 8.5% per °C above baseline, especially in drought-stressed Arabica fields, demanding resistant genotypes or species with tolerance traits.

4. Genetics, Breeding, and Production Challenges

Breeding timelines remain long-traditional Arabica breeding can take 20-30 years. F_1 hybrid development cycles (10-20 years) are faster but still slow relative to climate protection urgency.

Propagation is a constraint: Most F_1 hybrids require tissue culture or somatic embryogenesis, limiting scale. Starmaya's seed-medium propagation *via* male sterility is a breakthrough to scale elite hybrids affordably.

Adoption barriers: Smallholder farmers may struggle with high initial costs of hybrid seedlings; ensuring local adaptability and training is essential.

Seed and germplasm access: Seed banks and cooperative systems are vital for distributing resilient varieties and preserving biodiversity, though social and financial barriers exist.

5. Real-World Adoption & Farmer Projects

Kenya's Innovea project, led by World Coffee Research, supports breeding climate-resilient varieties across 9 countries. It is the largest global Arabica breeding initiative since the 1960s and targets immediate availability for farmers in highland regions.

Kew Gardens & Ugandan farmers are trailing *C. excelsa* and *C. stenophylla* in small-scale production and taste assessments, with positive blind-cup results and local buy-in.

In India, CCRI Kodagu's field station is evaluating four wild species (*stenophylla*, *excelsa*, *liberica*, *racemosa*) for climate resilience and cup acceptability, with growers exporting *excelsa* to global markets.

6. Consumer Acceptance & Cup Quality

F_1 hybrids (Centroamericano, Starmaya) and wild species must satisfy taste expectations. Starmaya scored approximately 82-83 in cupping tests, on par with specialty Arabica standards. *Stenophylla* has been described as "complex and naturally sweet with medium-high acidity," making it attractive for consumers and roasters. Excelsa and Liberica also show acceptable flavour when processed carefully, though quality variability is higher than Arabica in current trials.

7. Challenges & Future Directions

Scaling propagation remains difficult for tissue-cultured hybrids; seed-based F_1 varieties like Starmaya offer cost-effective production but require expanded seed gardens. Regulation & intellectual property must balance breeders' rights and farmer access to prevent monopolistic concentration.

Consumer awareness: for species like *stenophylla* and *liberica*, educating consumers about taste and climate benefit is key for mainstream adoption.

Biodiversity protection: Preserving wild germplasm requires conservation efforts alongside exploitation in breeding.

Integrated strategies: Varietal development must be paired with agroforestry, shade management, irrigation, and soil health practices to maximize resilience.

Conclusion

Developing climate-resilient coffee varieties is essential to secure global supply, conserve farmer livelihoods, and maintain quality in the face of rising heat, pests, and land loss. Interventions span powerful F1 hybrids like Starmaya and Centroamericano offering yield, rust resistance, and cupping quality; robust traditional varieties like Robusta and S795; and wild species such as *C. stenophylla*, *excelsa*, and *liberica* offering natural heat tolerance and low-elevation adaptability. Success depends on expanding seed systems, protecting germplasm, supporting farmer access and training, and building markets for diverse flavour profiles. Integrated with sustainable farming, these strategies position coffee for a credible future despite climate uncertainty.

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Mycotoxins in Grains: Occurrence, Health Impacts and Mitigation Strategies

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Abstract

Mycotoxins are toxic secondary metabolites produced by fungi that contaminate food and feed, especially grains. Found primarily in crops such as maize, wheat, rice and soybean, these toxins can originate during pre-harvest or postharvest stages, especially under warm and humid conditions. Major groups include aflatoxins, fumonisins, ochratoxins, zearalenone and deoxynivalenol (DON), each with severe health and economic implications. Chronic exposure can cause liver cancer, immunosuppression and reproductive disorders in humans and animals. This article reviews the sources, health risks, detection methods and mitigation strategies for mycotoxins, emphasizing the importance of good agricultural and postharvest practices to minimize contamination and safeguard public health and food security.

Introduction

Mycotoxins represent a significant and growing concern in global food safety. These naturally occurring toxins are produced by certain fungi, predominantly ***Aspergillus, Fusarium*** and ***Penicillium*** species, which infect crops under field conditions or during storage. Their contamination is influenced by multiple factors, including climate, harvesting techniques and storage practices. Grains such as maize, wheat, sorghum and soybean are particularly susceptible.

According to the **FAO,** up to 25% of global crops are contaminated by mycotoxins, though recent studies suggest this may reach **60-80%,** owing to advances in detection technology. Mycotoxins pose a dual threat-compromising **human and animal health** while causing substantial **economic losses** through food rejection, reduced livestock productivity and increased healthcare costs.

Occurrence and Classification of Mycotoxins

There are over 300 mycotoxins identified, but only a few are considered significant for food safety:

1) **Aflatoxins (AFs)** - Produced by *Aspergillus flavus* and *A. parasiticus*, these are the most toxic, often found in maize, peanuts and rice. Chronic exposure can lead to **liver cancer**, immune suppression and even death.
2) **Fumonisins** - Produced by *Fusarium verticillioides*, these affect corn and cause **organ damage** in animals. Detected in 93% of Indian corn samples (2011-2021).
3) **Deoxynivalenol (DON)** - Also known as vomitoxin, found in wheat, oats and barley. It disrupts protein synthesis and causes vomiting.
4) **Ochratoxin A (OTA)** - Detected in poorly stored grains, coffee, and dried fruits, OTA is nephrotoxic and possibly carcinogenic.
5) **Zearalenone (ZEN)** - Associated with reproductive issues, ZEN often contaminates corn, sorghum and wheat.

Environmental conditions, such as **humidity, temperature** and **storage method**, significantly influence their development. For instance, aflatoxins and OTA often thrive **postharvest**, whereas DON, ZEN and fumonisins are more prevalent **preharvest.**

Human and Animal Health Impacts

Mycotoxins are toxic at both acute and chronic exposure levels:

Human Health:

1) **Acute effects**: Nausea, vomiting, abdominal pain and liver failure.
2) **Chronic effects**: Liver cancer (aflatoxins), kidney damage (OTA), immune suppression, birth defects and developmental delays in children.
3) **High-risk groups**: Children, pregnant women, the elderly and immunocompromised individuals.

Transmission: Aflatoxin M1 can pass into **milk** from contaminated animal feed, posing further risks.

Animal Health:

Livestock exposed to contaminated feed suffer from:

- Reduced productivity (e.g., lower milk and egg output).
- Immune dysfunction.
- Reproductive problems.
- Economic losses due to animal illness and reduced growth rates.

Soybean in India showed up to **95% OTA contamination**, highlighting the widespread risk in feed chains.

Postharvest and Field Management Strategies

Postharvest contamination is largely preventable with proper practices:

1) **Drying**: Rapid and uniform drying of grains to moisture levels <13%.
2) **Storage**: Use of sealed, dry, ventilated, and cool storage units.
3) **Insect and pest control**: To prevent entry points for fungi.
4) **Transportation and packaging**: Clean, moisture-resistant materials are crucial.

Grain **processing**-such as sorting, cleaning, fermentation, baking, roasting and extrusion-can **reduce toxin levels.**

Field management includes:

1)**Crop rotation** to prevent fungal build-up.

2)**Resistant crop varieties** through genetic engineering.

3)**Biological controls** and **targeted fungicides**, although public concern over chemical use is increasing.

Detection and Monitoring:

Advancements in detection play a crucial role in managing risks:

HPLC-MS/MS: Highly accurate, detects multiple mycotoxins simultaneously.

ELISA kits: Cost-effective for preliminary testing in field conditions.

Biosensors and PCR: Emerging tools for real-time detection and early fungal identification.

The **FDA** and **USDA** collaborate on surveillance and set regulatory limits for aflatoxins and other major toxins, particularly in nuts and animal feed.

Conclusion

Mycotoxins are a persistent and evolving threat to global food and feed security. Their widespread occurrence in grains-particularly in tropical and subtropical climates-necessitates urgent and coordinated mitigation strategies. From improved farming practices and stringent storage protocols to cutting-edge detection technologies, multiple points in the supply chain offer opportunities for control. Effective risk management must integrate **Good Agricultural Practices (GAP), Hazard Analysis and Critical Control Points (HACCP)** and robust regulatory oversight to ensure food safety, protect public health and maintain the economic viability of agriculture worldwide.

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Carbon Farming and Green Extension: Paving the Way for a Climate-Resilient Indian Agriculture

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Abstract

As India confronts the dual challenges of climate change and food security, carbon farming has emerged as a transformative approach to make agriculture both environmentally sustainable and economically viable. This article explores the principles and practices of carbon farming, emphasizing its potential to sequester atmospheric carbon through soil management, agroforestry, organic inputs, and conservation agriculture. It highlights how green extension services infused with climate awareness, digital tools, and grassroots capacity building are crucial for promoting farmer adoption. The integration of carbon credit markets provides a financial incentive for farmers, enabling them to monetize climate-positive actions. Drawing from successful case studies, policy initiatives, and innovative partnerships, the article outlines a roadmap for scaling carbon farming across diverse agro-climatic zones in India. With proper institutional support, digital platforms, and farmer-friendly certification systems, carbon farming can help achieve climate resilience, enhance rural incomes, and establish Indian farmers as key players in global climate mitigation efforts.

Keywords: Carbon farming, Green extension, Carbon credit market, Sustainable farming, Carbon sequestration

Introduction: The Imperative for Sustainable Agricultural Transformation

India's agricultural sector, a cornerstone of the nation's economy and employment, is facing an existential challenge. With a population surpassing 1.4 billion, the pressure to produce more food is increasing, even as farming practices face the harsh consequences of climate change. Accounting for nearly 18% of the national GDP and providing employment to almost half of the country's labor force, agriculture is paradoxically both a cause of environmental degradation and one of its foremost casualties. According to recent government data, agriculture is responsible for approximately 14% of the country's total greenhouse gas (GHG) emissions. These emissions arise primarily from methane released by flooded rice fields and livestock, as well as nitrous oxide generated by synthetic fertilizers. Meanwhile, Indian farmers are grappling with unpredictable rainfall, extreme temperatures, and soil degradation—factors that threaten food production and rural livelihoods. Against this backdrop, carbon farming offers a promising solution. This practice seeks to enhance the soil's ability to capture and store carbon, transforming farms from emission sources into climate solutions. When this approach is coupled with environmentally-focused agricultural extension services and supported by a well-regulated carbon credit market, it can create a sustainable and economically rewarding agricultural model. This article explores how carbon farming, backed by green extension and financial incentives, can lead India toward a more climate-resilient and profitable agricultural future.

Understanding Carbon Farming: Turning Soils into Carbon Sinks

Carbon farming revolves around increasing the natural ability of soil and vegetation to absorb and store carbon from the atmosphere. Through photosynthesis, plants convert atmospheric carbon dioxide into organic matter. When managed correctly, this organic matter—via roots, crop residues, or organic amendments—becomes part of the soil organic carbon (SOC) pool. Studies by ICAR suggest that Indian agricultural soils have a much lower SOC content than their potential. Degraded farmlands currently have only 0.3–0.5% organic carbon, compared to their natural capacity of up to 2%. By adopting carbon farming techniques, SOC can be improved by up to 1.5 tons per acre each year, translating to the removal of several tons of CO_2 annually from the atmosphere.

Table 1: Carbon Sequestration Potential of Key Indian Cropping Systems

Cropping System	Current Carbon Stock (tCO_2/ha)	Potential Increase	Additional Income Potential (₹/acre/yr)
Rice-Wheat (Punjab)	25-30	+40-50% with DSR*	3,500-5,000
Cotton-Maize (MH)	15-20	+60% with agroforestry	4,200-6,000
Coffee (Karnataka)	40-50	+30% with shade trees	6,000-8,000 (premium pricing)
Millets (Rajasthan)	10-15	+80% with biochar	2,800-3,500

**DSR = Direct Seeded Rice | Source: ICAR All India Soil Carbon Assessment (2023)*

Major Techniques of Carbon Farming in India

India's diverse agro-climatic zones necessitate region-specific solutions. Some of the most effective carbon farming practices include:

- **Agroforestry**: Incorporating trees alongside crops or livestock to improve soil structure and enhance biodiversity.
- **Conservation Agriculture**: Practices like minimal tillage, cover cropping, and crop rotation help maintain soil health and reduce emissions.
- **Organic Nutrient Management**: Composting, vermicomposting, green manure, and biochar enhance soil fertility while sequestering carbon.
- **Efficient Water Use**: Innovations such as the System of Rice Intensification (SRI) and micro-irrigation with fertigation contribute to water and carbon efficiency.
- **Integrated Farming Systems**: Mixing crop cultivation with livestock, fishery, and forestry components ensures optimal resource use and carbon gain.

For example, the Indo-Gangetic Plains benefit from crop residue management and direct seeding of rice, while the Deccan Plateau emphasizes drought-resistant tree-based systems and in-situ water conservation.

Table 2: State-wise Carbon Farming Adoption & Benefits

State	Key Practice	Area Covered (2023)	Avg. Carbon Gain	Farmer Earnings
Andhra Pradesh	Zero-Budget Natural Farming	700,000 ha	0.8 tCO_2/ha/yr	₹5,200/acre/yr
Maharashtra	Agroforestry (Bamboo)	120,000 ha	2.1 tCO_2/ha/yr	₹7,500/acre/yr
Punjab	Happy Seeder Technology	1.5 million ha	0.6 tCO_2/ha/yr	₹3,800/acre/yr
Kerala	Organic+Coconut-Based	350,000 ha	1.2 tCO_2/ha/yr	₹9,000/acre/yr (incl. premium)

Source: State Agriculture Departments (2024)

Green Extension: A Catalyst for Climate-Smart Farming

While the scientific foundation for carbon farming is robust, implementation on the ground is still in its infancy. The lack of awareness, reluctance to change, and limited access to resources remain significant barriers. This is where **green extension services**—which promote eco-friendly practices along with productivity—can play a pivotal role.

India's extension ecosystem is undergoing a transformation:

- **Krishi Vigyan Kendras (KVKs)** are leading localized awareness campaigns. For example, KVK Malappuram has established "Carbon Farmer Clubs," while Solapur KVK has introduced "Soil Carbon Health Cards" to measure and improve SOC levels.
- **Digital Advisory Tools** like the Kisan Suvidha app, participatory videos, and AI-powered services from companies such as CropIn and Ninjacart are enabling real-time and personalized guidance.
- **Farmer Producer Organizations (FPOs)** are emerging as important platforms for training, aggregation, and collective marketing. Groups such as Sahyadri Farms and Sikkim's Organic Farmers Society exemplify successful FPO-led carbon initiatives.
- **Private Companies** are also stepping in, with ITC's water conservation program and Mahindra's "Prerna" initiative making tangible impacts in soil and water management.

Moreover, the National Institute of Agricultural Extension Management (MANAGE) is building the capacity of frontline workers by offering specialized training in climate change mitigation, carbon accounting, and digital extension methods.

Carbon Credits: Turning Sustainability into Profit

A key motivation for adopting carbon farming is its ability to generate **carbon credits**—tradable certificates representing a ton of carbon dioxide removed or avoided. These credits are sold in either compliance markets (regulated by governments) or voluntary markets (used by businesses seeking to offset emissions).

Indian farmers can tap into this system through:

1. **Project Setup**: Measuring baseline carbon levels and implementing certified carbon farming methods.
2. **Verification**: Getting certified by global bodies such as Verra or Gold Standard.
3. **Credit Sales**: Marketing the generated credits directly to buyers or through aggregation platforms like India's upcoming Carbon Exchange.

Case studies reveal significant benefits: natural farming practitioners in Andhra Pradesh earn up to ₹7,000 per acre annually through carbon credits, while farmers using direct seeding methods in Punjab receive additional payments. Coffee growers in Karnataka have even started selling "carbon-neutral" beans at premium rates.

Table 3: Cost-Benefit Analysis of Transition to Carbon Farming

Component	Year 1	Year 3	Year 5
Initial Costs (₹/acre)	8,000-12,000	3,000-5,000	1,000-2,000
Yield Impact	-10% to -15%	+5% to +10%	+15% to +25%
Carbon Credits	₹1,500	₹4,200	₹6,800
Total Net Benefit	-₹6,500	+₹7,200	+₹14,500

**Assumes 2-acre smallholder farm | Source: NABARD Pilot Studies (2023)*

Challenges and Strategies for Broader Inclusion

Several barriers must be addressed to make carbon markets accessible to all farmers, especially smallholders:

- High costs of certification and monitoring can be reduced through satellite imaging and group certification models.
- Technological complexity is being simplified using AI tools like ISRO's Carbon Atlas.
- Price unpredictability can be countered through price guarantees or long-term contracts, such as those supported by NABARD.

Policy Support: Enabling a Carbon-Smart Agricultural Economy

Numerous national and state-level policies are already fostering a supportive environment for carbon farming:

- The **National Mission for Sustainable Agriculture (NMSA)** promotes resilient, climate-smart practices.
- The **Soil Health Card Scheme** now incorporates carbon tracking.
- The **Paramparagat Krishi Vikas Yojana (PKVY)** focuses on the organic methods that contribute to carbon capture.
- States such as **Andhra Pradesh**, **Sikkim**, and **Kerala** are pioneering localized models that integrate carbon farming into mainstream agricultural development.

Table 4: Comparative Analysis of Global Carbon Farming Programs

Country	Program	Payment Rate	Area Enrolled	Key Lesson for India
USA	Conservation Stewardship	\$50-150/acre/yr	25 million ha	Pay-for-performance works
Brazil	ABC+ Low Carbon Plan	R\$1000-3000/farm/yr	18 million ha	Large-scale adoption possible
Kenya	Agricultural Carbon Project	\$6-10/tCO_2e	45,000 ha	Smallholder inclusion model
Australia	Carbon Farming Initiative	AUD\$15-30/tCO_2e	8 million ha	Simplified measurement protocols

Source: World Bank Climate Smart Agriculture Report (2023)

International collaborations with the **World Bank**, **EU**, and others further boost India's capacity in research, funding, and cross-learning.

The Road Ahead: Five Strategic Priorities

To truly scale up carbon farming, India must:

1. **Launch a National Carbon Farming Mission**, integrating it with existing schemes and setting measurable carbon targets.
2. **Build a robust carbon market**, with platforms designed specifically for agricultural stakeholders.
3. **Strengthen green extension infrastructure**, including helplines, mobile tools, and women-led outreach.
4. **Foster public-private collaboration**, leveraging CSR initiatives and market access partnerships.
5. **Invest in research and innovation**, especially for affordable measurement tools, biochar, and digital agriculture.

Conclusion: Sowing Seeds for a Climate-Smart Tomorrow

Carbon farming is not just a sustainability strategy—it's a pathway to transforming Indian agriculture into a low-emission, high-reward sector. By increasing carbon sequestration, supporting rural incomes, and enhancing resilience to climate shocks, this approach offers a blueprint for a greener, more inclusive future. India has the potential to capture more than 8 million tons of CO_2 annually through agricultural reforms. With the right alignment of policies, technologies, and extension mechanisms, the country can position its farmers not only as food providers but also as environmental stewards in the global climate mission.

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Participatory Rural Appraisal (PRA): Relevance in Modern Extension

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Introduction

In the evolving landscape of agricultural development, Participatory Rural Appraisal (PRA) stands as a timeless yet highly relevant approach to ensure farmer-centric, inclusive, and sustainable extension services. Rooted in the philosophy of *"learning with the people"*, PRA emphasizes local knowledge, active participation, and empowerment of rural communities. With the increasing complexities of agriculture due to climate change, market uncertainties, and technological advancements, modern extension can no longer be a one-way delivery system. This is where PRA finds renewed significance.

The concept of PRA was significantly developed and popularized by Dr. Robert Chambers, a British development scholar from the Institute of Development Studies (IDS), UK. He emphasized the importance of putting the last first—bringing the voices of the rural poor into planning and decision-making.

What is PRA?

Participatory Rural Appraisal (PRA) is a set of participatory and visual techniques employed by extension workers, researchers, and planners to gain a deep understanding of rural realities from the perspective of the local community. It enables the identification of problems and available resources, helps prioritize community needs, supports the design of context-specific interventions, and encourages solutions that are led and owned by the people themselves.

Participatory Rural Appraisal (PRA) is a collection of visual, interactive, and participatory tools that help communities analyze their own realities, identify challenges, and plan solutions. It is widely used in agricultural extension, rural development, and environmental planning to ensure farmer-led and context-specific development.

Relevance of PRA in Modern Agricultural Extension

1. Farmer Empowerment

Modern extension is not just about transferring technology—it's about co-creating knowledge. PRA gives voice to marginalized farmers, women, and youth, empowering them to participate in the planning and execution of extension activities.

2. Localized Solutions

Unlike top-down models, PRA respects indigenous knowledge systems. It ensures that the technologies or practices recommended are practical, relevant, and locally acceptable.

3. Real-time Ground-Level Data

PRA tools such as social mapping, seasonal calendars, resource mapping, and problem ranking help extension workers gather authentic and real-time information about communities, which is often missing in formal surveys.

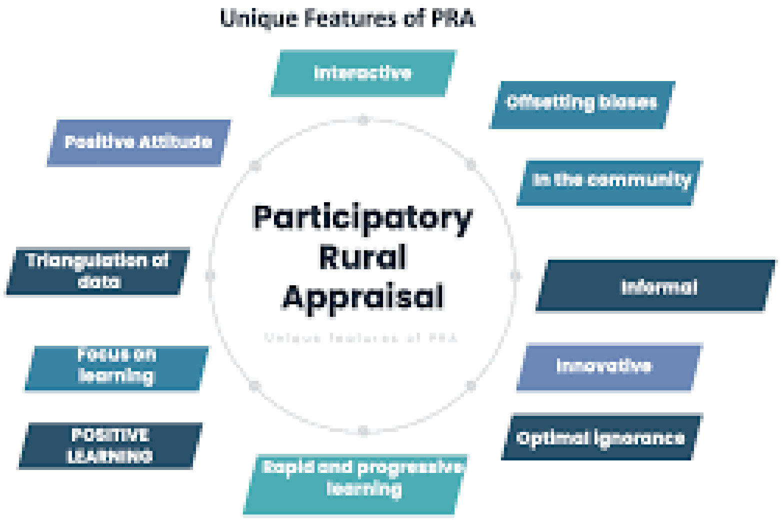
4. Promoting Ownership & Sustainability

When farmers are part of the decision-making process, they develop a sense of ownership over interventions. This leads to better adoption rates and more sustainable outcomes.

5. Adaptability with Digital Tools

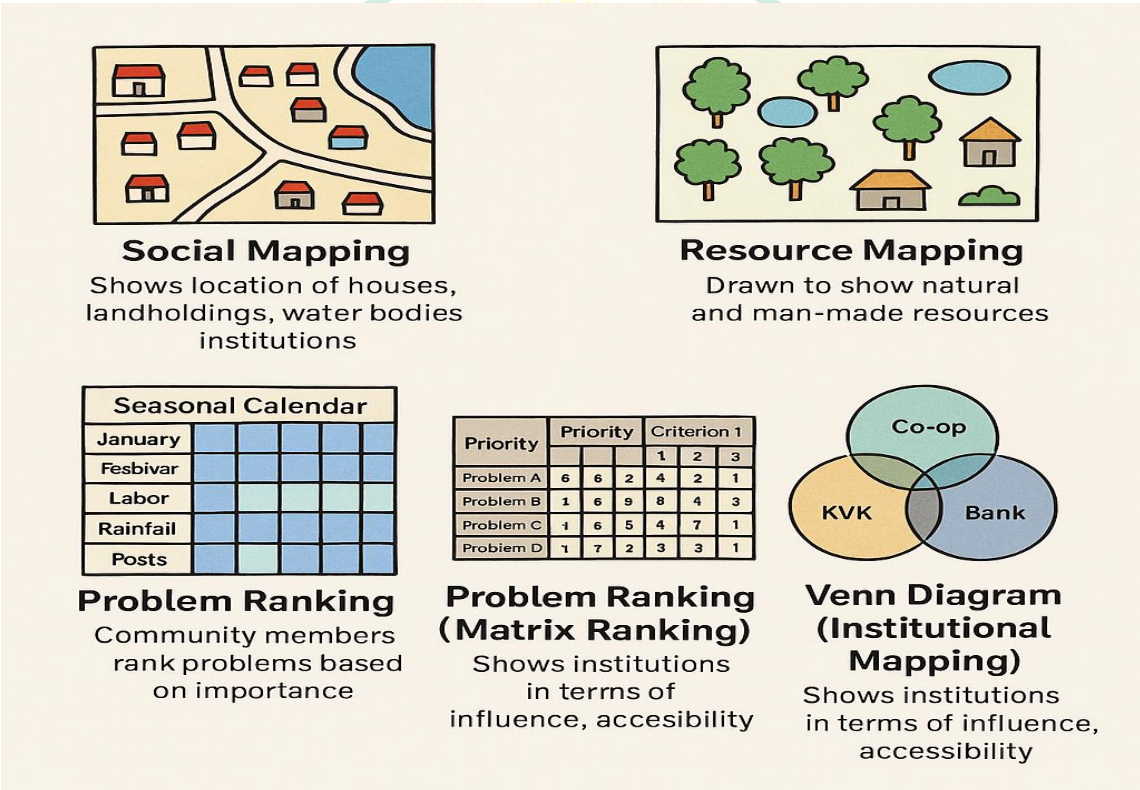
PRA is now being digitally enabled—maps, timelines, and feedback are being recorded through smartphones and apps. Thus, traditional methods blend well with modern ICT tools, enhancing reach and impact.

Modern Needs	PRA Contribution
Farmer Participation	Empowers rural communities to co-create solutions
Climate Resilience	Helps document local coping strategies
Sustainable Farming	Integrates indigenous knowledge
Digital Integration	PRA now merges with ICTs and mobile-based tools
Bottom-up Planning	Ensures need-based, not top-down interventions



Key PRA Techniques

Here are **some widely used PRA techniques** in agricultural extension:



1. Social Mapping

Social Mapping is a visual representation of the layout of a village. It is drawn with the help of community members and shows the location of houses, landholdings, roads, water bodies, and institutions. This technique helps extension workers understand resource distribution, social structure, caste patterns, and land use in a particular area. It also encourages community discussion on disparities and needs.

2. Resource Mapping

Resource Mapping is used to identify both natural and man-made resources within a village. Created by the villagers themselves, it includes features such as forests, wells, ponds, schools, temples, grazing lands, etc. This technique is particularly useful in planning resource utilization, management, and conservation based on local knowledge.

3. Seasonal Calendar

A Seasonal Calendar displays seasonal trends and patterns throughout the year. It records important information such as cropping seasons, labor availability, rainfall, pests and diseases, food availability, and income flow. This tool helps in planning agricultural interventions that are climate-resilient and well-timed to local conditions.

4. Problem Ranking / Matrix Ranking

In this technique, community members collectively list out their problems and rank them based on urgency or impact. It helps identify priority areas for development or intervention. Matrix ranking may involve scoring different options (e.g., crop varieties, farming tools) against criteria like cost, availability, and suitability.

5. Venn Diagram (Institutional Mapping)

A Venn Diagram is used to understand the roles and relationships of different institutions in a village. Circles represent organizations such as banks, cooperatives, NGOs, KVKs, and health centers. The size of the circle indicates importance, and its placement shows accessibility or influence. This tool helps assess institutional trust and connectivity in the community.

Challenges

While Participatory Rural Appraisal (PRA) offers significant benefits in empowering communities and improving extension outcomes, it also faces certain challenges in practice. One major concern is the time-consuming nature of PRA, especially when applied in large-scale implementations without proper planning and support. There is also a strong need for well-trained facilitators who possess both technical knowledge and the sensitivity to guide participatory processes without bias. Additionally, possible manipulation of participation can occur when community involvement is superficial or symbolic, rather than truly inclusive. Ensuring genuine community engagement and building a pool of skilled facilitators are critical steps in overcoming these challenges and maintaining the integrity of PRA in modern extension systems.

Way Forward

To strengthen the role of Participatory Rural Appraisal (PRA) in modern agricultural extension, it is vital to focus on training extension workers in PRA methodologies, ensuring they are equipped with facilitation skills and a participatory mindset. The digitization of PRA data collection and integration with digital platforms and Geographic Information Systems (GIS) can expand its reach and enhance data accuracy. Encouraging active participation of women and youth is essential to make the process more inclusive and gender-sensitive. Furthermore, linking PRA outcomes with policy decisions and local governance structures bridges the gap between grassroots insights and institutional action. Such efforts can ensure that PRA becomes a powerful tool for community empowerment and sustainable rural development.

Conclusion

In an era of precision farming and digital technologies, PRA reminds us to not lose sight of the human and participatory dimensions of agriculture. By allowing farmers to analyze, express, and lead, PRA ensures that extension services are not only effective, but also inclusive and sustainable. As Dr. Robert Chambers believed, the best insights come not from experts talking—but from villagers drawing in the dust.

In a time when participation, sustainability, and inclusivity are keywords in agricultural development, PRA serves not just as a tool, but a transformative approach. Its relevance in modern extension lies in its ability to connect hearts before hands, listen before acting, and empower before implementing. By putting the rural community at the center of decision-making, PRA makes extension not just effective, but truly meaningful.

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Modulating the Gut Microbiota: The Role of Probiotics and Prebiotics in Human Health

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Introduction

The age-old quote "Let food be the medicine and medicine be the food", by Hippocrates is the ideology of today's health-conscious population (Pandey *et al*.,2015). The concept of functional food stated that food is not only for living but also important in the prevention and reduction of risk factors for several diseases and are also capable of enhancing certain vital physiological functions. Functional foods not only provide essential nutrients like vitamins, fats, proteins, and carbohydrates, but they also have the ability to positively influence gut microflora (Rajesh et al., 2020). By including these foods in our diet, we can help maintain a healthy balance of gut microbes and support their metabolic activities. An imbalance or alteration in this microbial community has been linked to various diseases-and in turn, illness itself can further disrupt the gut microbiota (Dhar et al., 2020). A growing body of evidence highlights the beneficial effects of functional foods on the immune system and their role in reducing disease susceptibility (Olaimat et al., 2020). As public health expert William Foege emphasized, balanced nutrition isn't just about health maintenance—it also plays a powerful role in disease prevention (Infusino et al., 2020; Rajesh et al., 2020).

Human Gut Microbiota

The human gastrointestinal (GI) tract is not only our digestive powerhouse but also the largest immune organ in the body. Gut is home to a vast and diverse community of microorganisms known as the gut microbiota. Remarkably, our bodies contain about ten times more microbial cells than human cells (Dhar et al., 2020). These microbes don't just live in our gut-they're also found on our skin and in body fluids, forming an intricate ecosystem that lives in close partnership with us. We share a symbiotic relationship with these tiny organisms. While we offer them shelter and nutrients, they support us in countless ways-helping with digestion, producing essential vitamins, and training our immune system (Gänzle et al., 2021). Every person's gut microbiota is unique, and it plays a crucial role in protecting against harmful pathogens, breaking down complex carbohydrates, and shaping the development of our immune system (Cho and Blaser, 2012). These gut microbes regularly interact with immune cells, often promoting health and balance in the body. However, when harmful bacteria gain the upper hand and disrupt this balance, it can lead to a variety of diseases. Changes in the composition of our gut microbiota have been linked to numerous health issues. As research continues to grow, it's becoming clear that these microbes are vital players in our metabolism and immunity-and they may hold the key to developing new therapeutic strategies (Hu Jielun et al., 2021).

Probiotics

Probiotic term was derived from the Greek word pro, means "promoting" and biotic, means "life". Probiotic term was firstly introduced by Vergin while studying the detrimental effects of antibiotics and other microbial substances, on the gut microbial population (Pandey *et al*.,2015). Later in 1965 Lilly and Stillwell redefined the term probiotic as "A product produced by one microorganism stimulating the growth of another microorganism". Currently, probiotics defined by the Food and Agriculture Organization of the United Nations (FAO) and WHO as "live microorganisms which when administered in adequate amounts confer a health benefit on the host". Referring beneficial bacteria as probiotics isn't completely true. Probiotic must contain live microorganisms that has got to be beneficial, in adequate amounts to confer a health benefit. Probiotics include bacteria like *Lactobacillus acidophilus, L. amylovorus, L. brevis, L. bulgaricus, L. casei, L. cellobiosus, L. crispatus, L. curvatus, L. delbrueckii spp. bulgaris, L. fermentum, L. gallinarum, L. helveticus, L. johnsonii, L. lactis, L. paracasei, L. plantarum, L. reuteri, L. rhamnosus; Streptococcus thermophilus, Lactococcus lactis, Leuconostoc* *mesenteroides, Pediococcus pento- saceus, P. acidilactici, Bifidobacterium adolescentis, B. animalis, B. bifidum, B. breve, B. essensis, B. infantis, B. laterosporum, B. thermophilum, B. longum, Propionibacterium acidipropionici, P. freudenreichii, P. jensenii, P. thoenii, Enterococcus fecalis, E. faecium, Bacillus alcolophilus, B. cereus, B. clausii, B. coagulans, B. subtilis, Escherichia coli, Sporolactobacillus inulinus;* as well as only yeast such as *Saccharomyces boulardii* and *S. cerevisiae* (Olaimat *et al*., 2020). Probiotics contain beneficial microbes that can be of single strain and mixture of two or multiple strains. Probiotics effects are strain specific. A single strain exhibit different benefits depending on individual or combination uptake. Multi-strain probiotics are more competent than single strain (Markowiak *et al*., 2017). Probiotics exert their beneficial effects on the host through four main mechanisms: interference with potential pathogens, improvement of barrier function, immunomodulation and production of neurotransmitters. Ideal probiotic should be non-pathogenic, non-toxic and non-allergic to host and also able to survive the passage through the digestive system. Probiotic should have good adhesion or colonization property Probiotic should be able to maintain good viability and utilize the nutrients in a normal diet (Pandey *et al*., 2015). For probiotics to be effective, they need to remain stable and retain their beneficial properties throughout processing, storage, and transportation. Ideally, they should also offer anti-inflammatory, antimutagenic, and immune-boosting benefits (Markowiak et al., 2017). Probiotics are commonly consumed through foods or supplements, and they can come from both dairy and non-dairy sources. Dairy-based probiotic foods include familiar items like yogurt, curd, lassi, sour milk, cheese, ice cream, and even frozen synbiotic desserts. On the other hand, non-dairy probiotic options can be plant-based, such as bread, bakery items, health drinks, puddings, fruits, and vegetables, or even animal-based products like dry meat and fish sausages (Rajesh et al., 2020).

The health benefits of probiotics are wide-ranging. They can ease symptoms of lactose intolerance by improving digestion, help prevent allergic reactions, maintain a healthy gut pH, and may even assist in managing heart health by lowering cholesterol levels. Probiotics are also known to support the production of vitamin B, enhance the absorption of dietary calcium, and strengthen the immune system. Beyond simply enhancing nutrient absorption, probiotics actively support overall health and help regulate immune responses (Kechagia et al., 2013). Over the past two decades, they have also been explored as antimicrobial agents against respiratory viruses, including those responsible for infections like the common cold and influenza. The most compelling mechanisms behind their antiviral activity involve modulating the innate immune system and enhancing acquired immune responses (Sundararaman et al., 2021).

Research on various viral infections suggests that preventing such diseases often depends on a strong immune system, which can be supported by a balanced diet and the supplementation of key nutrients like vitamins, minerals, fiber, and probiotics (Olaimat et al., 2020). In particular, studies during the COVID-19 pandemic have shown that probiotics may help in prevention or recovery by boosting immune function. This includes the stimulation of Immunoglobulin A (IgA) secretion, and increased activity of Peyer's patches, neutrophils, macrophages, natural killer cells, mesenteric lymph nodes, and intraepithelial lymphocytes—all of which play crucial roles in immune defense (Bottari et al., 2021).

Prebiotics

Prebiotics are nondigestible dietary ingredient that beneficially affects the host by selectively stimulating the expansion or activity of a limited number of bacteria within the colon. Prebiotics concept was introduced by Gibson & Roberfroid in 1995 (Pandey *et al*.,2015). Prebiotics are the food source meant to stay probiotics alive. Prebiotics are an alternate for probiotics or their cofactors. Prebiotics are not bacteria; these are special nutrients. The most common forms (FOS, Inulin, GOS, resistant starch) are based upon 6-carbon sugars such as fructose, glucose, and galactose. XOS, AXOS are based upon 5-carbon sugars, and have a different bonding structure (Markowiak *et al*., 2017). Fermentation of prebiotics by gut microbiota produces short-chain fatty acids (SCFAs), including carboxylic acid, butanoic acid, and propanoic acid. Prebiotics have multiple effects on the body (Rajesh *et al*., 2020). Prebiotics are naturally occurring in many foods. A wide range of plant foods, like whole grains, legumes, tomatoes, bananas, onions, garlic, and Jerusalem artichokes, contain FOS. GOS are less common but occur in breast milk and fermented dairy products (Davani-Davari *et al*.,2019). Ideal prebiotic should supply nutrient to beneficial bacteria and escape digestion in the stomach to reach intestine. It should promote the proliferation of beneficial bacteria (Probiotics). Prebiotic favourably affect the immune system and provide improved resistance against infection. It also helps to increase the absorption of certain minerals such as calcium and magnesium by host body (Markowiak *et al*., 2017). There is no information directly linking prebiotics to COVID- 19 infections in any way, although a indirect effects is also hypothesized (Olaimat *et al*., 2020).

Probiotics and Prebiotics therapy has shown encouraging results in many clinical conditions of human being such as diarrhoea of multiple etiologies, irritable bowel syndrome (IBS), urogenital infections, allergic diseases, high blood pressure etc (Pandey *et al*.,2015). But Pro-prebiotics therapy found to significantly remodel the microbiome of an individual recovering from antibiotic therapy and therefore, recommended for the prevention of secondary infection (Olaimat *et al*., 2020).

Future Prospectus of pro-prebiotics study

Recent technological advancements-such as next-generation sequencing (NGS), metabolomics, and RNA sequencing have significantly propelled research in the fields of probiotics and prebiotics. These tools have deepened our understanding of how probiotics function, how they interact with the body's native microbiota, and how they ultimately impact human health. In particular, the rise of bioinformatics has played a crucial role in advancing probiotics and prebiotics research. Bioinformatics tools allow researchers to explore beneficial microorganisms in much greater detail, enabling their targeted use, safety evaluation, and overall effectiveness. The decreasing cost and increased accessibility of NGS technology has made these studies more feasible than ever before. Sequenced genomes of probiotic and prebiotic organisms are now routinely deposited into public databases such as GenBank, DDBJ, and ENA. Specialized platforms like the PROBIO database (for probiotics) and ODRAP database (for prebiotics) offer structured access to data on their functions and properties (Cunningham et al., 2021). Moreover, advances in bioinformatics and data integration have led to the creation of dedicated pro-prebiotic databases and large-scale analytical tools, breaking down many of the previous barriers in studying their effects. These technologies not only enhance our mechanistic understanding of how probiotics and prebiotics work but also help identify new candidate strains and substrates for future applications.

The scientific literature in this field has also expanded rapidly, especially in areas involving high-throughput analyses of the gut microbiome. In the coming years, research is expected to focus on integrating data from various omics platforms, including metagenomics, metatranscriptomics, metaproteomics, and metabolomics (Day et al., 2019). These multi-omics technologies are revolutionizing microbiome research by allowing for comprehensive characterization—from genetic blueprints to functional metabolic outcomes. As these technologies become more interconnected and sophisticated, they will provide a more complete picture of the physiological and biochemical interactions between host and microbes, opening new doors for health and therapeutic innovations (Kurian et al., 2021).

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ATHLETIC HEART IN DOGS

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Introduction:

Physiological adaptations that occur in the hearts of animals which include bradycardia, change in cardiac volumes like stroke volume (volume of blood pumped into the aorta / pulmonary trunk by each ventricular contraction (left / right) is referred to as stroke or pulse volume which is caused due to Ventricular Hypertrophy, all such adaptations are necessary for normal physiology of the body.

An athletic heart is commonly seen sporting type of dogs due to several factors related to their physiology, genetics, and lifestyle. The heart of an athletic dog works as a finely tuned machine, pumping blood efficiently to deliver oxygen and essential nutrients to all parts of the body especially muscles during intense training. The canine heart undergoes changes when a dog engages in continuous physical training.

Diagnosis:

1. **Increased Heart Size**: The heart chambers, especially the left ventricle, can enlarge to accommodate increased blood flow.
2. **Improved Stroke Volume**: The amount of blood ejected with each heartbeat (stroke volume) increases, allowing for more effective circulation during both rest and exercise.
3. **Lower Resting Heart Rate/Bradycardia**: Athletic dogs often have a lower resting heart rate (bradycardia) due to improved efficiency. This means the heart doesn't have to beat as often to maintain adequate circulation.
4. **Enhanced Myocardial Efficiency**: The heart's muscles adapt to intense training, become more efficient and tolerant, which allows the heart to work harder without experiencing fatigue.
5. **Increased Capillary Density**: Regular training can lead to an increase in capillary networks within the heart and surrounding muscles, improving oxygen delivery and waste removal to maintain the homeostasis.

Diagnostic Tests:

- **Electrocardiography (ECG):**

1. ECG can reveal sinus arrhythmia, variability in heart rate, these are common symptoms of athletic heart of a dog.
2. Changes in the QRS duration and the QT interval are observed in ECG of highly trained dogs.

- **Echocardiography:**

1. Its helps differentiate physiologic LVH (left ventricle hypertrophy) from pathologic hypertrophy.

Differential Diagnosis:

It is important to differentiate athletic heart from other heart conditions that may cause similar changes.

- Hypertrophic cardiomyopathy (HCM): it is a heart condition where the heart muscles, (particularly the walls of left ventricle) becomes thickened and this thickening can cause difficulty in pumping blood and causes myocardial fibrosis.
- Dilated cardiomyopathy: a disease in heart muscle that results in weakened and enlarged heart chambers.
- Valvular heart disease: degeneration of heart valves, leading to cardiac murmurs and heart failure.

Physiological Advantages of Athletic Heart

Hypertrophy is necessary for improved stroke volume as increased of heart size can enhance the cardiac output by pumping more blood/ beat, overall blood circulation and enhancing oxygen delivery to time leading to better performance.

It also helps in improving blood pressure regulation. Enhanced myocardial efficiency can reduce stress helping in better adaptation and intensifying the recovery.

Increased capillary density helps for reduce risk of ischemia (Ischemia refers to a condition where there is insufficient blood flow to a specific area of the body which leads to tissue death).

Conclusion:

Athletic heart in dogs is generally considered benign and doesn't require treatment, but it is crucial to monitor the dog for any symptoms like coughing, difficulty in breathing, lethargy or fainting and it is essential to differentiate athletic heart from underlying cardiac disease. Routine veterinary examination, including cardiac auscultation, electrocardiography and echo cardiography are essential to monitor cardiac health in cases of athletic heart. A balanced exercise program, healthy lifestyle, optimal cardiac function and regular veterinary care are essential for maintaining a healthy athletic dog.

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3G Cutting in Vegetables: A Smart Technique to Boost Yield and Productivity

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Abstract

In modern horticulture, improving yield and enhancing plant health while ensuring economic viability are paramount. Among various cultural practices, 3G cutting (Third Generation Cutting) has emerged as a promising technique for yield enhancement and better canopy management in certain vegetable crops, especially tomato, brinjal (eggplant), and chili. It involves systematic pruning of the plant to promote lateral branching and stimulate fruit production. The technique is simple, cost-effective, and eco-friendly, offering an excellent option for small and marginal farmers seeking to maximize productivity without intensive input use.

Keywords: 3G cutting, vegetables, horticulture, improvement, production

Introduction

In modern horticulture, scientific methods of pruning and training are increasingly adopted to improve plant growth, fruiting, and overall yield. One such effective and farmer-friendly technique is 3G cutting, especially beneficial in vegetable crops like tomato, brinjal (eggplant), chilli, and okra. "3G" stands for "Third Generation", referring to the selective pruning of plants to encourage bushy growth, more flowering branches, and ultimately higher production. This approach ensures better sunlight penetration, air circulation, and resource utilization, leading to healthier plants and more fruits per plant. This technique is cost-effective, easy to apply, and plays a significant role in improving crop architecture and productivity by enhancing fruit yield through controlled growth and branching.

3G Cutting

3G cutting is a systematic pruning or pinching method where selective branches of a vegetable plant are removed at different growth stages to encourage the development of side shoots. These side shoots are more productive as they bear more flowers and fruits. The practice is based on apical dominance control, redirecting the plant's energy from vertical growth to lateral growth, which leads to more fruit-bearing branches.

How it works

1. 1G (First Generation Cutting):
   - When the plant reaches about 45–60 days after transplanting or has developed 4–6 true leaves, the top/main shoot is pinched off.
   - This encourages the growth of two new lateral branches (2G).
2. 2G (Second Generation Cutting):
   - When these two branches reach a similar height (around 30–45 cm), their tips are again pinched to promote 3rd generation branches (3G).
   - Each 2G branch gives rise to 2 or more 3G branches.
3. 3G (Third Generation Cutting):
   - The 3G branches are the main fruit-bearing branches. They should be retained and allowed to grow naturally.
   - Avoid further pinching after 3G to let the plant focus on flowering and fruit setting.

Scientific Basis

The principle of 3G cutting lies in manipulating apical dominance, which is the natural tendency of the main stem to grow more vigorously than lateral branches due to the hormone auxin produced at the shoot tip. By removing the apical bud, cytokinins and gibberellins stimulate lateral bud growth, increasing the plant's bushiness and fruit-bearing capacity.

Benefits of 3G Cutting in Vegetables

- Increases Yield: Encourages more flowering and fruiting sites per plant.
- Compact Plant Growth: Helps maintain a bushy, strong structure that supports more fruits.
- Improves Air Circulation and Sunlight Penetration: Reduces the risk of fungal diseases.
- Better Pest and Disease Management: Makes it easier to monitor and control pests.
- Cost-effective: Requires no external inputs or chemicals.

Suitable Crops for 3G Cutting

Tomato

Most common crop for 3G cutting.
Typically results in a 30–50% increase in yield.
Best suited for indeterminate varieties.

Brinjal (Eggplant)

Promotes bushy growth.
Enhances number of marketable fruits per plant.

Chilli and Capsicum (Bell Pepper)

Especially effective in hybrid chilies.
Reduces the chance of viral infections like leaf curl.
Increases productivity significantly under controlled practices.

Okra (Lady's Finger)

Promotes branching and increases productivity

Precautions while practicing 3G cutting

- Use clean and sterilized tools to avoid infection.
- Perform cutting during cool hours (morning or evening).
- Apply cow dung slurry or neem paste on cut surfaces to prevent disease entry.
- Ensure proper irrigation and nutrient supply after cutting for recovery and regrowth.
- Avoid excessive cutting beyond 3G as it may weaken the plant.

Conclusion

3G cutting is a simple yet powerful technique that holds great promise for increasing vegetable productivity without incurring additional costs. By enhancing the plant’s natural branching and fruit-bearing capacity, farmers can achieve better yields, improve crop quality, and adopt a more sustainable cultivation practice. With increasing awareness, this technique is gaining popularity among vegetable growers across India.

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Importance of Next Generation Feeds and Fodders: Improving Livestock Health and Production in Climate Change Scenario

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Introduction

Livestock systems worldwide are under intense pressure due to the compounded challenges of climate change, population growth, declining natural resources, and the need for sustainable agricultural practices. Livestock production is a major component of global agriculture, contributing significantly to food security, rural livelihoods, and national economies. Feed and fodder availability, quality, and efficiency play a pivotal role in determining the health, productivity, and environmental footprint of livestock production.

However, traditional livestock feeding systems are increasingly becoming unsustainable due to environmental degradation, resource scarcity, and climate change. Feed constitutes over 60–70% of the total cost of animal production. Yet, in many parts of the world, especially in developing countries, feed scarcity and poor quality remain critical constraints to animal productivity. The advent of next-generation feeds and fodders encompassing innovations in genetic improvement, alternative feed resources, precision nutrition and biotechnology represents a transformative approach to ensure sustainable and climate-resilient livestock systems.

Climate change has exacerbated these challenges, affecting the quantity and quality of available forage and increasing the frequency of feed shortages. Rising temperatures, erratic rainfall, and increased incidence of extreme weather events disrupt pasture ecosystems and crop-livestock interactions. This necessitates a paradigm shift toward climate-smart, sustainable, and innovative feed strategies. Enter next-generation feeds and fodders, which include high-yielding and drought-tolerant forage crops, alternative protein sources like insect meal and algae, precision-fed rations and digital feed management technologies. This article explores the importance of next-generation feeds and fodders in improving livestock health and productivity under current climate change scenarios, highlighting key strategies, innovations, and future directions.

Climate change and its impact on livestock production

Effects on feed resources

Climate change directly affects the growth, distribution, and nutritional composition of feed crops and forages. Rising temperatures and erratic precipitation patterns reduce pasture availability and increase desertification. Drought stress leads to reduced biomass, protein content, and digestibility of forage crops.

Impact on livestock health

Heat stress and poor nutrition weaken immune responses, reduce reproductive efficiency, and elevate disease susceptibility in livestock. Water scarcity further exacerbates health and productivity losses, making it essential to enhance feed-water efficiency.

Greenhouse gas emissions

The livestock sector contributes approximately 14.5% of global greenhouse gas (GHG) emissions, mainly through methane (CH_4) from enteric fermentation and nitrous oxide (N_2O) from manure. Feed quality and digestibility directly influence emission levels, emphasizing the role of improved feeds in climate mitigation.

Role of feeds and fodders in livestock systems

Traditional feeds: Limitations

Traditional feed resources, including crop residues, low-quality grasses, and conventional grains, are often inadequate in protein, energy, and essential micronutrients. Over-reliance on such feeds leads to suboptimal performance and high methane emissions.

Importance of nutritive feeds

Balanced and nutrient-rich feeds improve animal growth, milk yield, fertility, and disease resistance. Feed efficiency also determines the economic viability of livestock farming and its environmental sustainability.

Next-generation feeds and fodders: Innovations and technologies

As the global demand for animal protein increases, the livestock sector faces the dual challenge of boosting productivity while minimizing environmental impact. Traditional feeding systems are no longer sufficient to meet these goals, prompting the development of next-generation feeds and fodder technologies. These innovations aim to enhance animal nutrition, improve feed efficiency, and promote sustainability across animal husbandry systems.

Alternative protein sources

One of the most transformative innovations is the incorporation of novel protein sources into animal diets. Insects such as black soldier fly larvae, algae (e.g., spirulina), and single-cell proteins derived from fungi and bacteria offer high protein content, fast growth cycles, and low resource requirements. These alternatives not only reduce dependency on conventional soy and fishmeal but also contribute to a circular economy by converting organic waste into high-value feed.

Insect meal: Rich in protein and amino acids; black soldier fly larvae and mealworms are gaining traction as sustainable protein sources.

Algae and seaweeds: Spirulina and red algae offer high protein and reduce methane emissions when added to cattle diets.

Single-cell proteins (SCP): Derived from fungi, yeast, or bacteria, SCPs utilize agricultural waste for protein-rich feed production.

Genetically improved forages

Through conventional breeding and genetic modification, new forage varieties have been developed with higher biomass yield, improved digestibility, and enhanced resistance to drought and pests. Crops like Napier grass, alfalfa, and hybrid sorghum are being optimized for nutrient content and adaptability, ensuring consistent feed availability in diverse agro-climatic zones.

Precision feeding technologies

Precision livestock farming integrates sensors, automated feeders, and AI-driven decision tools to monitor individual animal health and adjust feed intake in real-time. These technologies optimize feed conversion ratios, reduce waste, and allow for targeted nutrient delivery based on species, age, and physiological needs. Mobile applications and smart collars are making such systems increasingly accessible to small and medium-scale farmers.

Fermented and treated fodder

Ensiling and fermentation techniques enhance the nutritional value of roughages while increasing shelf life. Use of microbial inoculants and enzymes can improve fiber digestibility and reduce anti-nutritional factors. Additionally, biofortification of fodder with minerals and probiotics supports better animal health and productivity.

Climate-smart feed production

Climate-resilient fodder systems, including hydroponics and vertical farming of green fodder, are gaining attention. These systems use minimal land and water resources while producing high-quality forage year-round. Integration of solar-powered irrigation and smart water use further enhances sustainability.

Digital platforms and feed formulation software

Access to real-time data and cloud-based platforms helps farmers make informed decisions about feed sourcing, mixing ratios, and inventory management. Open-source feed formulation software allows precise nutrient balancing, which improves growth performance and reduces environmental load from excess nutrients.

High-yielding, climate-resilient forage crops

Genetically improved fodder varieties hybrid Napier such as drought-resistant sorghum and legumes like Stylosanthes) show greater biomass production, nutritional density and stress tolerance. Agroforestry systems integrate multipurpose trees with pastures to enhance fodder availability, shade, and soil fertility.

Feed additives and supplements

Probiotics, enzymes, and prebiotics enhance gut health and nutrient absorption. Rumen modifiers like tannins and essential oils reduce methane production by altering microbial fermentation pathways. Bypass protein and fat supplements increase nutrient availability in high-yielding dairy animals.

Precision feed formulation

Use of nutritional modeling software and Artificial Intelligence (AI) helps formulate customized rations based on animal needs, feed composition, and environmental conditions.

Near-infrared spectroscopy (NIRS) rapidly assesses feed quality to improve ration balancing.

Digital feed management

Smart feeding systems, automated feeders, and IoT sensors monitor feed intake, digestion efficiency, and health indicators in real time. Data-driven decisions reduce feed waste and improve fanimal performance.

Innovations in feed and fodder technologies are redefining animal agriculture. By embracing sustainable practices, alternative ingredients and smart technologies, the livestock sector can achieve higher productivity, reduce its ecological footprint and ensure food security for a growing global population.

Sustainable fodder production and conservation

With increasing pressure on global food systems, sustainable fodder production and conservation have become critical to ensuring the long-term viability of the livestock sector. Traditional fodder practices, often dependent on seasonal availability and natural pastures, can no longer meet the growing demands of intensified animal production. Next-generation approaches focus on resource efficiency, climate resilience, and year-round availability of quality fodder, while minimizing environmental impact.

Climate-resilient fodder crops

One of the key strategies in sustainable fodder production is the use of climate-resilient forage species. Drought-tolerant crops like Napier grass, cowpea, lucerne (alfalfa), and sorghum are being widely adopted for their high biomass yields and adaptability to changing climatic conditions. These crops are often more resistant to pests and diseases, reducing the need for chemical inputs and ensuring consistent feed supply even in extreme weather.

Integrated farming systems

Integrating fodder production into existing cropping systems enhances land use efficiency and promotes sustainability. Intercropping legumes with cereals, agroforestry systems, and crop-livestock integration enable farmers to produce both food and fodder from the same land. Legumes also fix atmospheric nitrogen, improving soil fertility and reducing dependency on synthetic fertilizers.

Hydroponics and vertical fodder cultivation

Hydroponic green fodder systems allow farmers to grow high-quality forage such as barley, maize, and wheat grass in controlled environments without soil. These systems use 80–90% less water than traditional methods and produce fodder within 7–10 days, making them ideal for areas with limited land and water resources. Vertical farming adds another dimension by enabling multi-layer production in confined spaces.

Conservation techniques: Silage and haymaking

Properly fermented silage and sun-dried hay allow year-round feed availability. Crops like maize, sorghum, and legumes can be conserved during surplus periods. To ensure year-round feed availability, conservation methods such as silage and haymaking are increasingly important. Silage, made by fermenting green fodder in anaerobic conditions, preserves the nutritional quality for several months. It is particularly useful during lean periods or drought. Haymaking, where fodder is dried and stored, is also widely practiced for preserving excess forage during peak seasons.

Use of renewable energy and sustainable inputs

Sustainable fodder production also involves reducing the carbon footprint of farming operations. Solar-powered irrigation systems, organic fertilizers, and reduced tillage techniques help in conserving energy and maintaining soil health. Encouraging the use of local and recycled inputs—such as compost and manure—enhances ecosystem services and supports circular farming models.

Sustainable fodder production and conservation are vital for resilient and productive livestock systems. By adopting climate-smart crops, modern cultivation methods, integrated systems, and efficient conservation techniques, farmers can ensure continuous, high-quality fodder supply while protecting the environment and natural resources for future generations.

Intercropping and crop residue management

Sustainable fodder intercropping and effective crop residue management are essential components of next-generation feeding strategies aimed at improving livestock nutrition, farm productivity, and environmental health. Intercropping involves growing fodder crops alongside main food crops, optimizing land use and enhancing soil fertility. Legume-cereal intercropping enhances biomass and soil fertility. Crop residues like straw and stover's are enriched using urea or fungal treatment to improve digestibility. For instance, intercropping maize with leguminous fodder like cowpea or lucerne improves biomass yield and provides a balanced feed rich in protein and energy. Legumes also fix nitrogen in the soil, reducing fertilizer needs and promoting sustainable agriculture.

Crop residues such as paddy straw, wheat straw, and maize stover are abundantly available post-harvest and offer significant potential as livestock feed. However, they are often underutilized or burned, contributing to pollution. Innovative treatments like urea enrichment, microbial inoculation, and densification improve their digestibility and nutritional value, transforming them into viable feed resources.

Integrating intercropping and crop residue management not only ensures year-round fodder availability but also supports circular agriculture by minimizing waste. These approaches enhance soil health, reduce feed costs, and promote climate-smart livestock farming. When combined with appropriate conservation methods like silage or haymaking, they form a robust foundation for sustainable, resilient, and efficient animal feeding systems.

Case studies and success stories

India: Climate-resilient fodder crops

The Indian Council of Agricultural Research (ICAR) developed improved varieties of cowpea, sorghum and berseem that withstand drought and yield high-quality fodder.

Africa: Brachiaria grass adoption

In East Africa, the introduction of Brachiaria grass improved milk yields by 15–40% due to its high crude protein content and climate adaptability.

Europe: Methane-reducing feeds

In Denmark and the Netherlands, inclusion of *Asparagopsis taxiformis* (red seaweed) in dairy rations cut methane emissions by over 30%.

Benefits of next-generation feeds

Enhanced livestock productivity

Improved nutrient profiles result in higher milk yield, weight gain, reproduction efficiency, and lower mortality rates.

Climate change mitigation

Better feed digestibility reduces methane emissions. Use of by-products and waste as feed lowers the environmental footprint.

Economic gains

Increased feed efficiency leads to lower input costs and higher profitability for farmers.

Improved animal welfare

Balanced nutrition improves immunity, reduces disease burden, and enhances the overall well-being of animals.

Challenges and barriers

- High cost of advanced feed technologies and supplements,
- Lack of awareness and training among smallholder farmers,
- Inadequate extension services and supply chain infrastructure,
- Regulatory hurdles in approving new feed ingredients (e.g., insects, algae),
- Research gaps in region-specific forage performance under changing climates.

Policy recommendations and future strategies

Investment in research and development

- Breeding programs for stress-tolerant fodder varieties,
- Biotechnological innovations in feed conversion and nutrient absorption,

Public-private partnerships

Collaboration among governments, research institutions, feed companies and farmers can drive innovation and scale-up adoption.

Capacity building

Training programme should be conducted for farmers and veterinarians in modern feed practices, digital tools and ration balancing.

Incentives and subsidies

Some incentives and subsidies should be provided as financial support for silage making, hydroponic units and improved seed access.

Environmental regulations

Enforcing standards to reduce emissions from feed-livestock systems while encouraging circular bio-economy models (e.g., waste-to-feed).

Conclusion

The livestock sector stands at a crossroads, where the demands of a growing population, environmental sustainability and resilience to climate change must be addressed simultaneously. Feed and fodder systems lie at the heart of this transformation. Next-generation feeds and fodders offer the potential to unlock sustainable, productive and climate-smart livestock farming. However, this potential can only be realized through integrated approaches that combine scientific innovation, farmer engagement, policy support and infrastructural investment. Ensuring availability, accessibility and affordability of these advanced feeds is crucial, especially for smallholders who form the backbone of livestock production in many countries. In the face of an uncertain climate future, resilient feed systems are not just an option they are a necessity. Through collective action, the next generation of feeds and fodders can ensure a healthier, more productive and sustainable future for livestock and the people who depend on them.

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Sowing of Seeds and Raising of Seedlings for Annuals Flowers

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Annuals flowers are a group of herbaceous plants which grow from seeds, produce flowers, set seeds and complete their life-cycle within one year or one season. But in their brief sojourn on earth, they exude the joy of life, putting forth a great profusion of flowers in a spectacular range of colours. They provide a beautiful display of colours in the garden. Therefore, more people prefer annuals to other plants for growing in pots, beds, borders, window boxes, hanging baskets or as cut flower for interior decoration. Whether it is a small home garden or a big public garden, it is incomplete without beds of annual flowers. They enhance the decorative value of a garden within a short span of time. At their blooming time, one feels elated when a rain of beauty drizzles in the garden.

USES:

1. Flowering annuals are grown in beds and pots.
2. They are used for various purposes in the garden.
3. In beds, they are grown individually with or without perennial plants in borders.
4. They are grown in hanging baskets,

a) Window boxes or
b) rock gardens,
c) for training on walls and trellises and
d) for planting in the form of edges,
e) Borders or ground covers.

5. Some annuals *viz.*, marigold, china aster, gypsophila, statice, gaillardia, annual carnation, annual chrysanthemum, cornflower, sweet sultan, bells-of-Ireland, piminella and larkspur are grown commercially for cut flowers for interior decoration or for loose flower purpose in Karnataka, Andhra Pradesh, Maharashtra, West Bengal, Uttar Pradesh, Rajasthan, Haryana, Madhya Pradesh, Tamil Nadu and Delhi.
6. Dried flowers of some annuals are also used for interior decoration.
7. Some annuals provide sweet fragrance.

Classification

Based on season, the annual flowers are divided into 3 groups

1. Winter season annuals,
2. Summer season annuals and
3. Rainy season annual flowers.

1. Winter season annuals

This group includes a large number of seasonal flowers. The important ones are acroclinium, agrostemma, amaranthus, anchusa, annual carnation, annual chrysanthemum, antirrhinum, arctotis, bells-of-Ireland, brachycome, calceolaria, calendula, campanula, candytuft, celosia, China aster, cineraria, clarkia, cornflower, daisy, delphinium, dianthus, dimorphotheca, echium, eschscholzia, gazania, godetia, helichrysum, helipterum, hollyhock, gypsophila, limonium, linaria, linum, lupin, marigold, matricaria, mesembryanthemum, mignonette, mimulus, myosotis, nasturtium, nemesia, nicotiana, nemophila, nigella, pansy, petunia, phlox, pimpinella, poppy, rudbeckia, salvia, saponaria, scabiosa, schizanthus, senecio, stock, sweet alyssum, sweet pea, sweet sultan, sweet william, venidium, verbena, viola and wall flower.

2. Summer season annuals

The common summer season annuals are coreopsis, cosmos, gaillardia, kochia, marigold, portulaca, sunflower, tithonia, zinnia etc.

3. Rainy season annuals

This group includes all summer season annuals and others like amaranthus, balsam, celosia, gomphrena and torenia.

List of widely cultivated annuals

1.	Acroclinium	2.	Ageratum	3.	Amaranthus
4.	Anchusa	5.	Antirrhinum	6.	Arctotis
7.	Balsam	8.	Calendula	9.	Candytuft
10.	Carnation (annual)	11.	Celosia	12.	China Aster
13.	Chrysanthemum	14.	Cineraria	15.	Clarkia
16.	Coreopsis	17.	Cornflower	18.	Cosmos
19.	Daisy	20.	Dianthus	21.	Dimorphotheca
22.	Eschscholzia	23.	Gaillardia	24.	Garden Poppy
25.	Gazania	26.	Godetia	27.	Gomphrena
28.	Gypsophila	29.	Helichrysum	30.	Hollyhock
31.	Larkspur	32.	Limonium	33.	Linaria
34.	Lupin	35.	African Marigold	36.	French marigold
37.	Matricaria	38.	Mignonette	39.	Myosotis
40.	Nasturtium	41.	Nemesia	42.	Nicotiana
43.	Nigella	44.	Pansy	45.	Petunia
46.	Phlox	47.	Portulaca	48.	Primula
49.	Rudbeckia	50.	Salvia	51.	Scabiosa
52.	Schizanthus	53.	Stock	54.	Sunflower
55.	Sweet Alyssum	56.	Sweet Pea	57.	Sweet Sultan
58.	Sweet William	59.	Venidium	60.	Viola
61.	Wall Flower	62.	Zinnia	63.	Mesembryanthemum

Propagation

Almost all annuals can be propagated by seeds. Marigolds can be propagated by cuttings also. Their sowing time depends upon climate. It varies in different parts of India.

I. Northern plains

1. **Winter season** annuals are sown during September-October. However, late-flowering types-China aster, carnation and cineraria are sown during August–September.
2. **Summer season annuals**: January–February
3. **Rainy season annuals**: May–June.

II. South India: September-October is ideal time for sowing annuals.

III. Northern hills: March–April is most appropriate time for sowing annual flower seeds, whereas March–May in southern hills.

Sowing and Bed preparation:

The seeds of annual flowers are sown in nursery beds, earthen pots, seed pans or wooden seed trays. The seeds of a few annuals like sweet pea, morning glory, lupin nasturtium and hollyhock which have bold seeds can be sown directly at permanent places. The seed compost should consist of one part each of garden soil, coarse sand, farmyard manure and leaf-mould. For preparing the nursery beds, the soil should be dug up thoroughly and sufficient farmyard manure should be mixed in soil. Raised nursery beds of convenient size (normally 60cm wide and 15cm high) should be prepared. If soil is heavy, some quantity of sand may be added. It is better if the soil of nursery bed or earthen pots is sterilized with 2% formalin. For this, soil is drenched with formalin solution and is covered with polythene sheet for 45hr. afterwards, the polythene is removed and soil is dried before sowing the seeds. Before sowing, the seeds should be treated with Captan (0.2%) prevent the seedlings from damping off disease. The seeds should be sown thinly and evenly as thick sowing causes damping off of seedlings. Mixing of fine sand in very small seeds is advisable for even sowing.

The seeds of echium, lobelia and flowering tobacco do not germinate unless first exposed to sunlight, while seeds of nigella and cineraria germinate only in dark. The seeds recently harvested from the plant, although given required conditions, fail to germinate. This may be due to physical condition or chemical reaction of seed coat of seeds. Seeds of clianthus need stratification or scarification for germination. Some seeds require after ripening period for germination. In nursery beds, the seeds are sown in rows spaced 6cm apart. Then, they are covered with finely sieved leaf-mould. Watering is to be done with a watering can having a fine rose both in beds and pots. In beds, when germination is over, water is given for proper moisture. Thereafter, the beds should be kept weed-free.

Cultivation

Planting

Their seedlings are transplanted 25 days after sowing at 4-leaf stage. Before transplanting, seedlings are hardened off by withholding water for 1 or 2 days or by exposing them gradually to sunlight. Transplanting is, generally, done either on a cloudy day or in the evening. Transplanting in evening is good as the night cool temperature is beneficial for the establishment. Light watering every day in early morning or late in the afternoon is required for about a week for proper establishment of the seedlings.

I. **Dwarf annuals** (30cm × 30cm): Acroclinium, ageratum, sweet alyssum, arctotis, daisy, brachycome, cacalia, calceolaria, campanula, wallflower, cuphea, cynoglossum, dianthus, echium, eschscholzia, felicia, gaillardia, gazania, godetia, candytuft, linaria, linum, lobelia, matricaria, stock, mesembryanthemum, mimulus, nemesia, nemophila, nierembergia, pansy, petunia, phacelia, phlox, portulaca, mignonette, salpiglossis, scabiosa, French marigold, torenia, nasturtium, venidium, verbena and viola.

II. **Medium-tall annuals (**45cm × 45cm) : Agrostemma, amaranthus, Anchusa, antirrhinum, Calendula, celosia, Sweet sultan, Cornflower, Cineraria, Clarkia, coreopsis, Cosmos, Larkspur, Carnation, Digitalis, Dimorphotheca, Gomphrena, gypsophila, Balsam, Kochia, Limonium, Lupin, bells-of-Ireland, Nicotiana, Nigella, garden poppy, Rudbeckia, salvia, Schizanthus and African marigold

III. **Tall annuals** (60cm apart): Hollyhock, Chrysanthemum, Sunflower, Helichrysum, Heliotrope, Pimpinella and Zinnia.

Manuring and fertilization

The farmyard manure or compost @ 3kg/m^2 is mixed in the soil. Chemical fertilizers— 20g urea, 60–120g superphosphate and 30–60g muriate of potash/m2 should also be added. Half quantity of urea and full of superphosphate and muriate of potash should be applied at the time of bed preparation. The remaining quantity of urea must be applied one month after transplantation. Spraying plants with 2% urea twice or thrice is beneficial for good growth and flowering. Fertilizers should never come in the direct contact of the foliage since they cause scorching. Fertilizers should never be applied in the pot-grown annual flowers. However, some readymade pot-mixtures can be used. The pot-mixture should consist of 2 parts of garden soil and one part each of coarse sand and farmyard manure. Instead of fertilizers, it is better if pot-grown plants are given liquid feeding. The liquid manure is prepared by fermenting 1–2kg each of fresh cowdung and oil cake in 10 litres of water in a drum for one week. It is diluted to tea colour and sieved with the help of a muslin cloth. It is applied @ 500–1000ml/ pot at 7–10 days intervals.

Growth and flowering

Environmental factors and various cultural conditions affect growth and flowering of many annuals. The *Cosmos bipinnatus*, *Nicotiana* sp. and *Callistephus chinensis* are typical short- day plants for vegetative growth and flowering, while *Dianthus barbatus* and *Nigella damascena* are typical long-day plants for vegetative growth as well as flowering. On the other hand, some annuals require long days for flower initiation followed by short days for flower development. An imbalance of N either hastens or delays flowering. Clarkia, candytuft and salvia flower prematurely if the soil is deficient in N. If N level is high in soil, sunflower, lupin, flowering tobacco and African marigold flower prematurely.

Growth retarding or promoting substances play a major role in getting dwarf plants or higher flower yield. Growth retarding chemicals—CCC (1,000–2,000ppm), B-Nine (2,000– 5,000ppm) and SADH (1,000–3,000ppm)—are used to control growth and flowering in hollyhock, arctotis, sweet sultan, coreopsis, cosmos, phlox and pansy. These chemicals retard plant height, produce more number of leaves and branches and improve flowering, Similarly, GA3 (100–400ppm) gives beneficial results in respect of growth and flowering in African marigold, China aster and antirrhinum. Application o f these growth substances is more effective at vegetative stage.

Aftercare

After transplanting, beds are weeded, hoed and watered regularly. As soon as seedlings are established in beds, pinching is done for making the plants bushy. Pinching is not practiced in antirrhinum, larkspur, lupin, stock and hollyhock. Sweet pea, carnation, morning glory and nasturtium, have weak, slender or straggling stems. They need support when they are 15–20cm tall. The stakes prepared from split bamboos are painted green so that they can be matched with the foliage colour of the plants. Sometimes, seedlings of carnation, marigold, China aster, cosmos and zinnia produce flower buds at an early stage. These buds should be removed as soon as they appear. The number of buds/stem is reduced by disbudding the auxiliary buds, if large blooms are desired.

Irrigation

Little water is needed everyday up to 7–10 days after transplantation. When the seedlings start new growth, profuse watering once or twice a week is required in beds. Later, frequency and quantity of watering depend upon soil and season. In lighter soils, more frequent irrigation is needed than that in heavy soils.

The season of planting also determines the frequency of irrigation. During summer season, irrigation should be done at weekly intervals in beds, while at 10–12 days intervals in winters. Irrigation during rainy season depends upon prevailing weather conditions. Potted plants need daily watering during summer, whereas on alternate days in winter.

Harvesting and Post harvest management

1. Most of the annual flowers are grown for garden display purpose in various ways.
2. Marigold, China aster, antirrhinum, gypsophila, statice, gaillardia, annual carnation, annual chrysanthemum, cornflower and bells-of-Ireland are grown commercially for cut flower or loose flower purpose. Their flowers are harvested when they are fully open and are sold in the local markets.
3. Antirrhinums are cut when one-third of the florets are open.
4. China aster flowers are cut along with their stems when they develop their original colour.
5. Marigold flowers are harvested when they are fully open.
6. Gypsophila flowers are cut when these are open, but not over mature.
7. The flowers, in general, are cut either late in the afternoon or very early in the morning. After harvesting, cut flowers should be put in a bucket of water filled up to one-fourth of the volume as it helps in their recovery from the shock of being cut away from the plant. As far as possible, the freshly opened flowers should be cut as freshness enhances their shelf-life.

In African marigolds, yield of 20–22 tonnes of fresh flowers is obtained from one hectare crop, whereas in french marigolds 10–12 tonnes/ha of fresh flowers is obtained. China aster gives the yield of 10–12 tonnes/ha of fresh flowers.

Some annuals are used as cut flowers. Therefore, proper post harvest management is necessary for prolonging their vase-life. The flowers are graded according to stem length, flower size, flower shape, flower colour and freshness. The cut flowers/loose flowers of most of the annuals are marketed in local markets. However, cut flowers of gypsophila, bells-of-Ireland and Limonium are traded in the international market.

Woody-stemmed flowers should have their stems split or crushed to enlarge the surface in contact with water. Remove all foliage from stems which are under water otherwise they decay and clog up the xylem vessels of stem. It is better to cut stems diagonally because it exposes more surfaces to water.

Antirrhinum flowers can be stored for short duration at a temperature –0.6°C to 1.7°C. For storing stock cut flowers, 4°C temperature is optimum. Gypsophila flowers can be stored for 1–2 days at 4°C. Statice cut flowers can be stored for 2–3 weeks at 2°C. A temperature of 0°–2°C is suitable for the storage of cut carnations.

Vase-life: Various formulations are used to prolong the vase-life of cut flowers.

1. **Antirrhinum**- a solution containing 300ppm of 8-HQC and 1.5% sucrose is most-suited to enhance

their vase-life.

2. **China aster**- a preservative containing 60g/litre sucrose + 250mg/litre 8-HQS + 70mg/litre CCC + 50mg/litre $AgNO_3$ extends their vase-life. For stock, a preservative containing 0.3g 8-HQC + 0.05g CCC + 50g sucrose/liter is ideal.
3. **Gypsophila**- A solution containing 25ppm $AgNO_3$ and 5–10% sugar produces largest blooms with longest vase-life.
4. **Carnations** -can be increased by placing them in solution containing 10% sucrose + 200ppm 8-HQ

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Warming Waters, Waning Stocks: The Threat of Climate Change to Fish Health and Productivity

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Abstracts

Climate change poses complex and far-reaching threats to the health and productivity of fish populations, carrying significant consequences for the long-term sustainability of global fisheries and aquaculture. Shifts in environmental conditions such as rising ocean temperatures, increasing acidification, changing salinity levels, and a greater incidence of disease are altering fish distribution, growth patterns, and survival rates. These disruptions jeopardize ecosystem balance and place immense strain on communities that rely on aquatic resources for food security and income. Studies show that fish yields have declined over time, species compositions are shifting after disturbances like coral bleaching, and small holder fish farmers particularly in Sub-Saharan Africa, Asia, and parts of Central and Western Africa face heightened risks. Pollution, toxic chemicals, and heavy metals like mercury add further stress, amplifying the challenges to fish health and productivity. Addressing these interconnected threats requires comprehensive adaptation and mitigation strategies, stronger management practices, and targeted research to bridge knowledge gaps and enhance resilience in the sector. This article highlights the urgent need for collective, proactive action to confront climate related pressures and secure the sustainability of fisheries and aquatic ecosystems for generations to come.

Keywords: Climate change; Fish health; Fisheries sustainability; Aquaculture; Ocean acidification; Species distribution; Coral bleaching.

Introduction

Climate change exerts diverse and far-reaching impacts on the health and productivity of fish, with consequences for both natural fisheries and aquaculture systems. Alterations in environmental conditions can shift fish distribution patterns, influence their growth and survival, and in turn affect the abundance and economic worth of fish stocks. Additionally, rising water temperatures and shifts in ocean chemistry disrupt aquatic ecosystems, posing serious challenges to the long-term sustainability of global fish resources. In this article, a spatially explicit mechanistic model covering the three main fish functional groups commonly caught in fisheries was combined with an Earth system model to project future trends up to 2100 (Petrik et al., 2020). To assess how rising temperatures have affected fish productivity, researchers applied population models that account for temperature dependence. These models analysed 235 distinct fish populations spanning 124 species across 38 different ecoregions. The findings indicate that, over the past eight decades, there has been a general decline in fish yields, highlighting the widespread impact of global warming on fisheries productivity worldwide (Free et al., 2019). This research investigates how expected changes in key environmental conditions particularly elevated sea temperatures and heightened ocean acidification resulting from climate change could influence various biological processes of the coral trout (*Plectropomus leopardus*), including its reproductive success, growth performance, and developmental stages. By examining these factors, the study aims to better understand the species' potential vulnerability and adaptability in a warming, acidifying ocean (Prachett et al., 2013).

Climate Change Factors Impacting Aquatic Environments

Climate change exerts a substantial and far-reaching impact on aquatic ecosystems, placing fish populations at particular risk due to a combination of interconnected stressors. Among the most significant of these are rising

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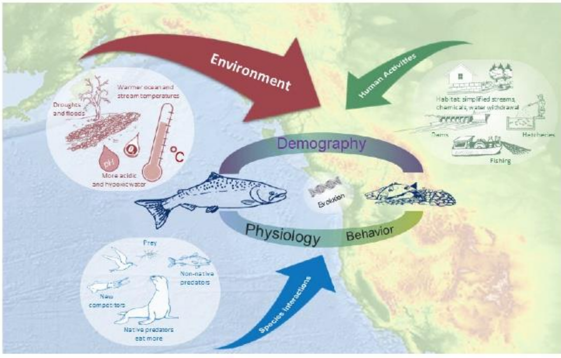
water temperatures, which can disrupt metabolic and reproductive processes; fluctuations in salinity, which can alter habitat suitability and species distributions; and an increased occurrence of diseases and parasites, which further threaten fish health and survival. Together, these factors are reshaping the structure and functioning of aquatic environments worldwide. This review investigates the effects of climate change on the physiological processes of fish, with a specific focus on how variations in temperature and salinity influence their functioning. It emphasizes the critical importance of collective measures to address the extensive consequences that these environmental changes pose for aquatic habitats and the cold-blooded fish species that inhabit them (Agarwal et al., 2024). The ongoing changes in climate are contributing to the rapid expansion of infectious diseases affecting fish worldwide, with increasing water temperatures presenting a significant hazard to aquaculture operations and wild fish populations alike. This escalating risk underscores the necessity for advanced research and robust management measures to help lessen its adverse effects (Okon et al., 2024). As noted by the authors, the effects of climate change and global warming on fisheries and aquaculture have significant consequences for communities and livelihoods, making it essential that adaptation and mitigation efforts remain focused on the people who depend on these sectors (Murthy, 2022).



Source: Crozier, L. G., & Siegel, J. E. (2023)

Impact on Fish Health

Pollution and toxic exposure have profound negative effects on fish health, triggering direct poisoning and disrupting key physiological processes. Such stressors can result in stunted growth, lower energy reserves, greater disease susceptibility, and reproductive challenges. Tackling these issues demands both proactive and reactive approaches, such as enforcing stronger environmental regulations, promoting sustainable methods, upgrading water treatment systems, implementing remediation measures, and restoring degraded ecosystems (Satkar et al., 2024). In this article, the authors underline the crucial role of water quality in maintaining fish health and outline possible control measures to manage it effectively. They also highlight the pressing need for research into how contamination of surface waters with various chemicals relates to disease outbreaks in wild fish populations and the mechanisms driving these interactions (Demeke & Tassew, 2016). This review paper explores how exposure to microplastics, pesticides, and nanoparticles in aquatic environments induces oxidative stress in fish, and considers the potential impacts of these contaminants on human health (Ramalingam et al., 2023). Mercury contamination has a profound negative effect on fish health, resulting in reduced growth, reproductive challenges, impaired immune function, and other physiological complications. Due to bioaccumulation and biomagnification, mercury concentrations are particularly high in apex predators. Addressing this global problem demands swift and collective intervention (Omach et al., 2023).

Impact on Fish Productivity

Climate change affects fish productivity through a range of interconnected pathways, influencing many facets of marine ecosystems and the fisheries that rely on them. It brings about changes in the composition and distribution of fish communities, modifies overall production rates, and disrupts the balance and interactions within marine food webs. These shifts can have cascading effects on ecosystem stability, resource availability, and the sustainability of fishery-dependent livelihoods. In this study, the researchers analysed how fish productivity and community composition changed in the Seychelles following extensive coral bleaching events. They compared reef sites that were able to recover and re-establish coral-dominated habitats with those that underwent a regime shift, becoming dominated by macroalgae instead. This comparison provided insights into how different reef recovery trajectories influence fish populations and ecosystem dynamics (Hamilton et al., 2022). Adjusting practices to cope with climate change is crucial for increasing fish production in ways that do not damage the environment. Various adaptation strategies can help raise aquaculture productivity, support sustainable environmental management, and bolster the sector's capacity to withstand the effects of a changing climate (Ahmed et al., 2019). Forecasts indicate that fish production is expected to increase in regions located at higher latitudes, whereas areas situated in low to mid-latitudes are likely to experience a decline in productivity. However, these trends will not be uniform, as significant regional variations are anticipated due to differing local conditions and ecosystem responses. In general, aside from a few outliers, the projected changes in fish production potential by 2050 are relatively modest, with most estimates suggesting shifts of less than 10%, averaging approximately 3.4% overall (Barange et al., 2014).

Socioeconomic Implications

Climate change exerts significant pressure on both the health and productivity of fish species, resulting in wide-ranging socioeconomic repercussions for communities whose food security and income depend heavily on fisheries and aquaculture. These impacts are multi-dimensional, as they disrupt ecological balance, alter species distribution and abundance, and reduce overall yields. Consequently, the livelihoods of many vulnerable coastal and inland communities face heightened risks, with reduced catches, unstable incomes, and greater competition for dwindling resources further threatening their economic and social well-being. Climate change creates serious socio-economic challenges for smallholder fish farmers across Sub-Saharan Africa. It is essential to thoroughly understand these impacts and develop practical adaptation strategies to help safeguard local livelihoods and ensure that aquaculture remains viable and sustainable in the face of changing climate conditions (Muthoka et al., 2024). In this paper, the researchers evaluated how susceptible 132 national economies are to the potential effects of climate change on capture fisheries, using an indicator-based method. The findings showed that countries in Central and Western Africa including Malawi, Guinea, Senegal, and Uganda as well as Peru and Colombia in northwestern South America, and four tropical Asian nations Bangladesh, Cambodia, Pakistan, and Yemen are identified as being especially vulnerable (Allison et al., 2009). This research explored the effects of climate change on marine socio-ecological systems, with particular attention to how climate-driven changes alter species distribution patterns. It also analysed the different factors that contribute to uncertainty when using models to predict future climate impacts (Jones, 2013).

Adaptation and Mitigation Measures

Climate change exerts significant pressure on fish populations and the broader fisheries sector, highlighting the urgent need for effective adaptation and mitigation efforts. Among the most pressing impacts are rising water temperatures, which can disrupt fish physiology and breeding patterns; shifts in species distribution, which may alter ecosystem balance and affect local fishing communities; and an increased incidence of diseases, which can further threaten the health and productivity of both wild and farmed fish. Together, these challenges pose a serious risk to the long-term viability and sustainability of global fisheries and aquaculture industries. Climate change is widely recognized as one of the most pressing environmental issues of the twenty-first century and continues to generate significant debate and controversy. There is an increasing level of concern about how these climatic shifts could affect fisheries yields and the condition of marine ecosystems, raising questions about future sustainability and resource management (Misganaw et al., 2015). This review explores the possible impacts of climate change on aquaculture production and discusses the implications for the sector's future sustainability. It presents a range of potential adaptation measures that could help the industry cope with these challenges, while also pointing out existing knowledge gaps and emphasizing the need for further research in critical areas (Maulu et al., 2021). In order to lessen the harmful effects of climate change on aquaculture both in Nigeria and worldwide, initiatives are underway to tackle its impact on different aquaculture systems. These actions seek to unpack the complex challenges posed by climate change and to identify practical mitigation measures that can help ensure more effective management and control in the years ahead (Anyanwu et al., 2015).

Conclusion

Climate change poses intricate and wide-ranging threats to fish health, productivity, and the sustainable future of wild fisheries and aquaculture around the globe. Challenges such as increasing temperatures, ocean acidification, shifting species ranges, and the spread of fish diseases disrupt ecosystem stability and jeopardize the well-being of communities that rely on fish for nutrition and livelihoods. These impacts are especially severe in high-risk areas like Sub-Saharan Africa, parts of Asia, and Central and Western Africa, where small-scale fishers are particularly exposed to climate-related risks. In light of these challenges, it is vital to implement comprehensive adaptation and mitigation strategies, expand research to close knowledge gaps, and adopt forward-thinking management practices that protect aquatic resources and strengthen the resilience of fisheries and aquaculture for future generations.

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Reverse Genetics – A Novel Approach for Crop Improvement

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Abstract

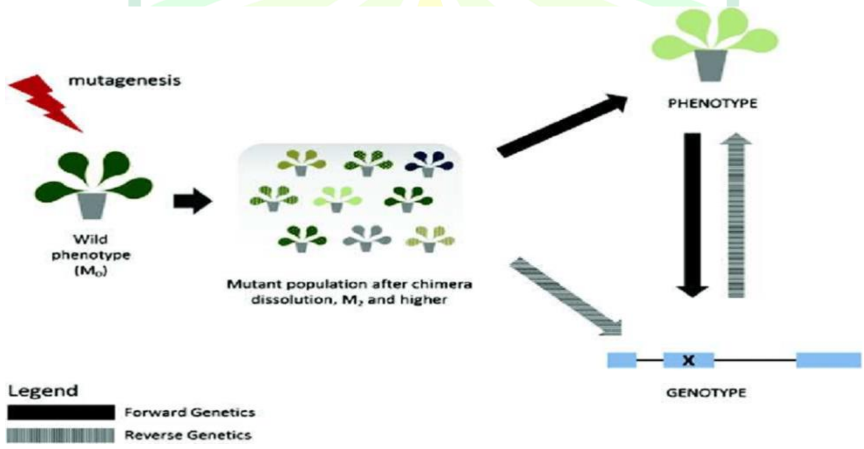
In the post-genomic era, reverse genetics has emerged as a powerful strategy to unravel gene functions and improve crop traits. Unlike forward genetics, which starts from phenotype to discover the underlying gene, reverse genetics begins with a known gene sequence and determines its function through targeted mutations. Advanced techniques such as TILLING, RNA interference (RNAi), antisense RNA technology, genome editing tools (ZFNs, TALENs, CRISPR/Cas9) and artificial microRNAs (amiRNAs) have revolutionized the way we manipulate genomes to achieve specific agronomic traits. Reverse genetics has been successfully employed to improve fruit shelf-life, enhance disease resistance, regulate metabolic pathways and delay bolting and flowering in crops. This review explores the principles, methodologies, achievements and prospects of reverse genetics in crop improvement, highlighting key case studies and recent innovations that exemplify its transformative impact on agriculture.

Keywords: Reverse genetics, TILLING, RNA interference, CRISPR/Cas9, crop improvement, gene silencing, genome editing, antisense RNA

Introduction

Modern agriculture is increasingly challenged by climate change, emerging pests and diseases and the need for higher productivity. Conventional breeding has limitations in precision and speed. Reverse genetics offers a gene-targeted approach for crop improvement by manipulating known DNA sequences to determine gene function and engineer desirable traits.

The transition from classical (forward) genetics to reverse genetics marks a paradigm shift. In forward genetics, random mutations are screened for phenotypes, followed by gene identification. In contrast, reverse genetics begins with a known gene and introduces specific mutations or silencing strategies to evaluate phenotypic outcomes.



Reverse Genetics: Concept and Need

Reverse genetics relies on the central dogma of molecular biology: DNA to RNA to protein. It allows targeted interventions at the DNA or RNA level to disrupt gene function or modulate gene expression. It is especially useful when:

- Gene function is redundant and masked in forward screens
- Phenotypes are subtle or environment-dependent
- Specific allelic variants are desired

- Targeted and non-transgenic approaches are needed

Classification of Reverse Genetics Approaches

Reverse genetics approaches are classified into two main types: targeted gene alteration and non-targeted gene disruption. Targeted alteration involves precise changes at specific loci using methods like RNA interference (RNAi), which degrades target mRNA and homologous recombination, which replaces or modifies gene sequences using a homologous template (Aklilu, 2021).

In contrast, non-targeted disruption includes methods like transposon-mediated mutagenesis, where mobile elements insert randomly into genes and chemical mutagenesis through TILLING, which induces random point mutations using agents like EMS. Both approaches help dissect gene function and improve crop traits through controlled genetic modifications.

Techniques in Reverse Genetics

a) TILLING (Targeting Induced Local Lesions IN Genomes)

TILLING is a non-transgenic technique that combines chemical mutagenesis (e.g., EMS) with high-throughput mutation detection (McCallum *et al.,* 2000). It is a reverse genetics technique that uses the mismatch-specific endonuclease cell to detect point mutations in target genes through heteroduplex formation across a mutant population. It involves PCR amplification with fluorescent primers, reannealing of mutant and wild-type DNA and enzymatic cleavage at mismatch sites. Fragment sizes are analyzed using a system like Li-COR. This method is applicable even in complex genomes like wheat. A major advantage is its non-GMO nature, making it acceptable in countries with strict GMO regulations.

Shelf-life extension in tomato has been successfully achieved through TILLING by inducing mutations in ethylene receptor genes such as SlETR1. These mutations reduced ethylene sensitivity, resulting in delayed fruit ripening, petal abscission and prolonged post-harvest shelf life without compromising fruit quality (Okabe *et al.,* 2011). Similarly, in pea, mutations in the PsBAS1 gene, which is involved in saponin biosynthesis, led to a significant reduction in saponin content. This improvement enhances the organoleptic quality of pea protein by minimizing bitterness, making it more acceptable for human consumption (Vernoud *et al.*, 2021).

Advantages:

- ✓ Applicable to diverse crops
- ✓ Retains public acceptance due to non-transgenic nature

b) RNA Interference (RNAi)

RNA interference (RNAi) is a gene-silencing mechanism where double-stranded RNA triggers the degradation of complementary mRNA, inhibiting gene expression. First discovered in *Caenorhabditis elegans* (Fire *et al.*, 1998), RNAi has become a valuable tool in reverse genetics for studying gene function in the absence of mutant alleles. The process involves the enzyme Dicer cleaving dsRNA into siRNAs, which guide the RISC complex to target and degrade specific mRNAs. RNAi operates across many organisms and is linked to post-transcriptional gene silencing in plants. It enables efficient generation of loss-of-function phenotypes for functional genomics.

Chen *et al.* (2018) used RNA interference to knock down the LsFT gene in lettuce, resulting in delayed bolting and enhanced tolerance to high temperatures. This approach extended the vegetative phase, improving yield and quality under heat stress.

c) Antisense RNA Technology

Antisense RNA technology is a gene-silencing approach that involves introducing a single-stranded RNA molecule that is complementary to a specific messenger RNA (mRNA) in the cell. This antisense RNA binds to the target mRNA through base pairing, forming a double-stranded RNA complex that blocks translation by preventing ribosome attachment or triggering degradation of the mRNA. One of the primary mechanisms of mRNA degradation involves RNase H, an enzyme that specifically cleaves the RNA strand of RNA-DNA hybrids. By inhibiting the translation of specific genes, antisense RNA effectively reduces or eliminates the production of the corresponding protein. This technique has been widely used in plant biotechnology to suppress undesirable traits, such as softening in tomatoes or production of harmful metabolites and serves as a valuable tool for functional genomics and crop improvement (Gupta *et al.,* 2011).

The first commercial application was the Flavr Savr tomato, where polygalacturonase gene expression was suppressed to delay softening. It is the first FDA approved genetically modified food developed by calgene in 1992 (Bruening & Lyons, 2000).

d) Genome Editing Tools

Reverse genetics has been revolutionized by the advent of site-specific nucleases, molecular tools that allow scientists to make precise edits in the genome (Fig. 1). Among these, Zinc Finger Nucleases (ZFNs) were the first to be developed, using customized zinc finger domains to recognize specific DNA sequences and introduce double-strand breaks *via* a FokI nuclease domain. Although powerful, ZFNs require complex protein engineering. Transcription Activator-Like Effector Nucleases (TALENs) soon followed, offering greater target specificity and flexibility. TALENs consist of TALE DNA-binding domains fused to a nuclease, enabling precise targeting of virtually any sequence (Zhang *et al.*, 2020).

The most transformative breakthrough, however, has been the CRISPR/Cas9 system, adapted from bacterial immune defenses. CRISPR employs a single-guide RNA (sgRNA) to direct the Cas9 enzyme to a complementary DNA sequence, where it induces a double-strand break. The simplicity, efficiency and versatility of CRISPR have made it the gold standard for reverse genetic manipulation. This technology has enabled the creation of gene knockouts, targeted trait enhancements and de novo domestication of wild species. Its precision and scalability offer unprecedented potential for dissecting gene function and accelerating crop improvement. CRISPR-based reverse genetics is ushering in a new era of programmable plant breeding faster, smarter and more targeted than ever before (Sapkota & van der Knaap, 2020).

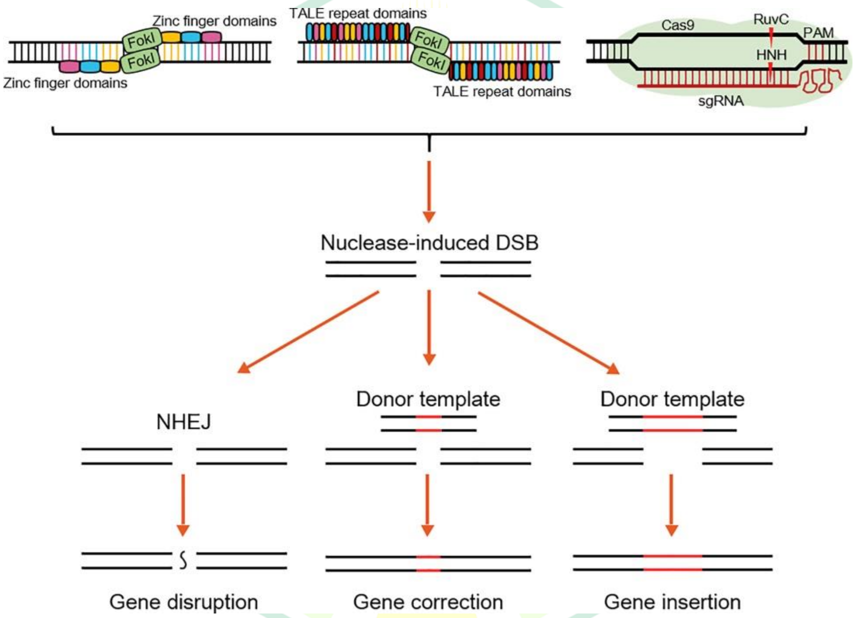


Fig 1. Genome Editing with mRNA Encoding (Zhang *et al.*, 2019)

CRISPR-based reverse genetics has enabled significant advancements in crop improvement. In tomato, Zsögön *et al.* (2018) utilized CRISPR to edit six domestication-related genes in Solanum pimpinellifolium, enhancing fruit size, shape and nutritional quality. In eggplant, Maioli *et al.* (2020) knocked out PPO genes, reducing enzymatic browning and improving post-harvest quality. Additionally, Yoon *et al.* (2020) introduced targeted mutations in the eIF4E1 gene in tomato, conferring effective resistance to Pepper Mottle Virus (PepMoV), improving disease resilience.

e) Homologous recombination

Homologous recombination is a gene-targeting method that relies on the repair of double-strand DNA breaks, typically through models like double-strand break repair and synthesis-dependent strand annealing. Though initially applied in organisms like Drosophila, where it requires the creation of specific transgenic lines, the technique has now been successfully adapted to plants such as rice. With advancements including site-specific recombination systems like Cre-lox, homologous recombination holds significant promise as a precise and routine tool for genome engineering in crop plants (Iida and Terada, 2004).

f) Transposon-mediated mutagenesis

Insertional or transposon-mediated mutagenesis involves mobile genetic elements like transposons that insert randomly into the genome, disrupting gene function (Hayes, 2003). This approach has been widely used in organisms such as Drosophila, *C. elegans* and Arabidopsis to study gene function through mapped transposon libraries. In plants, T-DNA from *Agrobacterium tumefaciens* has enabled insertional mutagenesis in over 70% of Arabidopsis genes (Alonso *et al.*, 2003). However, the method has limitations, including low mutation frequency, lethality in essential genes and limited application in crops like rice and maize. Despite these challenges, it remains a useful tool, often combined with other transformation techniques for genome studies.

Achievements in Crop Improvement *via* Reverse Genetics

Reverse genetics has been instrumental in modifying key traits:

Crop	Trait	Approach	Outcome
Tomato	Fruit shelf life	TILLING	Delay in ripening and petal abscission
Pea	Saponin content	TILLING	Reduced bitterness in seeds
Eggplant	Flesh browning	CRISPR	Lower PPO activity
Lettuce	Bolting time	RNAi	Delayed flowering under heat
Tomato	Virus resistance	CRISPR	Resistance to potyvirus infection
Eggplant	Male sterility	amiRNA	Hybrid seed production enabled

Advantages:

- Precise gene targeting
- Functional validation of unknown genes
- Suitable for complex genomes and polyploid crops
- Accelerates breeding timelines

Limitations:

- Requires prior knowledge of gene sequences
- Regulatory hurdles for genome-edited crops
- Off-target effects in genome editing
- Technical challenges in transformation

Future Prospects

As genome sequencing becomes routine and affordable, reverse genetics will play a central role in:

- ✓ **Speed breeding:** Rapid development of elite lines
- ✓ **Functional genomics:** Elucidating gene networks
- ✓ **Precision agriculture:** Tailoring crops to environmental conditions
- ✓ **Nutritional enhancement:** Manipulating metabolic pathways for biofortified crops

The integration of reverse genetics with multi-omics, machine learning and synthetic biology will revolutionize modern plant breeding.

Conclusion

Reverse genetics has transitioned from a molecular biology tool to a cornerstone of modern crop improvement. With tools like TILLING, RNAi, antisense RNA and CRISPR, breeders can now engineer crops with enhanced yield, stress tolerance, nutritional quality and shelf life. The approach enables targeted and often non-transgenic trait improvement, aligning well with sustainable agriculture and food security goals. Future advancements will continue to expand its utility, bridging fundamental research with applied plant breeding.

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Ghost Fishing: Threat to Ecosystems

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Abstract

Ghost fishing, driven by Abandoned, Lost and Discarded Fishing Gear (ALDFG), represents an under-recognized yet pervasive threat to marine biodiversity and ecosystem health. Durable synthetic materials such as nylon enable lost nets, traps and lines to continue entangling and killing marine fauna for years or decades beyond their intended use. Historically emerging as a critical concern in the 1970s with the adoption of synthetic gear, ghost fishing has since been linked to mortality in over 350 marine species, including commercially important fish, crustaceans, turtles, seabirds and marine mammals. Gear-specific dynamics reveal that gillnets maintain lethal catch rates long after loss, while traps and pots become self-baiting death traps and longlines continue passive fishing for weeks. Ecological impacts extend beyond entanglement mortality, encompassing habitat degradation such as damage to coral reefs and seagrass beds and ecotoxicological effects from microplastic fragmentation, which facilitates trophic transfer of hazardous pollutants. Globally, ALDFG constitutes nearly 10% of marine litter inputs, equating to an estimated 640,000 tonnes annually, with significant implications for food security, fisheries sustainability and marine ecosystem resilience. Addressing ghost fishing necessitates integrated solutions including gear marking, retrieval programs, biodegradable components and international policy frameworks to mitigate its ecological footprint and protect marine biodiversity.

Keywords: Ghost fishing, Habitat degradation, Fisheries management, Gear retrieval.

Introduction

Ghost fishing refers to the phenomenon where **Abandoned, Lost and Discarded Fishing Gear (ALDFG)** such as nets, lines, traps and devices continues to entrap, injure and kill marine organisms long after being lost or discarded. This gear, often constructed from durable synthetic materials like nylon and polypropylene, remains functional in the marine environment for years or even decades. Matsuoka et al. (2005) showed that derelict gillnets and pots maintain lethal catch rates well beyond their intended use, perpetuating a hidden mortality source that evades detection by both fishers and managers. The gear acts as persistent "edge" in marine habitats, entrapping species ranging from commercial fish and crustaceans to marine mammals, seabirds and turtles.

The global scale of the ALDFG problem is often underestimated due to the opacity of loss events. A meta-analysis by Do & Armstrong (2023) reviewed 90 studies and confirmed that ALDFG is a pervasive environmental hazard with significant ecological and socioeconomic ramifications. Despite this, vast deficits persist in understanding the spatial distribution, longevity and ecosystem-level impacts of ghost gear.

Adding complexity is the variety of gear types involved: passive gears like gillnets, traps and longlines, as well as active gears like trawls and Fish Aggregating Devices (FADs). Each gear type differs in buoyancy, durability and interaction with marine fauna, meaning the intensity and duration of ghost fishing activity vary widely. For example, loss rates of fishing nets range from 0 % to nearly 80 %, with an average annual loss estimated at 5.7 %. Similarly, lost lines and traps contribute another 29% and 8.6% respectively to gear loss globally. Collectively, these contribute millions of tons of derelict gear entering marine ecosystems each year.

Historical Context & Research Development

The recognition of ghost fishing as an environmental and fisheries issue emerged gradually over the latter half of the 20th century. The widespread adoption of synthetic materials like nylon in fishing gear during the 1960s marked a pivotal shift enabling previously short-lived gear made of natural fibers to persist and remain functional in the marine environment for years or even decades. These durable synthetic nets, being nearly invisible underwater, were soon found to continue trapping marine organisms well beyond their intended lifespan.

By the 1970s and early 1980s, reports began highlighting the unintended consequences of lost fishing gear, particularly nets and traps. In Alaska during the mid-1970s, marine mammal entanglements drew early attention to the phenomenon. By April 1985, the term "ghost fishing gear" had entered scientific discourse, acknowledging gear that continues its lethal function post-loss. Throughout the late 1980s and early 1990s, fisheries scientists and marine managers in the U.S., Canada, Japan and Hawaii spearheaded observational research and field studies, primarily focused on gillnet and crab pots. Notably, field experiments showed that derelict gillnets and traps could continue passive fishing activities, prompting Reno-scale mortality estimates among both target and non-target species.

A landmark meta-analysis by Richardson, Hardesty and Wilcox (2019) consolidated early scattered data, revealing alarming annual gear loss rates on average about 2.5 % of nets, with traps, lines and other gears also contributing significantly to total ALDFG. Furthermore, FAO and UNEP collaborated on a seminal 2009 report that quantified ghost gear as comprising nearly 10 % of global marine litter, estimating annual inputs of approximately 640,000 tonnes. This report catalyzed a broader international engagement, highlighting the need for targeted policy, monitoring and mitigation strategies.

In response to growing global awareness, the FAO's 1995 Code of Conduct for Responsible Fisheries urged nations to minimize the loss and discard of gear and mitigate the ecological impacts of fisheries. Subsequently, the Global Ghost Gear Initiative (GGGI) was founded in 2015 by World Animal Protection, with joint support from FAO, UNEP, WWF and others. The GGGI marked a systematic shift toward cross-sectoral frameworks, data collection and recovery efforts. Recent initiatives, such as biodegradable escape panels on pots, gear marking, GPS-based tracking and robust retrieval and recycling programs, reflect the evolving toolbox developed from decades of foundational research.

Mechanisms & Gear-Related Dynamics

The ghost fishing phenomenon varies significantly by gear type, with gillnets, traps and longlines exhibiting distinct retention and mortality dynamics due to their design and mode of deployment.

Gillnets

Gillnets function as submerged walls of mesh that entangle fish by the gills, making them effective both for intended catches and unintended bycatch. Modern gillnets made from durable synthetics like nylon or Dacron are anchored along the seabed with floats forming a vertical barrier. When lost, these nets can continue passive fishing, sometimes for months or years. For instance, in Laguna Verde, Chile, discarded gillnets caught 912 invertebrates over 156 days, with the net's effective area still over 40% after 19 days. This demonstrates the prolonged functionality of gillnets post-loss and their capacity to entangle a wide range of taxa.

Traps & Pots

Baited traps such as crab pots and lobster pots act as durable, self-baiting death traps when lost. FAO guidance highlights that lost pots continue actively trapping until structural degradation, although including biodegradable escape panels can mitigate this impact. Real-world data from Chesapeake Bay estimate 150,000 crab traps lost annually, with each potentially ghost-fishing for extended durations.

Targeted field studies reinforce these concerns. In coastal Louisiana, 65% of derelict crab traps recovered between 2012–2013 still ghost-fished, with mean catches between 2.4 and 3.5 blue crabs per trap. In Norway, divers retrieved 4,128 pieces of lost gear (84% traps, 5% gillnets); 29% of all gear carried live catch—with parlour traps averaging nearly 2 crabs and 0.9 fish per trap—highlighting the non-selective and persistent nature of ghost fishing.

Longlines & Trolline

Although less studied, longline and trotline gear can also ghost-fish. FAO notes that lost longlines may cause mortality, though their habitat impact is lower than nets or traps. In Texas reservoirs, abandoned baited trotlines caught channel catfish continuously for up to 52 days (winter), retaining over 50% of their fishable hooks. Such findings confirm that even less conspicuous passive gear contributes meaningfully to ghost fishing.

Ecological & Ecotoxicological Impacts

Ghost fishing gear inflicts profound ecological damage that extends far beyond the immediate capture mortality of marine animals. At its core, this encompasses **entanglement**, **habitat degradation** and the **release and trophic transfer of toxic substances**, all contributing to wide-reaching negative effects on marine ecosystems and food webs.

4.1 Entanglement and Biodiversity Loss

Abandoned nets, lines and traps indiscriminately ensnare marine fauna, including over 350 species: fish, crustaceans, turtles, seabirds, marine mammals and even coral. In the Chesapeake Bay, derelict crab pots alone kill an estimated 3.3 million blue crabs annually, alongside 40 bycatch fish species. The removal of these ghost pots could increase blue crab harvest by 17 million kilograms, demonstrating both ecological and economic consequences.

In reef systems, lost fishing lines entangled in hydrocoral (*Millepora alcicornis*) led to increased coral mortality, reduced abundance of herbivores like *Acanthurus bahianus* and disrupted reef herbivory functions critical to ecosystem balance.

4.2 Habitat Degradation

Ghost nets damage structurally complex habitats: seagrasses get torn, corals are smothered and benthic invertebrates foundation species for marine ecosystems are directly harmed. The result is diminished nursery grounds, reduced resilience of reef communities and diminished ecosystem services vital for fisheries and coastal protection.

4.3 Ecotoxicological Effects: Microplastics & Chemical Pollutants

As gear degrades, fragments into microplastics (<5 mm), acting as vectors for both physical and chemical stressors. Microplastics are ingested by a range of organisms—from zooplankton to fish—causing oxidative stress, hormonal disruption, impaired reproduction and genotoxicity . Furthermore, these particles carry a "Trojan Horse" load of toxic additives (e.g., phthalates, BPA) and adsorbed contaminants (PCBs, PAHs, PFAS), which are transferred through the food web . This dual burden of synthetic polymers and pollutants increases bioaccumulation and biomagnification posing risks to marine life and humans via seafood consumption.

4.4 Cumulative Impacts on Ecosystem Health and Resilience

The combination of lethal entrapment, habitat loss and chemical stress weakens ecosystem integrity. Reduced abundance of grazers like damselfish and parrotfish exacerbates algal overgrowth, decreasing coral recruitment and reef regeneration potential . Less resilient habitats are less capable of recovering from physical (storms, trawling) and climate-induced (bleaching, acidification) disturbances.

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Colocasia esculenta: The Zero-Waste Supercrop for Nutrition and Sustainability

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Introduction:

Colocasia esculenta Linn., commonly known as taro, is a herbaceous, tuberous perennial plant belonging to the family Araceae (Arum family). Often referred to as an "orphan crop," it holds significant importance in traditional agriculture and diets, particularly across Asia, Africa, and the Pacific Islands. In India, it is cultivated in various regions including Uttarakhand, Kerala, Tamil Nadu, Karnataka, Maharashtra, Andhra Pradesh, Odisha, West Bengal, Sikkim, Uttar Pradesh, Madhya Pradesh, Tripura, Nagaland, Assam, and Mizoram, primarily in warm and moist agroclimatic zones.

This plant is recognized for its versatility and sustainability, often termed a "zero-waste crop" as all parts—corms, petioles, and leaves—are utilized for food, medicinal, or cultural purposes. The leaves are large, heart-shaped, and exhibit a dark green coloration on the upper surface and a lighter green on the underside. They are hydrophobic due to a waxy, microscopically textured surface that repels water, a feature that supports the plant's adaptation to high-moisture environments. The leaves are strongly attached to upright stalks, giving the plant a height of approximately 3 to 6 feet, typically flourishing during the monsoon months (July–August).

The edible underground stems, known as corms, are rich in complex carbohydrates and serve as a significant energy source in local diets. In addition to carbohydrates, various parts of *Colocasia esculenta* are rich in micronutrients, dietary fiber, and bioactive compounds with reported antioxidant and anti-inflammatory properties. Traditionally, taro has been used in Ayurvedic medicine and folk remedies for managing digestive issues and treating insect bites.With a long history of domestication in Southeast Asia, *C. esculenta* is one of the oldest cultivated crops and continues to play a vital role in food security, especially in subsistence farming systems. Its culinary applications are diverse, with all plant parts incorporated into regional delicacies, affirming its significance in both nutritional and cultural contexts.

Traditional Recipes:

Nigeria stands as the world's largest producer and consumer of Colocasia, reflecting the crop's importance as a staple food. It is also extensively cultivated in India and other parts of Asia, where it holds deep cultural and culinary significance. Taro is highly versatile in its use and is consumed in various forms—boiled, fried, baked, dried, or processed into flour. Its adaptability in traditional and modern cuisines makes it a valuable dietary component in many regions. However, while the leaves are highly nutritious, they contain needle-like calcium oxalate crystals known as *raphides*. When consumed raw or undercooked, these crystals can cause itching, irritation, or inflammation in the mouth and throat. To make the leaves safe and palatable, traditional culinary methods include thorough blanching or boiling—often with salt, turmeric, or lemon juice—to neutralize the calcium oxalates. These preparation techniques are essential not only for taste but also for reducing the risk of dietary oxalate toxicity. In India, various traditional dishes creatively incorporate every part of the Colocasia plant—from roots and stalks to leaves—highlighting its status as a *zero-waste crop*. This holistic use aligns with sustainable food practices, making Colocasia both nutritionally valuable and environmentally responsible.

The dishes prepared using Colocasia plants in India are:

Plant Part	**Dishes**
Leaves	Patrode, Curry, Chutney, Shaag, Pakode
Corms	Curry, Soup, Chips, Taro boba tea, Savoury snacks
Stalks	Decoctions, Soups, Stir fried salad, Curry, Stew

Nutritional Properties and Health Benefits:

Leaves:

The leaves of *Colocasia esculenta* (commonly known as taro) are a highly nutritious leafy vegetable, prized for being low in calories and high in essential micronutrients and antioxidants. They are an excellent source of crude dietary fiber, which supports digestive health and helps relieve constipation naturally. Taro leaves are rich in minerals such as iron, calcium, magnesium, potassium, zinc, sodium, selenium, manganese, and copper—making them a valuable component of a balanced diet. They also provide a wide array of vitamins, including vitamin A, vitamin C, and B-complex vitamins like niacin, folic acid, riboflavin, and thiamine. One of their most notable compounds is β-carotene, a precursor to vitamin A that plays a critical role in maintaining vision, immune function, and preventing vitamin A deficiency. Beyond their nutritional value, taro leaves contain a diverse range of phytochemicals known for their health-promoting properties. These include alkaloids, steroids, glycosides, flavonoids, gallic acid, carotenoids, phenols, saponins, β-sitosterols, tannins, and terpenoids—many of which are found in both the tubers and leaves, especially in methanolic extracts. The leaves, in particular, are rich in phytosterols and phenols, which are known for their antioxidant, anti-inflammatory, and other therapeutic effects. These bioactive compounds contribute to a range of pharmacological benefits, positioning taro leaves as not just a food source, but a functional food with potential to support overall health and wellness.

Stalk:

Colocasia stalks are valued not only for their culinary versatility but also for their rich nutritional profile. These stalks are an excellent source of dietary fiber, which aids digestion and supports gut health. They are low in calories and contain essential vitamins and minerals, including vitamin C, vitamin B6, potassium, magnesium, and iron. The presence of antioxidants and polyphenols further enhances their health-promoting properties, contributing to reduced oxidative stress in the body. Additionally, colocasia stalks provide a moderate amount of plant-based protein and have a low glycemic index, making them a favourable option for individuals managing blood sugar levels.

Corms:

The corms of *Colocasia esculenta* are not only energy-dense but also packed with essential nutrients, making them a valuable addition to a healthy diet. Rich in complex carbohydrates and dietary fiber, they serve as a naturally gluten-free option—ideal for individuals with celiac disease or those seeking gluten alternatives. Compared to common starch sources like potatoes and white rice, colocasia has a lower glycemic index, which means it causes a slower, steadier rise in blood sugar levels—especially beneficial for people managing diabetes. With 70–80% of its content made up of starch, colocasia is a highly digestible root vegetable. It contains mucilaginous gums and fine starch granules that make it not only easy on the digestive system but also desirable in food processing industries. Its low amylose content, high swelling capacity, and excellent water and oil retention stability further enhance its industrial appeal. What sets colocasia apart nutritionally is its combination of resistant starch and high soluble fiber content. These qualities support digestive health, act as natural prebiotics to nourish the gut microbiome, and may even help lower the risk of colon cancer. Beyond macronutrients, colocasia corms are a good source of essential minerals such as calcium, iron, magnesium, potassium, sodium, phosphorus, manganese, zinc, copper, and selenium. They also offer a variety of important vitamins, including vitamins C, A, and E, as well as folate and niacin.Moreover, colocasia is rich in beneficial plant compounds or phytochemicals—like flavonoids, glycosides, and polyphenols—that contribute to its wide range of health-promoting and pharmacological effects. One particularly interesting compound is tarin, a glycoprotein found in colocasia, which has shown the potential to stimulate the immune system and combat inflammation, infections, and even degenerative diseases. Early research suggests that tarin may hold promise as a natural agent in cancer therapy, opening exciting avenues for further exploration.

Conclusion:

Colocasia esculenta, often overlooked in mainstream agriculture, is a hidden gem rooted in traditional practices and smallholder farming systems. Every part of the plant is usable, exemplifying a zero-waste, orphan crop that holds immense untapped potential. Its ability to thrive with minimal inputs and adapt to a wide range of climatic conditions makes it exceptionally suited for sustainable and eco-conscious agriculture. Rich in both nutritional and pharmacological properties, *Colocasia esculenta* offers a wholesome, plant-based resource for promoting a healthy and balanced lifestyle. In an era where climate resilience and resource efficiency are paramount, this versatile crop stands out as a promising alternative. It can meaningfully contribute to food security, environmental sustainability, and economic resilience—making it a valuable asset in building a more sustainable future for global agriculture.

Sapota - A potential fruit for semi-arid ecosystem of Rajasthan

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Sapota (*Achras zapota* L. *Syn. Manilkara achras* (Mill.) Forsberg) is one of the prominent fruits and belongs to family "*Sapotaceae*". It is also known as sapodilla or *chiku* in India. Sapota is a native of Mexico and Central America, and now widely cultivated throughout tropics for its delicious fruits. Sapota is an evergreen tree usually growing up to 10 m height. Being a hardy crop, it can be grown on wide range of soil and climatic conditions. India is the largest producer of sapota followed by Mexico, Guatemala and Venezuela. The area under sapota in India is estimated to be 1.77 lakh hectares, with an annual production of 17.44 lakh metric tonnes and productivity 9.91MT (NHB, 2014). The state's growing sapota in India on commercial scale is Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Tamilnadu, Kerala, Punjab, West Bengal and Haryana. It is not known when it was first introduced into India but sapota cultivation was taken up for the first time in Maharashtra in 1898 in a village named Gholwad. Information on area and production of sapota in Rajasthan is not readily available as the fruit has recently been introduced in the state and major plantations have not been developed on significant scale, but potential districts might be Kota, Sirohi, Udaipur and Banswara.

Figure 1. Overview of Sapota plantation in semi-arid ecosystem

Sapota fruit when fully ripped is delicious and eaten as dessert fruit. The pulp is sweet and melting. The fruit skin can also be eaten since it is richer than the pulp in nutritive value. The sapota fruits are a good source of sugar which ranges between 12 and 14 per cent. A 100 g of edible portion of fruit contains moisture (73.7 g), carbohydrates (21.49 g), protein (0.7 g), fat (1.1 g), calcium (28 mg), phosphorus (27 mg), Iron (2 mg) and ascorbic acid (6 mg) as reported by Bose and Mitra (1990).

Sapota fruits are used for making jams, jellies, osmodehydrated slices and squash. Products like sweet chutney, dried sapota pieces, sapota milk shake, nectar, blended sapota drinks, pickle, preserve and candy can also be prepared with good sensory. The bark of the tree is used for preparation of chicle used in chewing gum.

Climate and soil

Sapota, a crop of tropical region, needs warm (10-38 ^{o}C) and humid (70% relative humidity) climate where it flowers and fruits throughout the year. Areas with an annual rainfall of 125-250 cm are highly suitable. However, if taken to subtropics or to places of higher elevation like in Punjab, Haryana and Rajasthan, it gives only one crop from summer flowering in April and May. Under moisture stress also, it produces one crop only. Sapota can be grown on a wide range of soils. Drainage is most important. There should not be a hard pan in the sub-soil. Deep and porous soils make a good growth. The sapota can tolerate the presence of salts in the soil or in irrigation water to some extent.

Varieties

The important and widely adopted varieties are Kalipatti and Cricket ball (Calcutta large). The other varieties are, Pilipatti, Chhatri, Baramasi, Dwarapudi, Bhuripatti, Banglore, Dhola Diwani, Co-1, Co- 2, PKM-3, DHS-1 etc.

Propagation and root stocks

Sapota on Rayan or *khirni* roots is the best combination in respect of plant vigour, productivity and longevity. Propagation of sapota by inarching using rayan as rootstock is the most accepted method of its commercial cultivation. Two years old potted rayan plant with pencil thickness are utilized and grafting is done in December and January. The plants are ready for separation in June-July of following year. The method is tedious, cumbersome and time consuming. Softwood grafting using rayan as rootstock gives 93% success in situ. It is an economically viable, faster, efficient and best technique. July- August is ideal time for it.

Planting and season

Since sapota is a crop of warm and humid tropics, it can be planted in any season provided irrigation facilities are available. But it is beneficial to plant the grafts in beginning of rainy season. In areas having heavy rainfall, it can be planted in September. In light soils pits of 60 cm x 60 cm x 60 cm size, whereas in heavy and gravely soils pits of 100 cm x 100 cm x 100 cm size are made in April-May with 8m x 8m spacing and exposed to sun till mid of June. Top 30 cm soil is mixed with equal quantity of well rotten compost or farm yard manure, 3 kg single super phosphate and 1.0 kg muriate of potash are used for pit filling. To begin with all sides and bottom of the pit are dusted with 5% Fenvalerate dust and pits mixture is added to fill the pit and remaining vacant space is filled with remaining soil to height of 15 cm above soil surface. Such pits are left to monsoon rains for seedling and then planting is done at appropriate time. At the time of planting, a small hole sufficient accommodate the ball of soil and roots of graft is made in the centre of the pit and planted with scion in the direction of heavy wind to avoid damage to joint. After planting soil around the plant is gently and firmly pressed and stalks are provided to avoid sun heat. The plants are then lightly watered. Young plant should also be protected against sun scald by providing dry grass thatch on top and three asides excepting the South-east for sun light. Such well cared plants establish fast.

Since sapota tree makes uniform all round growth, square system of planting is recommended. However, in lands with 5-15% slope, contour planting is recommended

Manuring and fertilization

Owing to evergreen nature of the plant, any inadequacy in its nutrition leads to sub optimal yield. Deficiency of N leads to allowing of leaves from margin to mid rib. The P deficient plants have purplish flecks on lamina with rusty pigmentation all over and inadequacy of K is marked by development of chlorotic symptoms long leaf margins which become dark grey in advanced stage. Zinc deficiency is marked by small and erect leaves. Short internodes and defoliation of terminals, whereas in calcareous soils iron deficiency causes general yellowing of leaves with premature shedding.

A dose of 50 kg farm yard manure, 1000g N, 500g P_2O_5 and 500g K_2O/tree /year is optimum. This quantity can be regulated on the basis of age of tree and status of nutrients is soil especially of P and K. under rainfed condition, dose of N should be raised to 1.5 kg/tree. Castor cake is beneficial for high quality fruits. Application of more N is reported to increase the yield. Under rainfed condition, fertilizers should be applied before the onset of monsoon. However, under irrigated conditions it should be applied in to splits, total quantity of organic manure and half of chemical fertilizers should be applied at the beginning of monsoon and remaining half in the post-monsoon period (September- October). Since 90% of active roots are distributed with in drip up to a depth of 3 cm, nutrients should be applied under tree canopy and mixed thoroughly in soil up to a depth of 15 cm. in zinc and iron deficiency, the requirement should met through application of organic manures and spraying of zinc sulphate and ferrous sulphate (0.5%).

Aftercare

Depending on growth habit of sapota tree, a planting distance of 8 x 8 m to 10 x 10 m is ideal. Being a slow grower, it takes longer to occupy allotted space. Therefore, intercropping is imperative. Intercrops like papaya, French bean, tomato, brinjal, cabbage, cauliflower and cucurbits can be grown profitable during the pre-bearing period. In established orchards, pre-monsoon and post-monsoon inter cultivation is recommended for better aeration and effective weed control. Frequent weeding or mulching should be regular for first few years. Spraying

SADH 100% ppm gives good fruit set and (Planofix) NAA 300 ppm gives fruit retention. Sprayings are done twice before flowering and again at pea stage.

Irrigation

Habit of tree and its vegetative growth demand continuous supply of water. But sapota is grown both under irrigated and non-irrigated conditions. Sapota requires irrigation at 30 days in summer. Adoption of drip irrigation system is also beneficial, saving 40% water with 70-75% higher net income. This system should be laid out with 2 drippers spaced 50 cm from tree during initial 2 years and 4 drippers at 1 m from tree until 5 years of age. With dripper discharge rate of 4 liters/ hr, the system should be operated for 4 hr during winter and 7 hr during summer on alternate days.

Training and pruning

A seedlings tree grows excellently giving a shape of an umbrella. However, plants raised through inarching require training for appropriate shape and frame work development. No definite system of training has been developed for sapota. Most trees are trained in central leader system. Sapota being an evergreen tree requires no regular pruning but regulation of vegetative growth to improve productivity and quality of fruits is necessary. At times thinning of branches is affected in old plantation. Pruning in sapota is confined to open the tree to light and removal of dead and diseased branches.

Harvesting and yield

Sapota may start bearing 2nd or 3rd year but commercial yield can be obtained from 7th year onwards. It takes about 7- 10 months from fruit set to maturity of fruits depending on variety, season and locality. Fruits followed double sigmoid pattern of growth. Properly developed fruits have high TSS and sugar and reduced acidity, astringency, latex and vitamin C. Best symptoms of maturity are: milky latex on scratching will be reduced and shows yellow streak than green streak. Brown scaly material gets reduced. Dried stigma at the tip of the fruit drops easily. Develops dull orange or potato colour. Fruits should be harvested with stalk intact. Peak harvesting periods are Jan-Feb and May-June in Maharashtra and March-May in Punjab, Haryana and Rajasthan.

Post harvest handling and storage

Sapota is a climacteric fruit, it has to be ripening artificially. Fruits are highly perishable and they undergo rapid ripening changes within 5-7 days during which the fruits become soft, sweet and develop excellent aroma with decline in tannins, latex sapotin, aldehydes and acidity. These changes are associated with increase in production of ethylene, rate of respiration, catalase, peroxidase and PME activities. These changes can be regulated through chemicals, temperature and storage gas composition. Harvested fruit should be cleaned of latex and scurf by washing in clean water to make them look attractive. Such fruit should be graded in to big, medium and small sizes. Fruits should be tightly packed in cardboard boxes of 10 kg capacity with rice straw as padding material and with ethylene absorbents and transported quickly to wholesale markets. For extending shelf life and to avoid storage rots, fruits can be dipped in GA 300 ppm + bavistin 1000 ppm solution at pre-packing stage. For uniform and rapid ripening ethephon (1000 ppm) cn be utilized at 20-25 ^{o}C. Modified storage with 5-10% (c/c) CO_2 can be employed for long storage (21-25 days). Refrigerated vans (12-23 ^{o}C) should be utilized for long distance and export markets.

Pests and Diseases

Stem borer: The grub f this small beetle bores into bark of the sapota trunk and feeds on the living tissue inside the bark. The chewed bark is seen on the hole.

Control measures:

1. Kill the insect by trusting stiff wire into the tunnel.
2. Plug the hole with a wad of cotton in kerosene at 0.1 per cent and plaster with wet mud. This treatment creates suffocation inside the hole or tunnel which results in death of the insect inside.

Leaf minor: The tinny caterpillar of a grayish moth mines into the surface of young leaves. Affected leaves curl up, mines are on the surface of leaves and sometimes caterpillars are found inside the mines. Later on, affected leaves get destroyed, dry up and fall.

Control measures: Spray once or twice Dimethoate (1.5 ml/ litre of water) or Malathion (1.5 ml/ litre of water).

Mealy bug: It is sucking type of insect. It is a small, over in shape with a cottony white, waxy on the under surface of leaves and base of the fruit near the fruit stalks. They suck the sap and secrete large quantities of sugary sub stones. Leaves have a block coating which gives them a sickly appearance.

Control measures:

1. Spray Dimethoate with 1.5 ml/ litre of water.
2. Try to keep free sapota plantation from red ants because these help in distributing mealy bugs from one tree to another. Red ants are effectively controlled with a dusting of a mixture of fenvalerate 5 per cent and sulphur dust with 2:1 ratio.

Scale insects: They suck the sap by infesting along the sides of midrib and surface of leaves and twinges. These scales are green or grown in colour and oval shaped.

Control measures: Dimethoate or Malathion at 1.5 ml in one litre of water.

Fruit borer: Borer attacks on fruits and some time buds which can easily be detected seeing the latex which comes out on the surface of the infested fruits, the latex later crystallizes.

Control measures:

1. Spray of Fenvalerate with 0.01 per cent just before pre-flowering stage.
2. Second spray of 0.05 per cent Malathion when fruit gets pea size.

Diseases:

Wilt or die back: It is a common where sapota cultivation is being extended to traditionally rice growing regions. Due to anaerobic conditions in monsoon and post season in such areas wilt is of common appearance aggravated by *Fussarium spp*. First symptoms start with the onset of monsoon. Appearance of light yellow foliage with loss of turgidity and epinasty. Plants at later stage show premature shedding and defoliation.

Control measures:

1. This can be controlled by effective drainage facility before planting.
2. Drenching the plant with Dithane M-@ 2g in one litre of water.

Leaf spot: The casual fungus results in dark brown, the adjacent spots on leaves. When infection is severe, the adjacent spots become large irregular whitish patches. In severe easer, the defoliation of leaves may be noticed.

Control measures:

1. Spray Dithane M-45 or Dithane Z-78 @ 0.2 per cent at interval of 30 days.
2. Grow resistant varieties like Co-1, Cricket ball. The varieties Co-2 and Kalipatti are tolerant but Calcutta round are susceptible.

Sooty mould: sooty mould is incited by Capnodiuor. The causal fungal disease develops on the honey like excretion by scale insects and mealy bugs.

Control measures:

1. Spray Zineb @ 2 g/ litre of water.
2. Spray starch solution @ 5 g/ litre of water. Starch forms this flakes and drop.

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Sustainable Fishing Gear: Enhancing Efficiency and Selectivity

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Abstract

The development and implementation of sustainable fishing gear are critical for balancing the demands of productive fisheries with the urgent need to protect marine biodiversity and maintain healthy ecosystems. Advances in gear selectivity through innovative design improvements, enhanced material choices, and the integration of modern technologies have proven effective in reducing bycatch, safeguarding juvenile fish, and minimizing habitat damage. Collaborative efforts between researchers and the fishing industry have driven practical solutions, such as the use of larger hooks, improved cod end designs, and the adoption of alternative gear types, all of which contribute to more responsible and efficient fishing practices. Despite technical, ecological, and operational challenges, ongoing innovation in modelling methods, simulation tools, and gear design frameworks continues to create new opportunities for sustainable fisheries management. Moving forward, prioritizing gear refinement, exploring alternative technologies, and implementing strong regulatory measures will be vital to sustaining fish stocks, conserving marine biodiversity, and supporting resilient fishing communities for the future.

Keywords: Sustainable fishing gear; gear selectivity; bycatch reduction; fisheries management; marine biodiversity.

Introduction

The development and adoption of sustainable fishing gear are essential for improving the operational efficiency of fisheries while ensuring greater selectivity in what is harvested. Such gear addresses the critical issue of how to maximize the catch of desired species without unintentionally capturing non-target species, known as bycatch, which can have significant ecological impacts. In recent years, considerable progress has been made in refining fishing gear designs and integrating advanced technologies that enable fishers to better target specific species and sizes. These advancements contribute significantly to the goal of ecological sustainability by reducing wasteful practices, conserving marine biodiversity, and supporting healthier, more resilient aquatic ecosystems. Implementing hooks with considerably larger sizes on a broad scale could be a practical conservation measure. This method supports the preservation of marine biodiversity by giving smaller, unintended species a better chance to avoid capture, while still permitting fishers to harvest target species responsibly and sustainably (Swimmer et al., 2011). A detailed age-structured population model was utilized to analyse the influence of gear selectivity on both the spawning stock biomass (SSB) and the overall yield of the fishery. This approach allowed researchers to assess not only how selective harvesting practices affect the reproductive capacity and long-term productivity of fish populations, but also to compare these effects with the impacts of different levels of fishing pressure (exploitation rates) and a range of biological characteristics, such as growth rates, natural mortality, and age at maturity. By examining these relationships, the model provides valuable insights into how adjustments in gear selectivity can contribute to sustainable fishery management (Vasilakopoulos et al., 2016).

Concept of Sustainable Fishing Gear

Sustainable fishing gear refers to the thoughtful integration of materials, design features, and fishing practices that together aim to lessen environmental harm, cut down on waste, and protect marine biodiversity. Such gear is specifically crafted to efficiently capture target species while reducing unintended bycatch and limiting damage to aquatic habitats. Embracing this strategy is vital for safeguarding fish populations and supporting the long-term sustainability of marine ecosystems. Over the past decade, extensive bottom-up collaboration through workshops and research involving fishers from major tropical tuna purse seine fleets has led to significant progress in mitigating the ecological impacts linked to the use of fish aggregating devices (FADs). These joint efforts have resulted in the development and adoption of innovative, more sustainable fishing practices now implemented across all oceans (Murua et al., 2023). The authors discuss how various management controls can influence the behaviour of fishers, particularly in their decisions to use more selective fishing gear. They illustrate how specific regulatory approaches can either support or undermine conservation efforts, and describe methods to either deter or encourage the continued use of gear that is less selective (Graham et al., 2007). A semi-demersal trammel net specifically developed for targeting cuttlefish has demonstrated notable success in reducing the unintended capture of juvenile or undersized flounder during prawn trawling activities. By selectively allowing only the intended catch to be retained, this gear modification effectively minimizes bycatch, supporting both resource conservation and more sustainable fishing practices (Matsuoka, 2023).

Technological Innovations in Fishing Gear

Advancement in fishing gear technology has significantly reshaped the fishing sector by boosting operational efficiency while addressing crucial environmental issues. These advancements cover diverse aspects, such as the development of more sophisticated gear designs and the adoption of refined fishing practices, all aimed at lowering the ecological footprint of fishing activities. By implementing these modern solutions, the industry can more effectively limit bycatch, reduce damage to sensitive habitats, and promote responsible harvesting of fish stocks. Altogether, these measures play an important role in safeguarding the long-term sustainability and health of marine ecosystems. The development and broad adoption of synthetic materials in fishing gear, combined with notable advancements in vessel design, navigation technology, gear handling machinery, fish-finding systems, and scientific understanding of fish behaviour, have brought about substantial changes in the construction, design, and operation of today's fishing equipment. These innovations have significantly increased the effectiveness and catch potential of modern fishing techniques like trawling, purse seining, and longlining. Altogether, these technological strides have driven large-scale improvements throughout the fishing sector, boosting productivity while reshaping the way commercial fisheries operate (Boopendranath, 2019). New and advanced technologies in the fisheries sector are driving significant changes by making operations more sustainable, boosting overall effectiveness, and ensuring better transparency throughout the supply chain (Latief et al., n.d.). This paper integrates systematic literature reviews, expert analyses, and descriptive case studies to showcase the multiple ways in which technological advancements are reshaping recreational fishing. In addition, it explores the broader implications of these innovations for how fisheries should be managed and regulated in the future, and discusses how the oversight and adaptation of new technologies can help support sustainable fishing practices (Cooke et al., 2021).

Improving Efficiency in Fisheries

Enhancing the selectivity of fishing gear is essential for promoting sustainable fishing, reducing unintended bycatch, and protecting marine biodiversity. Recent studies highlight the importance of a comprehensive strategy that brings together advanced gear design improvements, insights into fish behaviour, and close cooperation between researchers and the fishing community. Linear Mixed-effects Models are used to identify functional traits—such as body size, vision, and movement abilities that distinguish captured individuals from those that manage to escape (Mouchet et al., 2019). The authors suggested a broader, more unconventional approach to tackle bycatch issues associated with trawl fishing by exploring the use of entirely alternative gear types. Their proposed strategy includes: (1) assessing the practical limits of improving poorly selective fishing gears through existing bycatch reduction techniques, and (2) evaluating the potential of alternative gear designs that, due to their unique construction or method of operation, incorporate selective features that could be adapted to improve the performance of problematic gears (Broadhurst et al., 2007). The findings show that modifications to both the square mesh panel (SMP) and, in particular, the cod end design greatly influence the size selectivity and catch composition for hake and blue whiting. It is recommended that future research should focus primarily on optimizing cod end selectivity, with the possibility of incorporating additional selective devices once cod end designs with effective selective performance are developed (Cuende et al., 2022).

Enhancing Selectivity

Improving gear selectivity, whether in fisheries or mechanical systems, requires multiple approaches focused on boosting effectiveness and minimizing unintended catches or operational inefficiencies. This can be accomplished through creative design improvements, careful choice of materials, and adjustments to how the gear is used in practice. The conclusion suggests that, subject to additional testing, cod ends constructed with mesh sizes close to 29 mm and mounted on the bar are likely to offer suitable size and species selectivity for use in Wallis Lake stow nets and lagoon seines (Macbeth et al., 2005). A simulation-driven design approach that combines virtual simulations with material selection charts is suggested to enhance design efficiency during the early stages of product development. This method allows designers to flexibly identify suitable material options for their gear designs according to specific performance requirements (Yazdanshenas et al., 2020). A new forward, performance-driven approach for determining gear parameters is introduced, which enhances both efficiency and precision by developing performance evaluation models combined with a linear weighting technique. This method produces optimized asymmetric gear designs that outperform those created using traditional design methods (Zheng et al., 2024).

Environmental and Ecological Benefits

Fishing gear selectivity plays a vital role in reducing environmental and ecological impacts by controlling which species and sizes of fish are captured, directly affecting the sustainability of fisheries and the well-being of aquatic ecosystems. Enhancing gear selectivity offers substantial ecological advantages, such as minimizing bycatch, safeguarding juvenile fish populations, and helping to maintain healthy marine habitats. Whether traditional artisanal fishing gear in coral reef habitats selectively harvests fish species that exhibit specific ecological traits, including feeding type, body size, depth preference, vertical position in the water column, activity periods, and schooling tendencies (Mbaru et al., 2020). The authors reference Bahamon et al., who analyse the effects of better gear selectivity on European hake, Norway lobster, poor cod, and greater forkbeard by assuming that all vessels would replace the standard 40 mm diamond-mesh cod end with a 40 mm square mesh (SM40) cod end (Bahamon et al., 2007). The authors provide an overview of recent progress in fishing gear technology, highlighting advancements that enhance selectivity and the creation of gear designs that are less harmful to the environment, thereby helping to reduce some of the ecological impacts associated with fishing (McShane et al., 2007).

Challenges and Barriers

Challenges and obstacles related to gear selectivity are complex and span technical, ecological, and methodological aspects. In fisheries, for example, gear selectivity is a key factor for sustainable management, as it determines how effectively target species are harvested while safeguarding non-target species and their habitats. Similar complexities exist in other gear-dependent sectors, like manufacturing and vehicle transmissions, where technical and operational issues also significantly influence performance and efficiency. The challenges associated with both conventional and powder metallurgy (PM) gear production are outlined to identify the key factors that must be taken into account when conducting cost-benefit analyses focused on sustainability (Kianian & Andersson, 2017). Grammars, and particularly graph grammars, offer an effective way to model and generate the relational structures of shaft arrangements and transmission topologies. By combining these techniques with recent advances in reinforcement learning, inverse problem-solving through machine learning, and graph neural networks, there is great potential for automating the design and dimensioning of gear transmission systems (Sendlbeck et al., 2023).

Future Directions

Future efforts to improve gear selectivity in fisheries aim to make fishing practices more efficient while reducing bycatch and supporting sustainable resource use. Achieving this goal requires a comprehensive approach that combines the refinement of current gear, the development of alternative designs, and strong collaboration between researchers and the fishing sector. It has been shown that modifications to both the square mesh panel (SMP) and, more importantly, cod end design, greatly influence the size selectivity and catch patterns for hake and blue whiting. Therefore, it is recommended that future research should focus primarily on improving cod end size selectivity, with the option of introducing additional selection devices once cod end designs with strong selective performance are established (Cuende et al., 2022). Fisheries have suffered due to the use of harmful and non-selective fishing methods and gear, including practices like trawling and beach seining, the deployment of gill nets with mesh sizes that capture juvenile fish, and the expansion of mechanized fishing operations (Ogutu-Ohwayo et al., 2000).

Conclusion

Looking ahead, sustainable fishing gear stands as a cornerstone for achieving the delicate balance between productive fisheries and the urgent need to safeguard marine ecosystems. Ongoing advancements in gear selectivity driven by creative design innovations, improved material choices, and cutting-edge technologies are playing a crucial role in lowering bycatch, protecting juvenile fish, and minimizing habitat damage. Collaborative research efforts, coupled with the proactive involvement of fishers, have shown that practical measures like the use of larger hooks, optimized cod end designs, and alternative gear configurations can greatly enhance fishing practices. Despite persistent challenges technical, ecological, and operational the continued development of simulation tools, advanced modelling, and modern gear design strategies offers promising solutions. As the demand for sustainable fishing intensifies, it is essential that future initiatives prioritize the refinement of current gear, the adoption of alternative technologies, and the implementation of strong management frameworks to ensure their effective use. Together, these actions will help secure healthy fish stocks, preserve marine biodiversity, and build resilient fishing communities well into the future.

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Nature's Hidden Workforce: Harnessing Pollinators for Thriving Fruit Crops and Sustainable Agriculture

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"Pollinators play a crucial role in enhancing productivity, quality, and biodiversity in fruit crop cultivation. More than 75% of major food crops, including a wide array of fruits, depend on pollinators for fertilization and improved yield. However, pollinator populations are declining globally due to multiple challenges such as pesticide misuse, habitat loss, and climate change. This article reviews the significance of pollinators in fruit crop production, the threats they face, and sustainable management strategies to conserve and enhance pollination services."

Keywords: Fruit crops, Honeybees, Pollinators

Introduction

Pollination is a vital ecological service essential for the reproduction of flowering plants and the production of many horticultural crops. Fruit crops such as apples, mangoes, citrus, strawberries, almonds, and melons benefit significantly from both natural and managed pollinators. The dependence on animal-mediated pollination is directly linked to yield improvement, fruit quality, and economic gains for farmers.

Globally, the decline of pollinators poses a significant threat to food security and ecosystem health. Effective pollinator management practices are urgently required to address these challenges and ensure sustainable horticultural production.

Importance of Pollinators in Fruit Crop Production

Pollinators contribute to:

- **Increased Fruit Set:** Successful transfer of pollen improves fruit set and ensures better seed development.
- **Enhanced Fruit Quality:** Pollination can influence the size, shape, and sweetness of fruits.
- **Genetic Diversity:** Cross-pollination promotes genetic diversity, leading to disease resistance and robust plant populations.
- **Higher Yields and Economic Returns:** Crops like apples, guava, litchi, and watermelon show substantial yield improvements when pollinators are effectively managed.

Major pollinators in horticulture include:

- Honeybees (*Apis* spp.)
- Bumblebees (*Bombus* spp.)
- Solitary bees
- Butterflies and moths
- Birds and bats

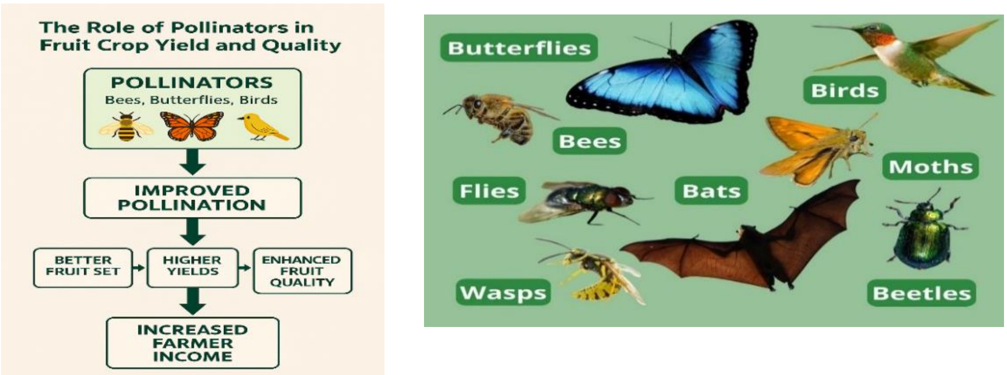

Plate No. 1. The role of pollinator in fruit crops yield and quality

Challenges to Pollinators

Several factors are contributing to the alarming decline in pollinator populations:

Pesticide Misuse

- Broad-spectrum pesticide use, especially during flowering periods, harms pollinators directly and reduces floral resources.

Habitat Loss

- Urbanization, deforestation, and monoculture practices lead to the destruction of pollinator habitats, nesting sites, and food sources.

Climate Change

- Rising temperatures and altered weather patterns disrupt the synchronization between plant flowering and pollinator activity.

Diseases and Invasive Species

- The spread of pests and diseases among pollinators, such as the Varroa mite in honeybees, further exacerbates population declines.

Lack of Awareness

- Limited knowledge among farmers and stakeholders about the role of pollinators hinders conservation efforts.

Sustainable Pollinator Management Strategies

To address these challenges, a combination of ecological, technological, and management practices is necessary:

Habitat Enhancement

- Establishment of flowering strips, cover crops, and hedgerows within and around orchards to provide continuous forage.
- Conservation of wild habitats and nesting sites for native pollinators.

Pesticide Management

- Adoption of Integrated Pest Management (IPM) that minimizes pesticide use.
- Use of selective, bee-safe chemicals and careful timing of applications to avoid peak pollinator activity.

Managed Pollination Services

- Introduction of managed honeybee hives or bumblebee boxes in orchards during flowering periods.
- Training farmers in the handling and placement of pollinator hives.

Conservation of Native Pollinators

- Protecting and promoting native bee populations, which often outperform introduced honeybees in certain crops.
- Avoiding land-use practices that disturb native bee habitats.

Climate-Resilient Pollination

- Breeding and selection of crop varieties that are better adapted to changing climates and maintain attractiveness to pollinators.
- Research into alternative pollination methods, including artificial pollination and robotic pollinators.

Case Studies and Success Stories

- **Apple Orchards in Himachal Pradesh:** The integration of managed honeybee colonies has resulted in a 30-50% increase in apple yields and improved fruit quality.

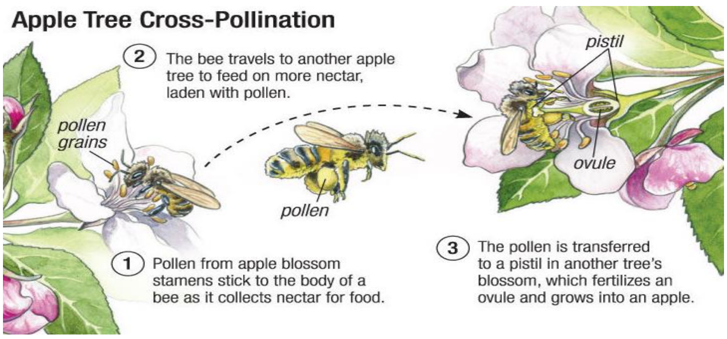

Plate 2. Apple tree Pollination through Honey Bee

- **Strawberry Cultivation in Maharashtra:** Encouraging the growth of wildflower borders around strawberry fields has enhanced natural pollinator abundance, reducing dependence on chemicals.

Future Prospects

Pollinator conservation is not only an environmental concern but also an agricultural necessity. Future research should focus on:

- Development of pollinator-friendly agricultural policies.
- Public-private partnerships for pollinator habitat restoration.
- Increased awareness programs for farmers on pollinator importance.
- Technological innovations in precision pollination and monitoring.

Conclusion

Pollinator management is integral to the sustainability and profitability of fruit crop production. A balanced approach involving habitat conservation, judicious pesticide use, managed pollination services, and farmer education can significantly enhance pollination services. By adopting these strategies, the horticulture sector can ensure food security, biodiversity conservation, and improved livelihoods for farming communities.

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"Integrated Farming System: A Sustainable Model for Indian Agriculture"

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1. Introduction

Integrated Farming System (IFS) is a sustainable agricultural strategy that involves the integration of various agricultural activities such as crop production, livestock, aquaculture, agroforestry, and more. The primary aim is to maximize resource utilization and productivity per unit area sustainably. It ensures food security, enhances income, provides employment opportunities, and maintains ecological balance.

IFS is based on the principle of complementary and supplementary relationships among different enterprises. For example, crop residues can be used to feed livestock; animal waste can be used for biogas production and as manure for fields; water from fish ponds can be reused for irrigation. These interconnected systems result in efficient use of natural resources and minimize wastage.

In India, where agriculture is the main livelihood for a large portion of the population, IFS is especially relevant. It allows farmers to reduce dependence on a single commodity and increases resilience to climate change, market fluctuations, and pest outbreaks. With land holdings shrinking and input costs rising, IFS provides an economically and ecologically sound approach to sustainable agriculture.

Moreover, IFS plays a crucial role in ensuring nutrition security by producing a variety of food products like cereals, pulses, vegetables, fruits, milk, eggs, and meat. It also contributes to climate adaptation and mitigation by enhancing biodiversity and soil health while reducing greenhouse gas emissions.

2. Objectives of IFS

The Integrated Farming System (IFS) approach has been designed to meet multiple goals—economic, environmental, and social—within the scope of sustainable agriculture. The core objectives of IFS are as follows:

1. Efficient Resource Utilization

IFS aims to make the most efficient use of available natural and farm resources such as land, water, solar energy, and biomass. By integrating different enterprises (e.g., crops, livestock, fishery, etc.), it reduces resource wastage and enhances productivity per unit area.

2. Risk Minimization through Diversification

Crop failure due to pests, diseases, or climate variability can be compensated by income from livestock, poultry, or fisheries. Thus, IFS helps in minimizing economic risks through enterprise diversification, making the farming system more resilient.

3. Sustainable Income and Livelihood Security

By ensuring year-round production from multiple farm activities, IFS generates continuous income and employment for farm families, especially small and marginal farmers, contributing to poverty reduction and rural development.

4. Nutritional Security

IFS contributes to a balanced diet for farm families by producing diverse foods such as cereals, pulses, fruits, vegetables, milk, meat, and eggs. This helps to combat malnutrition and ensure better family health.

5. Environmental Protection and Soil Health

IFS promotes reduced use of chemical inputs and enhances the use of organic manures (e.g., farmyard manure, compost, vermicompost). This supports soil fertility, biodiversity conservation, and ecological balance.

6. Waste Recycling and Resource Circulation

One of the most important objectives of IFS is to reuse farm residues: for example, using animal dung for biogas or compost, crop residues for mushroom cultivation or mulch, and pond silt as a soil conditioner. This internal resource flow reduces dependency on external inputs and saves cost.

7. Employment Generation

IFS engages family labor throughout the year due to the continuous demands of different components. This reduces migration to urban areas and helps retain rural youth in agriculture by making farming more viable and interesting.

8. Climate Resilience

IFS enhances the adaptability of agriculture to climate change through diversification, organic matter build-up in soil, water conservation, and reduced greenhouse gas emissions, contributing to climate-smart farming practices.

9. Optimal Use of Family Labor and Infrastructure

Since multiple activities are carried out on the same farm, family members can be productively engaged, utilizing existing labor and facilities (e.g., shed, machinery, irrigation system) across enterprises.

3. Major Components of IFS

Integrated Farming System (IFS) is based on the synergistic combination of various farm-based enterprises. The selection of components depends on the **agro-climatic zone**, **resource availability**, and **farmer's need**. The key idea is that the output (by-product) of one enterprise serves as the input for another, ensuring minimal waste and maximum efficiency.

1. Crop Production (Field Crops)

The backbone of any farming system, crop cultivation provides food, fodder, and raw materials. Depending on the season and region, farmers grow:

- **Cereals** (rice, wheat, maize)
- **Pulses** (gram, lentil, pigeon pea)
- **Oilseeds** (mustard, groundnut, soybean)
- **Vegetables and spices** (onion, garlic, tomato, chili)

Residues from crops are used for livestock feed, mulching, compost, or mushroom beds.

2. Livestock (Dairy, Poultry, Goatery, etc.)

Livestock is a vital source of milk, meat, eggs, manure, and traction power. Key livestock components include:

- **Dairy animals** (cow, buffalo) – Milk and dung
- **Goats/Sheep** – Meat, milk, and manure
- **Poultry** – Eggs and meat; their droppings enrich manure
- **Pigs/Rabbits** – Fast-growing source of meat

Livestock also provides organic waste useful for composting and biogas.

3. Fisheries (Aquaculture)

Wherever water is available (ponds, canals, tanks), **fish culture** can be integrated.

- Fish species like rohu, catla, common carp are reared.
- **Duck-cum-fish culture** helps feed the fish with duck droppings and increases farm profitability.

4. Horticulture (Fruits, Vegetables & Floriculture)

Horticultural crops add diversity and nutritional value to the farm system.

- **Fruit crops:** Mango, guava, banana, papaya
- **Vegetables:** Tomato, brinjal, okra, cauliflower
- **Flowers:** Marigold, rose, jasmine

Fruit trees on farm boundaries or as intercropping can also act as windbreaks.

5. Agroforestry

Combining agriculture and forestry on the same land improves land productivity and sustainability.

- Trees like **Subabul, neem, moringa, babul** are planted.
- Provide **timber, firewood, fodder, green manure**, and **shade**
- Improve **soil health**, prevent erosion, and act as carbon sinks.

6. Beekeeping (Apiculture)

- Bees assist in **crop pollination**, boosting yield in oilseeds, pulses, fruits.
- Honey and wax provide income.
- Can be integrated with orchards, mustard crops, and forest trees.

7. Mushroom Cultivation

- Utilizes agricultural waste like **paddy straw, wheat straw, or sugarcane bagasse**.
- Grows in sheds and unused rooms with minimal space.
- Generates quick income and protein-rich food.

8. Vermicomposting and Compost Units

- Converts farm waste, crop residue, and dung into **nutrient-rich organic manure** using **earthworms**.
- Reduces dependency on chemical fertilizers.
- Enhances soil microbial activity and structure.

9. Biogas Plant

- Animal dung and kitchen waste are used to generate **methane gas** for cooking and lighting.
- The **slurry** from biogas is a valuable **organic fertilizer**.
- Reduces fuelwood dependence and indoor pollution.

10. Agro-Processing and Value Addition

- Processing farm produce increases shelf life and profit margins.
  Examples:
- Milk → curd, paneer
- Fruits → jams, pickles

4. Benefits of Integrated Farming System (IFS)

The Integrated Farming System (IFS) provides numerous advantages that address economic, ecological, and social dimensions of sustainable agriculture. These benefits are especially crucial in the context of small and marginal farmers, who face increasing challenges due to climate change, land degradation, and input cost escalation.

1. Economic Benefits

a) Higher Productivity per Unit Area

By combining multiple enterprises (crops + livestock + fishery + horticulture, etc.), farmers make full use of available resources throughout the year, resulting in higher total output per hectare.

b) Diversified and Stable Income

Income does not depend on a single commodity. If one enterprise fails (e.g., crop loss due to drought), income from dairy, poultry, or fishery helps ensure financial stability.

c) Year-Round Employment

IFS generates continuous work opportunities for family labor and reduces seasonal unemployment, especially in rural areas.

d) Better Input Use Efficiency

Outputs like manure, crop residues, and slurry are recycled within the system. This reduces external input costs (chemical fertilizers, feeds, fuel) and improves farm profitability.

2. Environmental and Ecological Benefits

a) Waste Recycling and Reduced Pollution

Wastes from one activity (e.g., livestock dung, crop residues) are inputs for another (e.g., composting, biogas). This minimizes pollution and reduces the environmental footprint.

b) Soil Fertility and Health Improvement

Organic recycling (compost, vermicompost, green manures) enhances microbial activity and soil structure, improving water retention and reducing erosion.

c) Biodiversity Conservation

IFS encourages mixed cropping, intercropping, agroforestry, and animal integration, supporting diverse species and beneficial insects.

d) Lower Chemical Dependency

With reduced reliance on synthetic fertilizers and pesticides, IFS supports sustainable farming and protects soil, water, and air quality.

3. Social Benefits

a) Nutrition Security for Farm Families

IFS provides a range of foods: cereals, pulses, milk, meat, fish, vegetables, fruits, and eggs. This diversity ensures a balanced diet and reduces malnutrition in rural households.

b) Reduced Rural Migration

By making agriculture more profitable and engaging, IFS discourages migration of rural youth to urban areas in search of jobs.

c) Empowerment of Women and Youth

IFS activities like poultry, mushroom cultivation, vermicomposting, and kitchen gardening are easily managed by women, promoting gender equity and rural entrepreneurship.

4. Risk Management and Climate Resilience

a) Diversification Minimizes Climate Risk

In mono-cropping, a drought or pest attack can ruin the entire crop. In IFS, such losses are offset by other components, reducing vulnerability.

b) Builds Climate Resilience

Practices like agroforestry, mulching, and water harvesting enhance adaptability to changing weather patterns, while organic matter build-up improves drought tolerance.

5. Efficient Resource Management

a) Optimal Utilization of Resources

Farm waste, labor, machinery, water, and space are used more efficiently. Crop-livestock integration, for example, reduces feed and manure costs.

b) Sustainable Land Use

IFS allows intensive cultivation even on small holdings, making better use of marginal lands, wetlands, or hilly terrains with appropriate models.

6. Value Addition and Market Linkage

a) Scope for Value Addition

Products like milk, fruits, vegetables, and fish can be processed into cheese, pickles, dried vegetables, or fish fillets, improving shelf life and value.

b) Improved Market Opportunities

Diverse products attract multiple buyers, improving farmers' market access and bargaining power.

5. IFS Models for Different Agro-Climatic Zones (Examples)

India has diverse agro-climatic zones, ranging from arid deserts to humid tropics, high altitudes to coastal plains. Integrated Farming Systems (IFS) must be **customized** to suit the local **soil, water, climate, socio-economic conditions**, and **resource availability**.

Below are some **region-specific IFS models** successfully practiced across India:

1. Rainfed (Dryland) Areas

Suitable Regions: Bundelkhand, Rajasthan, Karnataka (dry belts), parts of Madhya Pradesh, Telangana
Key Features: Low rainfall, water scarcity, marginal land

Model Example:

☞ **Crop + Goat + Poultry + Vermicompost**

- **Crops:** Millets, pigeon pea, chickpea
- **Livestock:** Goats for meat; poultry (native breeds)
- **Composting:** Organic recycling from droppings
- **Benefits:** Low input, drought-resilient, continuous income

2. Irrigated Plains (High Input Zone)

Suitable Regions: Punjab, Haryana, Uttar Pradesh, parts of Bihar and Tamil Nadu
Key Features: Good irrigation, fertile alluvial soil

Model Example:

☞ **Crop + Dairy + Fishery + Biogas**

- **Crops:** Paddy, wheat, sugarcane
- **Dairy:** Cows and buffaloes (crossbred)
- **Fishery:** Pond in waterlogged area
- **Biogas:** Dung used for clean energy and slurry as manure
- **Benefits:** High yield, zero waste, income from milk and fish

3. Hill and Mountain Ecosystems

Suitable Regions: Uttarakhand, Himachal Pradesh, Northeast India
Key Features: Sloping terrain, terrace farming, limited mechanization
Model Example:

☞ **Crops + Horticulture + Goat/Pig + Beekeeping**

- **Crops:** Barley, maize, buckwheat
- **Fruits:** Apple, citrus, kiwi
- **Livestock:** Goat and pigs for meat
- **Apiculture:** Honey production from wild flora
- **Benefits:** High-value products, eco-tourism potential

4. Coastal Areas

Suitable Regions: Odisha, Andhra Pradesh, Kerala, Tamil Nadu coast
Key Features: High humidity, saline conditions, waterlogged fields
Model Example:

☞ **Rice + Fish + Duck + Coconut**

- **Crop:** Paddy (short-duration varieties)
- **Fish:** Integrated in rice field bunds or ponds
- **Duck:** Improves water quality and pest control
- **Tree:** Coconut or banana on bunds
- **Benefits:** Excellent nutrient cycling, dual harvest from same field

5. Tribal and Forest Fringe Areas

Suitable Regions: Chhattisgarh, Jharkhand, Odisha, parts of Madhya Pradesh
Key Features: Dependence on forest produce, shifting cultivation, subsistence farming
Model Example:

☞ **Crop + Backyard Poultry + Minor Fruits + Medicinal Plants**

- **Crops:** Maize, pulses
- **Livestock:** Indigenous poultry
- **Fruits:** Jackfruit, custard apple, tamarind
- **Medicinals:** Ashwagandha, tulsi
- **Benefits:** Nutrition and income security with local knowledge

6. Wetland / Water-Abundant Areas

Suitable Regions: Eastern India, Brahmaputra valley, Kerala (Kuttanad)
Model Example:

☞ **Rice + Fish + Duck + Banana/Plantation Crops**

- Utilizes standing water post-rice
- Ducks help in pest control and fertilization
- Fish grow in bunded fields
- Fruits or spices like turmeric can grow on bunds

7. Urban/Peri-Urban Areas (Small Landholdings)

Model Example:

☞ **Vegetable + Mushroom + Poultry + Terrace Farming**

- High-value short-duration crops
- Mushroom cultivation in sheds
- Small-scale poultry for eggs/meat
- Kitchen waste used in compost/vermiculture

6. Economic and Ecological Impact of Integrated Farming System (IFS)

Integrated Farming System (IFS) is more than just a farming technique—it's a strategic model to **transform rural livelihoods** by promoting **sustainable resource use** and **economic resilience**. It addresses both income generation and environmental sustainability through its multifunctional approach.

I. Economic Impact

IFS offers strong economic advantages, especially for small and marginal farmers who constitute more than 85% of India's farming population.

1. Enhanced Farm Income

- Multiple income sources (milk, vegetables, eggs, honey, fruits, fish, etc.) lead to higher **gross and net returns per unit area**.
- Studies have shown that IFS can **double or even triple the income** compared to monocropping systems. **Example:** A dairy-based IFS in Haryana increased net returns by 65% compared to traditional rice-wheat farming.

2. Low Cost of Cultivation

- **Recycling of farm waste** (e.g., manure, crop residues) reduces the need for costly fertilizers, pesticides, and feeds.
- Family labor is better utilized across enterprises, lowering labor costs.

3. Income Round the Year

- IFS provides **continuous revenue streams** through staggered harvesting and non-seasonal enterprises like dairy, poultry, mushroom, etc.

4. Employment Generation

- Engages family members across diverse tasks: crop care, livestock feeding, composting, marketing, etc.
- Encourages **on-farm entrepreneurship** and **rural self-employment**. **Data:** IFS can generate 400–600 man-days of employment annually per hectare, compared to 150–180 in monocropping.

5. Value Addition Opportunities

- Farm products like fruits, milk, and cereals can be processed into high-value items like jam, ghee, flour, etc.
- Increases **profit margin** and shelf life of perishable items.

6. Economic Resilience

- Farmers are **less vulnerable** to market price fluctuations, climate disasters, or crop failures since other income streams remain intact.

II. Ecological and Environmental Impact

IFS plays a critical role in preserving the natural resource base for current and future generations.

1. Soil Health Improvement

- Use of **organic manures**, **green manuring**, and **vermicomposting** boosts soil microbial activity and organic carbon.
- Reduces **soil degradation** from continuous chemical use.

2. Waste Utilization and Recycling

- Animal dung → compost/biogas → organic manure
- Crop residues → livestock feed or mushroom beds
- Pond silt → soil conditioner for crops. This internal resource cycling reduces environmental waste and input dependency.

3. Water Conservation

- Integration of **mulching**, **drip irrigation**, and **fishery-based nutrient recycling** promotes water-use efficiency.

- Agroforestry components reduce **evapotranspiration** and enhance moisture retention.

4. Climate Change Mitigation

- Agroforestry and crop-livestock systems promote **carbon sequestration**.
- Reduced use of synthetic fertilizers and fossil fuels (via biogas) helps lower **greenhouse gas emissions**.

5. Pollution Reduction

- Organic-based farming reduces chemical runoff to water bodies, thereby **improving water quality**.
- Biogas units minimize **indoor air pollution** compared to firewood use.

6. Biodiversity Conservation

- Crop rotation, intercropping, agroforestry, and bee-friendly plants support **natural enemies of pests** and **pollinators**.
- Promotes both **agro-biodiversity** and **wild biodiversity** on the farm.

7. Land-Use Efficiency

- Multiple enterprises utilize vertical and horizontal space: trees on bunds, fish in ponds, poultry under sheds, etc.
- Enhances land productivity even in **small and marginal landholdings**.

7. Challenges in Adoption of Integrated Farming System (IFS)

While the Integrated Farming System (IFS) is highly beneficial for sustainable agriculture, its widespread adoption is **still limited** in many regions. Farmers often face multiple **technical, socio-economic, institutional, and infrastructural barriers** that prevent full realization of IFS potential.

I. Technical Challenges

1. Lack of Knowledge and Awareness

- Many farmers, especially smallholders, are **unaware of IFS principles** or the benefits of integrating enterprises like poultry, fishery, and composting.
- **Limited exposure** to success stories, training, or demonstrations.

2. Inadequate Technical Skills

- Proper management of livestock, fish ponds, mushroom units, or biogas plants requires **multidisciplinary knowledge**.
- Lack of **extension services** and scientific guidance hampers integration.

3. Climate and Soil Constraints

- In some agro-ecological zones, components like horticulture or aquaculture may not be feasible due to **climatic extremes** or **poor soil conditions**.

II. Economic and Financial Challenges

1. High Initial Investment

- Infrastructure like sheds, fish ponds, irrigation systems, compost pits, and biogas units demand **significant upfront cost**, which small farmers often cannot afford.

2. Credit and Insurance Gaps

- Difficulties in **accessing farm loans**, especially for integrated units rather than just crops.
- Lack of insurance products covering **multiple enterprises** (crop + livestock + fishery) increases financial risk.

III. Land and Resource Constraints

1. Small and Fragmented Landholdings

- IFS models may need space for diversification; **fragmented plots** limit flexibility in integrating trees, animals, or fish ponds.

2. Water Scarcity

- Integration of horticulture and aquaculture requires consistent water supply. In dryland zones, **limited water availability** restricts component options.

IV. Marketing and Infrastructure Barriers

1. Poor Market Access

- Lack of **organized markets**, cold chains, or transportation for perishables like milk, vegetables, eggs, or fish.

- Farmers face **price fluctuations** and **middlemen exploitation**.

2. Lack of Storage and Processing Facilities

- Without **value addition units** (e.g., milk chilling centers, fish drying, fruit processing), farmers sell raw products at low prices.

V. Socio-Cultural and Behavioral Challenges

1. Resistance to Change

- Traditional monoculture practices are deeply rooted. Many farmers are **reluctant to try new methods** due to fear of failure or lack of trust.

2. Labor Shortage

- Some IFS activities are labor-intensive. **Migration of rural youth** to cities creates a shortage of farm labor, especially during peak seasons.

3. Gender Roles and Access

- In some regions, **women are restricted** from owning or managing assets like livestock, fisheries, or finances—limiting full system integration.

VI. Institutional and Policy Barriers

1. Lack of Convergence Between Departments

- Agriculture, animal husbandry, fisheries, and horticulture departments often **work in silos**, lacking coordination to promote IFS holistically.

2. Inadequate Government Support

- Most subsidies and schemes still favor **individual enterprises**, not **integrated models**.
- Extension programs are often crop-centric, ignoring livestock or ecological integration.

8. Government Initiatives Supporting IFS in India

Recognizing the potential of Integrated Farming Systems (IFS) to achieve **sustainable agriculture, rural employment, and food security**, the Government of India—through various ministries, councils, and missions—has introduced several schemes and initiatives to promote and support IFS adoption among farmers, especially smallholders and marginalized groups.

1. Indian Council of Agricultural Research (ICAR) – AICRP on IFS

- **AICRP-IFS (All India Coordinated Research Project on Integrated Farming Systems)** is a flagship research program under ICAR initiated in **2005**.
- Focuses on **location-specific IFS models** in different agro-climatic zones.
- Research stations across India test, validate, and recommend **economically viable and ecologically sound IFS models**.
- Helps in **technology dissemination**, training of extension workers, and farmer participation.

2. National Mission for Sustainable Agriculture (NMSA)

- Launched under the **National Action Plan on Climate Change (NAPCC)**.
- Promotes **climate-resilient farming** including IFS, soil health management, and efficient water use.
- Provides support for:
  - **Vermicomposting units**
  - **Biogas plants**
  - **Agroforestry**
  - **Water conservation structures**
  - **Organic farming**
- Focuses on **resource efficiency and productivity enhancement** through integration.

3. Rashtriya Krishi Vikas Yojana (RKVY)

- A centrally sponsored scheme aimed at **holistic agricultural development**.
- Funds used by states to promote IFS, particularly through:
  - Livestock integration (dairy, goatery, poultry)
  - Horticulture promotion
  - Creation of farm ponds and compost units
- Provides infrastructure support and **subsidies for integrated units**.

4. National Livestock Mission (NLM)

- Promotes integration of **dairy, goatery, backyard poultry, and piggery** within IFS models.
- Offers financial assistance for:
  - Livestock shed construction
  - Breed improvement
  - Fodder development
  - Training in animal husbandry

5. Mission on Integrated Development of Horticulture (MIDH)

- Supports **integration of fruits, vegetables, spices, and floriculture** in farming systems.
- Provides assistance for:
  - High-density plantations
  - Protected cultivation
  - Post-harvest infrastructure
  - Beekeeping and mushroom cultivation

6. Krishi Vigyan Kendras (KVKs)

- Over **731 KVKs** under ICAR across districts of India are conducting:
  - On-farm trials of IFS models
  - Farmer training and demonstrations
  - Advisory services on enterprise integration
  - Encouraging youth and women in IFS

7. Paramparagat Krishi Vikas Yojana (PKVY)

- Aims to promote **organic and ecological farming**, an integral part of IFS.
- Encourages **bio-inputs**, composting, and mixed farming with minimum external inputs.
- Cluster-based approach supports **group certification and marketing**.

8. Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)

- MGNREGA funds are used for creating **farm infrastructure** that supports IFS, such as:
  - Farm ponds and water tanks
  - Tree planting (agroforestry)
  - Compost pits
- Promotes **convergence with agriculture schemes** for sustainable livelihoods.

9. Blue Revolution – Integrated Fish Farming

- Ministry of Fisheries supports **fish-cum-duck, rice-fish, and integrated pond systems**.
- Subsidies available for pond construction, hatchery units, and feed.

10. Biogas Development Programme (MNRE)

- Ministry of New and Renewable Energy promotes **family-type biogas plants**, an essential IFS component.
- Dung from livestock is converted into **clean fuel**, and **biogas slurry** is used as manure.

11. NABARD and Financial Institutions

- NABARD (National Bank for Agriculture and Rural Development) supports:
  - Integrated farming clusters
  - Agri-entrepreneurship in IFS-based activities
  - Provides **refinance support** and **low-interest loans** for infrastructure creation

12. State-Specific Initiatives

Many Indian states have launched their **own programs** to promote IFS:

State	Initiative
Tamil Nadu	Integrated Farming System Promotion Program
Kerala	Haritha Keralam Mission (organic + IFS)
Madhya Pradesh	Integrated Agriculture Model in tribal districts

State	Initiative
Chhattisgarh	Godhan Nyay Yojana (compost from dung)
Sikkim	100% Organic State using IFS practices

Impact of These Initiatives

- Increased **income** and **nutritional security** among participating farmers
- Improved **soil health**, **resource recycling**, and **climate resilience**
- Enhanced **market access**, **value addition**, and **employment**

9. Conclusion

Integrated Farming System (IFS) is a dynamic, sustainable, and holistic approach to agriculture that addresses the **economic, environmental, and social challenges** faced by farmers, especially those with small and marginal landholdings. By combining different components—such as crops, livestock, fishery, horticulture, agroforestry, and value addition—IFS maximizes productivity, minimizes waste, and ensures income throughout the year.

IFS promotes **efficient resource use**, including labor, land, water, and organic residues, by fostering synergy among various enterprises. It not only enhances **food and nutritional security** but also builds **resilience against climate change** and market fluctuations. Additionally, the system supports environmental sustainability by improving **soil health, water conservation, and biodiversity** while reducing chemical input use and greenhouse gas emissions.

Despite its immense benefits, the adoption of IFS faces several **challenges**, such as lack of awareness, limited access to credit, fragmented landholdings, inadequate training, and poor market infrastructure. However, through strong government support, institutional convergence, capacity building, and community-based models, these hurdles can be gradually overcome.

With the right policy interventions, infrastructure support, and farmer-centric extension services, IFS has the potential to transform Indian agriculture into a **resilient, self-sufficient, and eco-friendly sector**. It is not only a strategy for agricultural development but also a pathway to achieving **doubling of farmers' income**, **climate-smart agriculture**, and **sustainable rural livelihoods** in India and beyond.

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Raising the Roots: High-Tech Nurseries for Vegetable Revolution

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Abstract

The backbone of successful vegetable cultivation lies in the quality of planting material. High-tech nurseries are emerging as game-changers by offering healthy, uniform and early-stage seedlings through scientific interventions like plug tray systems, grafted seedling production and automated mist chambers. These nursery advancements not only improve plant survival and productivity but also reduce pest and disease pressure, thus supporting sustainable and climate-smart vegetable farming. This article explores the latest technologies in vegetable seedling nurseries, their benefits and their growing adoption across India with special insights from Odisha.

Introduction:

Vegetables are short-duration, high-value crops and any setback at the seedling stage whether due to poor germination, pest attack or climatic stress—can severely affect the final yield. Traditionally, farmers raised vegetable seedlings in open beds, often leading to weak, disease-prone and non-uniform transplants. With changing climate and intensive cropping, the demand for robust and uniform seedlings has increased significantly. This is where high-tech nurseries offer a reliable solution by using controlled environments, scientific growing media and advanced nursery practices (Kumar *et al.*, 2020). These nurseries are now a vital part of vegetable production systems in both open-field and protected cultivation.

Key Technologies in Modern Vegetable Nurseries:

1. Plug Tray Seedling Production:

a) Uses plastic trays with 50–128 cavities filled with soilless media like cocopeat, vermiculite or perlite.
b) Ensures uniform germination, root pruning and easy handling during transplanting.
c) Results in stronger root development and minimum transplant shock.
d) Popular for crops like tomato, chilli, brinjal, cabbage and capsicum.

2. Grafted Vegetable Seedlings:

a) Combines a vigorous rootstock (for resistance to soil-borne diseases) with a scion of a high-yielding variety.
b) Commonly used in tomato, brinjal, cucumber and watermelon.
c) Offers resistance to Fusarium wilt, bacterial wilt, nematodes and flooding.
d) Grafted seedlings are now widely adopted in Maharashtra, Karnataka and Odisha (Bhatt *et al.*, 2021).

3. Automated Mist Chambers & Net Houses:

a) Provide ideal humidity and temperature for germination and seedling growth.
b) Protects against high temperatures, rain and direct sunlight.
c) Helps harden seedlings before transplanting.
d) Encourages year-round nursery production.

4. Root Trainers and Pro-tray Systems:

a) Specialized trays that encourage downward root growth.
b) Reduces root coiling and enhances transplant success.
c) Preferred for onion, cabbage and exotic leafy vegetables.

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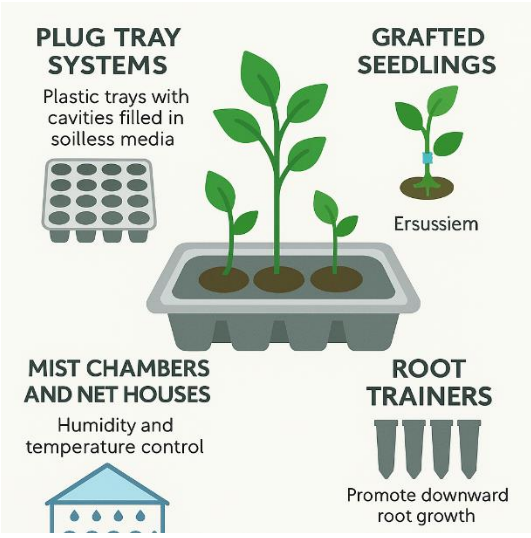

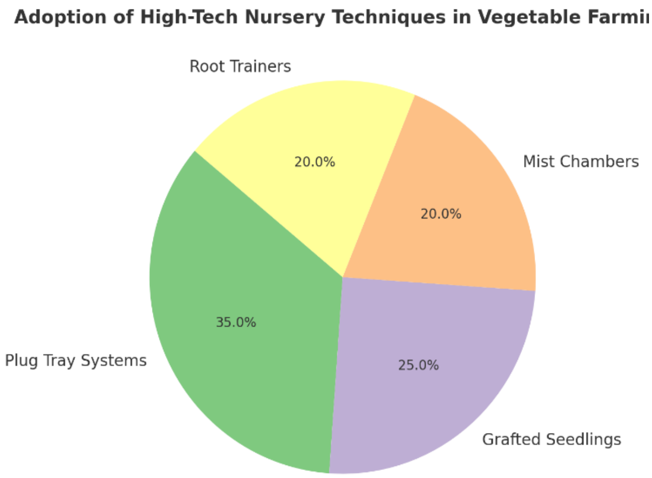

Benefits of High-Tech Vegetable Nurseries:

Parameter	Traditional Nursery	High-Tech Nursery
Germination rate	60–70%	90–95%
Uniformity of seedlings	Poor	Excellent
Pest/disease incidence	High	Low
Transplant shock	Common	Minimal
Crop duration	Longer	Shorter (early maturity)
Suitability for mechanization	Difficult	Highly suitable

These advantages lead to higher yields, early harvest and better income, especially when integrated with protected cultivation (Patel *et al.*, 2022).

Indian Success Stories and Initiatives:

IIHR, Bengaluru

- Developed plug tray-based nurseries and trained over 2,000 farmers and entrepreneurs
- Demonstrated 30–40% yield improvement with hybrid tomato and capsicum seedlings raised in hi-tech nurseries

KVK, Khurda (OUAT)

- Introduced plug-tray tomato and brinjal seedlings to tribal farmers
- Resulted in **80% reduction in seedling mortality** and **25% higher marketable yield** in 2022–23 season

Farmer Startup in Maharashtra

- An agri-preneur set up a **100,000-seedling capacity nursery** supplying grafted chilli and tomato seedlings
- Sells to over 500 farmers across 3 districts with high customer retention due to seedling survival and uniformity

MIDH & RKVY Support

- Government programs like **Mission for Integrated Development of Horticulture (MIDH)** provide 40–50% subsidy
- State horticulture departments are encouraging nursery entrepreneurship, especially among FPOs and rural youth

Scope for Odisha and Eastern India:

Odisha has diverse agro-climatic zones and is expanding area under vegetables like brinjal, tomato, chilli, okra and cabbage. However, most seedlings are still raised on-farm in unprotected conditions.

i. Promoting district-level hi-tech nurseries, especially in vegetable clusters, can support smallholders.
ii. Tribal areas in Koraput, Kalahandi and Kandhamal can benefit from grafted tomato and brinjal seedlings resistant to wilt and nematodes.
iii. Integration with Krushak Assistance for Livelihood and Income Augmentation (KALIA) and OUAT-KVK network can scale this innovation.

Way Forward:

High-tech nurseries are not just about better seedlings — they represent a shift toward scientific, resilient and climate-smart farming. Their expansion holds the potential to:

a) Reduce seed wastage and input costs
b) Enable timely planting and multiple cropping
c) Encourage nursery-based enterprises and employment
d) Support export-oriented vegetable production

To accelerate this, greater extension, demonstration and convergence with rural employment schemes are needed.

Conclusion:

The future of profitable and sustainable vegetable farming in India begins at the seedling stage. By adopting high-tech nurseries, farmers can ensure a strong start to their crop cycle, reduce risks and enhance returns. As climate challenges grow, investing in the "root" of production is truly the smart way forward.

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HYDROGELS: THE HIDDEN HEROES OF WATER-WISE AGRICULTURE

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ABSTRACT

Global population growth is driving urbanization and environmental degradation, significantly hindering food production. Water scarcity, intensified by depleted groundwater and unpredictable rainfall, critically impacts the cultivation of horticultural crops. This paper investigates the potential of hydrogels as a sustainable solution to mitigate water stress and enhance agricultural output. Hydrogels, even when applied at low concentrations (2-5 kg/ha), have been shown to improve critical soil properties, including porosity, bulk density, and water-holding capacity, across various soil types and climatic conditions. A key advantage of hydrogels is their biodegradability, ensuring they decompose naturally without leaving harmful residues in the soil or crops. This makes them an environmentally sound option for sustainably boosting horticultural crop production in regions facing water deficits.

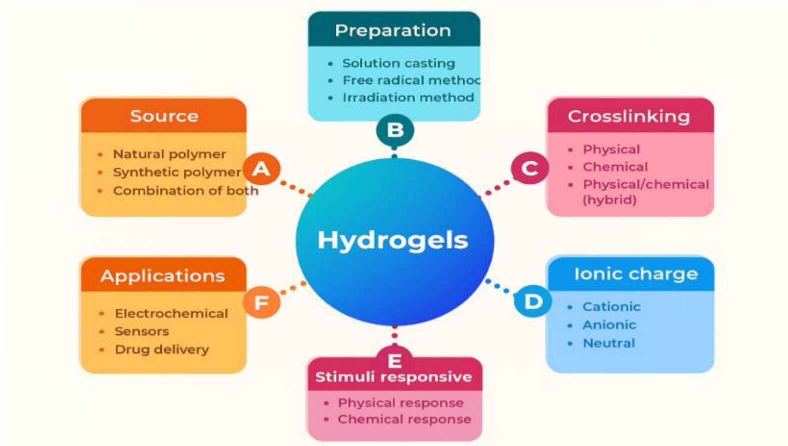
KEY WORDS: Hydrogel, water scarcity, scanty rainfall, sustainability, water holding capacity.

INTRODUCTION

In 1950, India had plenty of water-more than enough for everyone. But that's changed a lot. Today, we have far less water per person, and many parts of India are facing a serious water shortage. This problem is getting worse; for example, October 2018 was one of the driest months in decades, showing how our environment is changing. A big reason is that India relies heavily on monsoon rains to fill up our lakes and rivers. However, due to climate changes, these rains are now unpredictable. This means we desperately need better ways to manage our water. Looking ahead, the world's demand for water is expected to jump by 50% by 2030, making water scarcity a global issue. Agriculture, which grows our food, uses about 70% of all fresh water. India, unfortunately, is one of the countries most affected by water stress. Despite having a small portion of the world's land and water, India is home to a huge chunk of the global population. Feeding so many people requires a lot of food, which, in turn, needs a lot of water. Our country's water needs are expected to nearly double by 2050. While factories and homes use some water, farms use by far the most. So, finding ways to reduce water use in farming is incredibly important. This is where hydrogels come in, offering a promising solution to help our farms use less water and grow more food.

HYDROGEL

Hydrogels, often called plant gels or super absorbent polymers (SAPs), are unique materials composed of cross-linked polymers. This cross-linking is crucial because it allows them to absorb vast amounts of water-typically 400-500 times their dry weight—without dissolving. If they weren't cross-linked, they simply dissolve in water. Their exceptional water storage capacity and soft, gel-like nature are their defining characteristics. What makes hydrogels so valuable, especially in agriculture, is their ability to gradually release up to 95% of their stored water as the surrounding environment dries out. This cycle of absorption and slow release can last for 2-5 years before biodegradable hydrogels naturally decompose. The speed at which hydrogels absorb water depends on their internal structure and the quality of the water itself. They can effectively capture both irrigation water and rainwater, helping to reduce water loss through deep percolation by making both capillary and gravitational water available to plants. Because they swell significantly upon contact with water, agricultural hydrogels are also known as water retention granules. Hydrogels can be made from both natural and synthetic polymers. Natural forms include polysaccharides like agarose and alginate, as well as proteins such as collagen and gelatin. Synthetic hydrogels are typically created using chemical polymerization. Essentially, a hydrogel is a single, large polymer molecule where all the network chains are interconnected, giving it properties that are neither fully liquid nor fully solid. This "semi-liquid, semi-solid" nature allows them to exhibit interesting behaviors, such as significant volume changes in response to external stimuli like temperature, solvent quality, pH, or electric fields.



GENERAL USE OF HYDROGEL

Hydrogels are incredibly versatile materials, valued for their remarkable ability to absorb large amounts of water. This makes them useful in a wide range of everyday products and advanced technologies. You'll find hydrogels in diapers and sanitary napkins, where their super-absorbent properties are essential. They're also key ingredients in personal care items like hair gels and sweat-soaking body powders. Beyond daily essentials, hydrogels play a crucial role in more specialized fields. They're used for sealing, in novelty items like artificial snow, and significantly in agriculture to help manage water. In pharmaceuticals, hydrogels are vital for controlled drug delivery systems. Their compatibility with biological systems also makes them indispensable in biomedical applications, including tissue engineering, regenerative medicine, and wound dressings. Furthermore, they're employed in advanced techniques for separating cells or biomolecules and controlling biological adhesion.

USE IN AGRICULTURE

Agricultural hydrogels, also known as Super Absorbent Polymers (SAPs), are synthetic polymers with a remarkable ability to absorb water many times their own weight. This makes them incredibly useful for enhancing soil's water retention, especially in dry regions. According to Fidelia and Chris (2011), these hydrogels are environmentally safer due to their biodegradability. Their unique capacity for water absorption and retention makes hydrogels valuable in various agricultural applications. They can be used with all crop types and in all soil conditions, offering a simple solution for water-intensive crops or those vulnerable to moisture stress. Hydrogels can be directly incorporated into the soil during sowing or mixed into the growth medium for nursery plants and potted cultures. Their application has demonstrably improved overall crop productivity in a wide range of horticultural crops.

KEY CHARECTERISTICS OF HYDROGEL

Agricultural hydrogels offer several valuable properties that make them beneficial for crop cultivation, especially in challenging environments:

- **Effective in Arid Conditions**: These natural, cellulose-based polymers are highly absorbent, even in hot temperatures (40-50°C), making them ideal for semi-arid and arid regions.
- **Soil and Chemical Compatibility**: With a neutral pH, hydrogels do not alter soil composition, nutrient availability, or the effectiveness of other agrochemicals like fertilizers, herbicides, fungicides, or insecticides. They also improve the physical properties of soil, enhancing its water holding capacity, porosity, bulk density, infiltration rate, and permeability.
- **Boosts Soil Biology**: Hydrogels promote increased biological and microbial activity in the soil, which in turn leads to better oxygen and air availability in the plant root zone.
- **Low Application Rates**: Only small amounts are needed; field crops require 2.5-5 kg per hectare, while nursery horticultural crops need just 1-2 kg per hectare.
- **Salt-Tolerant**: Their performance is minimally affected even when salts are present in the surrounding soil.
- **Exceptional Water Retention and Release**: Hydrogels can absorb up to 400 times their dry weight in pure water and release it slowly as plants need it.

- **Enhances Plant Establishment**: Applying hydrogels improves seed germination and seedling emergence rates. This is due to increased soil porosity, which encourages healthy root growth and density, and helps reduce soil erosion caused by compaction.
- **Reduces Water Stress and Irrigation Needs**: By delaying the permanent wilting point and minimizing water loss through evaporation, hydrogels help plants endure prolonged moisture stress and reduce the frequency of irrigation.
- **Optimizes Resource Use**: They contribute to increased water and nutrient use efficiency in plants by fostering extensive root growth.

S. NO	PARAMETER	CHARACTERISTIC AND POTENTIAL APPLICATIONS
1	Chemical constitution	Cross linked anionic polyacrylate
2	Appearance	Amorphous granules
3	Particle size	20-100 mesh (micro granules)
4	pH	7.0-7.5
5	Stability at 50O C	Stable
6	Sensitivity of UV light	Not sensitive
7	Temperature	40-50 °C
8	Stability	~ 2 Years

MECHANISM OF WATER ABSORBTION

Hydrogels exhibit exceptional water absorption capacity due to specific structural and chemical properties. Their polymeric chains are endowed with numerous hydrophilic functional groups, such as carboxy acid, acrylamide, acrylate, and acrylic acid. These groups are characterized by their strong affinity for water molecules. When a hydrogel is immersed in an aqueous environment, water molecules ingress into the polymer network via an osmotic pressure gradient. This ingress initiates a critical chemical reaction where hydrogen atoms from the surrounding water interact with the polymer, leading to the dissociation and release of positive ions (protons). Consequently, the polymer backbone accumulates an abundance of negative charges. The presence of these uniformly distributed negative charges along the polymer chain induces strong electrostatic repulsion among them. This repulsive force causes the coiled or collapsed polymer chains to undergo a significant conformational change, resulting in their unwinding and expansion.

These exposed hydrophilic groups form numerous hydrogen bonds with the incoming water molecules, further stabilizing the absorbed water within the polymer matrix. This intricate mechanism allows hydrogels to absorb a remarkable volume of water, typically 400 to 500 times their dry weight. Moreover, hydrogels possess the crucial property of reversible water release. As the ambient environment becomes desiccant, the hydrogel progressively releases up to 95% of its stored water. Upon subsequent re-exposure to water, the hydrogel readily rehydrates, initiating the absorption-release cycle anew. This reversible process can sustain for an extended period, typically 2 to 5 years, before the biodegradable hydrogel undergoes complete decomposition.

HOW TO APPLY AGRICULTURAL HYDROGEL AND RECOMMENDED RATES

The application rate for agricultural hydrogel varies depending on soil type. For clay soil, you should apply 2.5 kg per hectare (kg/ha) at a depth of 6 to 8 inches. Sandy soil requires a higher rate, up to 5.0 kg/ha, applied at a shallower depth of 4 inches. Hydrogel should be placed precisely where it's needed, directly below or near the root or seed. Key application methods include mixing it with soil in furrows during sowing, root dipping, and incorporating it into nursery beds.

APPLICATION METHODS BY CROP TYPE:

- **For Field Crops:** Before sowing, combine hydrogel with fine, dry soil in a 1:10 ratio. This mixture can then be applied directly into opened furrows or blended with seeds or fertilizers. For best results, ensure the hydrogel is placed close to the seeds.

- **For Nursery Beds (Transplants):** Apply a hydrogel mixture evenly to the top two inches of the nursery bed at a rate of 2 grams per square meter (g/m²), or follow the recommended rate. For pot cultures, mix 3-5 grams per kilogram (g/kg) of soil before planting.
- **During Transplanting:** Prepare a hydrogel solution by mixing 2 grams (or the suggested rate) per liter of water. Stir until the mixture is free-flowing, then allow it to settle for 30 minutes. Before planting, dip the plant's roots into this solution.

SUCCESS STORY AND ACHIEVEMENTS

Laxmi Lokkur, a farmer from Udikeri village in Karnataka's Belgaum district, has seen a remarkable threefold increase in her farm's yield over the past two years, thanks to the use of hydrogel. Previously, due to water scarcity, she could only cultivate 3-4 acres of her land. However, after incorporating hydrogel, she's been able to expand her cultivation to 15 acres. Her cotton yield soared to 12 quintals per acre, significantly outperforming her neighbors who typically harvested 6 to 8 quintals. Similarly, her jowar and wheat yields also saw substantial improvement, reaching 6 to 8 quintals each, compared to the 4 quintals harvested by other farmers in her area.

Applying 5.0 kg/ha of Pusa hydrogel with an irrigation interval of 14 days has shown significant benefits for ginger. This combination led to the highest plant height, number of leaves, number of tillers, essential oil percentage, and fresh rhizome yield per plant and per hectare. These findings clearly indicate that hydrogel substantially improves ginger's growth, yield, and oil content.

For Senna, a crucial export-oriented crop, applying 3000 g of hydrogel per hectare resulted in a substantial increase in both pod and leaf yield.

In the medicinal plant roselle, the most desirable quantitative traits were achieved when 200g of hydrogel was used in conjunction with a full irrigation treatment.

CONCLUSION

The world faces growing challenges from climate change, leading to unpredictable weather patterns that cause either prolonged droughts or heavy rains that are largely lost to runoff and evaporation. With agricultural production projected to decline significantly by 2050, improving water use efficiency and optimizing existing water resources are critically important. In this context, innovative solutions like Pusa hydrogel offer a promising path forward. Developed by IARI, Delhi, to overcome limitations of synthetic hydrogels, Pusa hydrogel can absorb up to 400 times its weight in water and gradually release it to plants. This capability is vital for enhancing soil's water absorption and retention, thereby combating water scarcity and mitigating drought stress. By conserving soil moisture and optimizing water use, hydrogels present a viable and cost-effective strategy for increasing agricultural output and promoting environmental sustainability, especially in water-scarce regions. Ultimately, moisture conservation techniques such as the use of Pusa hydrogel are essential for addressing India's low water application efficiency and safeguarding resources for future generations.

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CANINE TRANSMISSIBLE VENEREAL TUMOUR (CTVT) IN DOGS

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ABSTRACT:

Canine transmissible venereal tumour (CTVT) is an excessive and coordinated proliferation of cells with no useful functions. It is most commonly spread through mating and the CTVT cells can be transmitted to susceptible animals and transferred, in each dog, to other mucous membranes. Spontaneously through injured skin, or mucosa during coitus, licking, fighting/ biting, sniffing. Clinical signs include cauliflower-like growths and haemorrhagic discharge from the genitalia. Definitive diagnosis is done by physical and microscopic examinations. Chemotherapy, particularly with vincristine, is the treatment of choice in CTVT and has shown excellent therapeutic response.

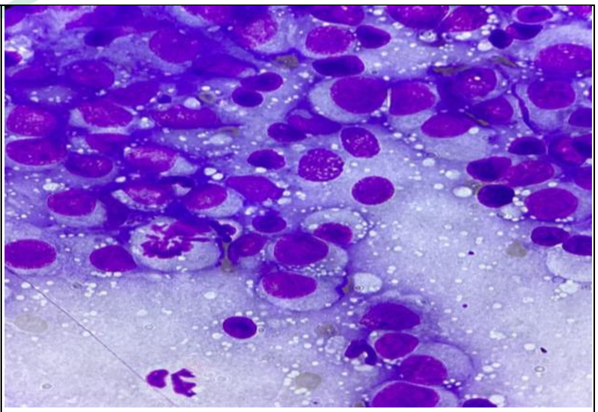
Keywords: Canine transmissible venereal tumour (CTVT), Vincristine, Tumour, Mucous membrane, Chemotherapy.

INTRODUCTION

Canine transmissible Venereal tumour (TVT), also known as Sticker's sarcoma, transmissible venereal tumour, venereal granuloma, canine condyloma or infectious sarcoma. It is most commonly spread during mating, and the CTVT cells can be transmitted to susceptible animals and transferred, in each dog, to other mucous membranes. Spontaneously through injured skin, or mucosa during coitus, licking, fighting/ biting, sniffing. It affects both males (penis, prepuce) and females (vulva, vagina), especially those aged 2-8 years.

DIAGNOSIS:

CVTV is often identified during physical examination as a cauliflower-like mass on the external genitalia in dogs (Fig.1). Definitive diagnosis is achieved through cytological evaluation, such as fine needle aspiration (FNA) or impression smears. Microscopically, the tumour cells appear as discrete round cells with pale or basophilic cytoplasm, which appears bluish with stains. Dot-like cytoplasmic vacuoles are also seen this indicate highly characteristic of CTVT (Fig.2). The nucleus is typically round to oval and located centrally within the cells. The net-like genetic material also appears. Biopsy and Histopathology further confirm the diagnosis.

	
Fig 1: External vaginal tumour in a female dog	**Fig 2: Pleomorphic round cells-vacuolated-Giemsa stain (100X)**

TREATMENT AND DISCUSSION

- Chemotherapy remains the most effective and preferred treatment for CTVT.
- The animal was administered Inj. Vincristine sulfate @ 0.025mg/kg bwt strict IV, the calculated dose was diluted with Normal saline, at a weekly interval.
- Supportive therapy included Inj. Ranitidine @ 0.2mg/kg bwt or Pantoprazole @ 0.7mg/kg bwt along with Inj. Amoxicillin @ 11mg/kg bwt for five days.

Marked reduction in the size of the tumour after 3 cycles of treatment was observed (Fig.3) and was completely cured after successful 5 cycles of treatment (Fig.4).

Note: Doxorubicin @ 1mg/kg bwt is used in cases that are resistant to Vincristine.

Fig 3: 3 weeks of Treatment

Fig 4: 5 weeks of Treatment

PROGNOSIS:

Vincristine administration is the treatment of choice with 90% of dogs being cured and the Vincristine chemotherapy is excellent. Prognosis is excellent when diagnosed early and treated appropriately.

CONTROL AND PREVENTION:

- Animals diagnosed with CTVT should not be used for breeding.
- In case of stray dogs, it is difficult to control the transmission and maintain strict spay, neuter practices and the effective treatment of clinical cases.
- Maintain hygiene shelter conditions to prevent tumour cell transmission.
- Avoid physical contact between infected and healthy dogs.
- Wash your hands after handling a dog to avoid contaminated living cells on your hands that could come into contact with other dogs.

CONCLUSION:

In dogs, CTVT is the most common and naturally occurring tumour transmitted during mating. Chemotherapy, especially with vincristine, provides excellent results. The dogs must be presented by owners and the dog breeders for animal examination, and veterinarians must include the examination of CTVT, including palpation of the vagina in bitches and extrusion of the penis in males. Early diagnosis, public awareness, and responsible pet ownership, including neutering and spaying, are key to controlling the disease and limiting its spread.

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Immunomodulation in Chickens to Combat Infections: A Practical Perspective

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Introduction

Poultry production is one of the fastest-growing sectors of livestock farming globally, contributing significantly to food security and rural livelihood. However, the intensification of poultry farming comes with its share of challenges, most notably infectious diseases. The emergence of antibiotic resistance and restrictions on antibiotic growth promoters have pushed the poultry industry to seek alternative strategies to improve bird health. One promising avenue is immunomodulation — the targeted manipulation of the immune system to enhance its ability to fight infections. This article delves into the concept of immunomodulation in chickens, its practical applications, and its potential as a tool to combat infectious diseases in modern poultry production systems.

Understanding Immunomodulation

Immunomodulation refers to any process that alters the immune response. It can involve enhancing the immune system's ability to recognize and respond to pathogens (immunostimulation) or suppressing unwanted immune responses, such as inflammation or autoimmune reactions (immunosuppression). In the context of poultry, the focus is largely on immunostimulation to promote disease resistance, particularly during periods of stress, vaccination, or outbreaks.

The chicken's immune system comprises innate and adaptive components. The innate immune system offers the first line of defense, responding rapidly but non-specifically to pathogens. The adaptive immune system, involving B and T lymphocytes, provides specific and long-lasting immunity but takes longer to respond. A well-functioning immune system involves effective coordination between these two arms. Immunomodulators aim to fine-tune this balance to achieve optimal health and productivity.

Why Is Immunomodulation Important in Poultry?

1. Rising Antibiotic Resistance

The overuse of antibiotics has led to the emergence of resistant strains of bacteria, making it harder to treat common infections. Immunomodulation provides a non-antibiotic approach to disease management.

2. Early Life Immunity Gap

Chicks hatch with an immature immune system and rely heavily on maternal antibodies in the early days. Immunomodulators can help bridge the immunity gap during this vulnerable phase.

3. Stress and Immunosuppression

Environmental, nutritional, and management-related stresses (e.g., heat stress, overcrowding, transport) can impair immunity. Immunomodulators help mitigate stress-induced immunosuppression.

4. Vaccine Efficiency

Immunomodulation can enhance the efficacy of vaccines by promoting stronger and longer-lasting immune responses.

Types of Immunomodulators in Poultry

1. Probiotics and Prebiotics

These are beneficial bacteria (probiotics) or substances that promote their growth (prebiotics) in the gut. A healthy gut microbiota enhances mucosal immunity and reduces pathogen colonization.

2. Herbal and Phytogenic Products

Extracts from medicinal plants such as Withania somnifera (Ashwagandha), Curcuma longa (turmeric), and Ocimum sanctum (Tulsi) have shown immunostimulant properties.

3. Vitamins and Trace Elements

Vitamins A, C, E, and minerals like zinc and selenium play a crucial role in maintaining immune function. Supplementing these micronutrients supports both innate and adaptive immunity.

4. Beta-Glucans

Derived from the cell walls of yeast or fungi, beta-glucans activate macrophages and other immune cells. Their role in reducing mortality and improving vaccine response is well-documented.

5. Cytokines and Immunological Proteins

Though more experimental, administering cytokines like interleukins or interferons can directly enhance or modulate immune responses.

6. Toll-Like Receptor (TLR) Agonists

These molecules stimulate the innate immune system by mimicking microbial structures. TLR agonists are being explored as vaccine adjuvants and stand-alone immunostimulants.

Practical Application in Poultry Farming

a) Early Chick Management

Administering immunostimulants in the hatchery or at the farm within the first few days of life can significantly improve survival rates. For example, in-ovo or immediate post-hatch application of probiotics and beta-glucans primes the chick's immune system and improves gut health.

b) Vaccination Support

Administering herbal immunomodulators or vitamin supplements a few days before and after vaccination improves the antibody response and reduces post-vaccination stress. Beta-glucans have shown particular promise in boosting responses to Newcastle Disease and Infectious Bursal Disease vaccines.

c) During Disease Outbreaks

Immunostimulants can be added to water or feed during the early signs of respiratory or enteric infections. Though not a substitute for antibiotics or vaccines, they reduce morbidity and improve recovery.

d) Nutritional Fortification

Inclusion of immune-boosting vitamins and trace elements in feed formulations ensures birds remain resilient, especially during high production stress periods like peak egg laying or broiler finishing stages.

e) Biosecurity and Management Synergy

Immunomodulation should be seen as a complement—not a replacement—for biosecurity, vaccination, and hygiene. A strong immune system is still susceptible if birds are exposed to overwhelming pathogen loads.

Case Studies and Field Insights

Case 1: Probiotics for Necrotic Enteritis Control

In a commercial broiler farm in southern India, routine outbreaks of necrotic enteritis were reduced by over 50% after adopting a regime of probiotic supplementation (*Lactobacillus and Bacillus spp.)* during the first 7 days and again at 21 days. Notably, antibiotic use dropped by 40%, and feed conversion ratios improved.

Case 2: Herbal Immunomodulators in Layers

A trial conducted on a layer farm in North India evaluated a polyherbal extract containing *Tinospora cordifolia, Emblica officinalis,* and *Withania somnifera.* Birds supplemented from 18 to 30 weeks showed improved antibody titers post-vaccination and maintained higher production rates during peak summer stress.

Case 3: Beta-Glucans in Breeders

In a breeding operation, oral supplementation of beta-glucans during vaccination schedules resulted in higher hatchability and reduced early chick mortality, attributed to stronger maternal antibody transfer.

Challenges and Considerations

1. Product Variability

The effectiveness of immunomodulators can vary based on source, formulation, and dosage. Quality control and standardization are crucial.

2. Economic Viability

While many immunomodulators are cost-effective, some products, especially purified cytokines or novel molecules, may be expensive for widespread use.

3. Scientific Validation
More research is needed to understand the mechanisms of action, optimal combinations, and long-term effects of various immunomodulators.
4. Integration with Farm Systems
Farmers need clear guidelines on when and how to use immunomodulators alongside routine farm practices. This requires farmer education and veterinary support.

Future Perspectives

Immunomodulation holds immense promise for disease control in poultry, particularly in the face of rising antimicrobial resistance and evolving pathogens. With advances in immunology, biotechnology, and nutrigenomics, more precise and effective immunomodulators are likely to become available. The integration of immunomodulation into standard poultry health management will not only improve productivity but also align with sustainable and antibiotic-free farming goals.

Going forward, tailored immunomodulation strategies based on bird age, genetic strain, production system (broiler vs. layer vs. breeder), and prevailing disease challenges will be the key. Research collaborations between veterinarians, immunologists, and the poultry industry are vital to harness the full potential of this approach.

Conclusion

Immunomodulation in chickens represents a powerful and practical tool to enhance disease resistance, reduce dependency on antibiotics, and improve overall poultry health. By understanding and applying immunostimulants like probiotics, phytogenics, vitamins, and beta-glucans, poultry farmers can effectively fortify the immune systems of their flocks. While challenges remain in terms of standardization and cost-effectiveness, the benefits of immunomodulation—improved survival, better performance, and enhanced vaccine responses—make it a cornerstone of modern, sustainable poultry production. With responsible use and scientific backing, immunomodulation is set to revolutionize the way we protect poultry against infections.

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Plant water relations and nutrient acquisition in field crops under changing climate

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Introduction

Climate change has emerged as a critical threat to global agriculture, particularly affecting plant water relations and nutrient acquisition in field crops. Increasing temperatures, altered precipitation patterns, rising atmospheric CO_2 levels, and the frequency of extreme weather events are placing enormous stress on agroecosystems. These climatic shifts are disrupting water availability, leading to both drought and flooding conditions, while simultaneously affecting nutrient dynamics in the soil, crop physiology, and overall productivity. For farmers, the uncertainty of climate behaviour means more than just unpredictable yields—it challenges traditional farming practices, soil fertility management, and irrigation strategies.

Water, a vital component for plant growth and metabolism, is increasingly becoming a limiting factor. Drought stress causes stomatal closure, reduces photosynthesis, disturbs nutrient uptake, and ultimately hampers plant development. Conversely, excessive rainfall or poor drainage leads to nutrient leaching, root oxygen deprivation, and reduced nutrient-use efficiency. Climate-induced changes in evapotranspiration and water holding capacity of soils further complicate water management, especially in rainfed systems that dominate much of the developing world.

Nutrient acquisition is equally challenged under changing climates. Elevated CO_2 may increase plant biomass, but often dilutes nutrient concentrations, particularly nitrogen, in plant tissues. Heat stress can inhibit enzymatic functions involved in nutrient uptake, while erratic rainfall influences microbial activity critical for nutrient cycling in the soil. These stresses often act in combination, reducing the effectiveness of conventional fertilizer regimes and increasing the risk of nutrient imbalances.

In light of these challenges, farmers must explore adaptive strategies that enhance resource-use efficiency and resilience. These include adopting drought-tolerant crop varieties, optimizing irrigation through technologies like drip or sensor-based systems, and applying integrated nutrient management (INM) practices. Conservation agriculture, biofertilizers, mulching, and crop diversification also offer promising ways to improve soil health, water retention, and nutrient availability. Policymakers, researchers, and extension services must work together to promote climate-smart practices and deliver location-specific solutions to farmers.

As the climate crisis intensifies, its impact on agriculture becomes increasingly visible—especially in the field crops that sustain billions across the globe. Shifting rainfall patterns, rising temperatures, increasing CO_2 concentrations, and frequent extreme weather events are threatening the very foundations of crop production: water and nutrients. For farmers and agricultural planners alike, understanding how climate change affects plant water relations and nutrient acquisition is no longer optional—it's essential for survival.

The Silent Crisis: Water and Nutrient Stress in Crops

Water is not just a requirement for plant survival; it is the medium through which nutrients are absorbed, biochemical processes are conducted, and growth is regulated. When water becomes scarce or excessive—both of which are becoming more frequent due to climate change—plants suffer. Drought conditions force plants to close their stomata, limiting photosynthesis and reducing the plant's ability to take in nutrients. On the other hand, heavy rainfall can lead to waterlogging, washing away vital nutrients and suffocating root systems.

Nutrient acquisition, too, is deeply climate-sensitive. Rising atmospheric CO_2 levels may increase plant biomass but often dilute nutrient density, particularly nitrogen and micronutrients. Heat stress reduces the activity of soil microbes vital for nutrient cycling, while erratic moisture levels disrupt root-soil interactions. The net result is poor nutrient-use efficiency, stunted growth, and lower yields—particularly in major crops like wheat, maize, rice, and pulses.

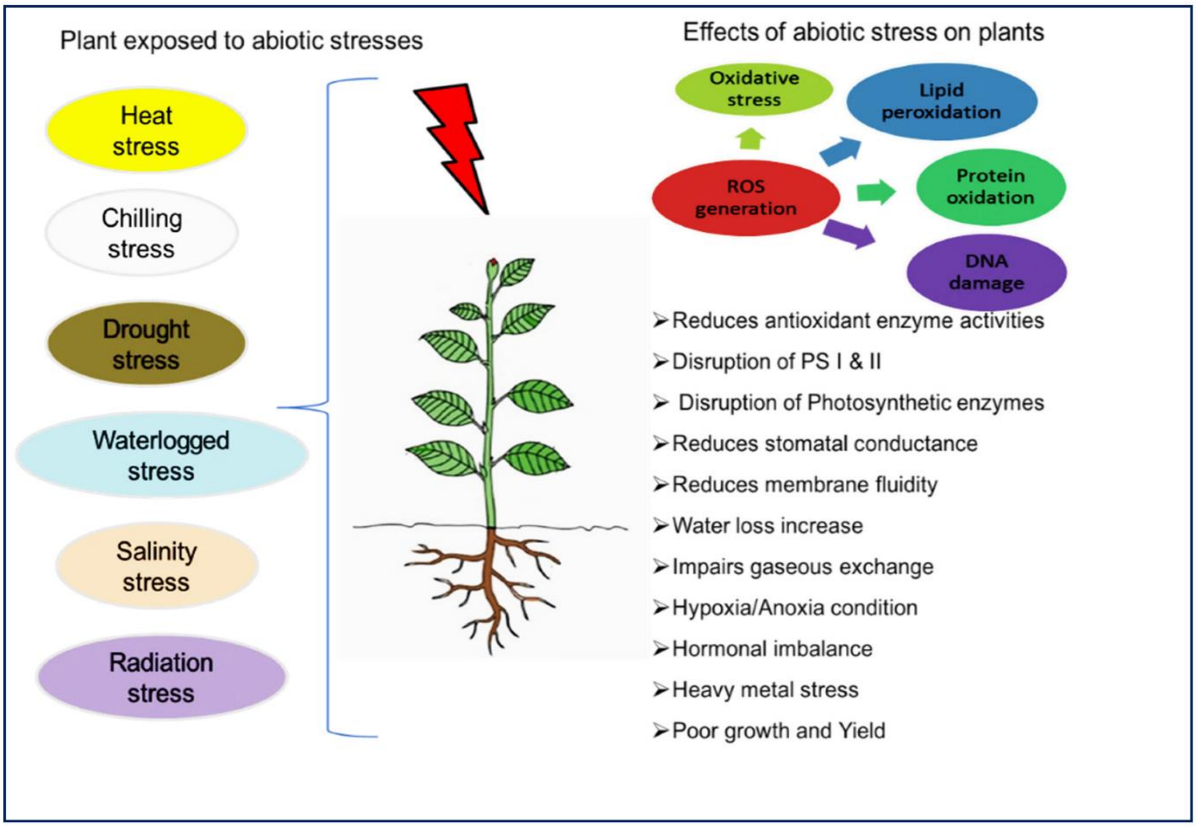

Fig. 1 Effects of Abiotic stress on plant

How Farmers Are Coping

Fortunately, farmers are not helpless in this changing climate. Across regions, several adaptation strategies are proving effective in buffering the impact of water and nutrient stress:

- **Climate-Resilient Crop Varieties**: Development and promotion of drought-tolerant, heat-resistant, and nutrient-efficient crop varieties are helping maintain productivity under stress conditions.
- **Precision Irrigation**: Technologies like drip and sprinkler irrigation, coupled with soil moisture sensors, are enabling farmers to use water more efficiently, avoiding both drought stress and overwatering.
- **Integrated Nutrient Management (INM)**: Combining organic and inorganic fertilizers, biofertilizers, and micronutrient applications helps improve nutrient availability and soil health.
- **Soil Conservation Practices**: Mulching, conservation tillage, and cover cropping not only conserve soil moisture but also enhance soil organic matter, improving the soil's water and nutrient-holding capacity.
- **Agroforestry and Crop Diversification**: Diversifying crop systems and integrating trees into farmland create more resilient agroecosystems that can better withstand climatic fluctuations.

Science and Policy Must Walk Together

Adaptation at the farm level must be supported by strong science and enabling policy. Research institutions must focus on understanding the plant-soil-water nexus under different climate scenarios. Policymakers, in turn, must ensure that farmers have access to climate-resilient seeds, appropriate training, and financial support for adopting climate-smart technologies.

Extension services should be strengthened to bridge the gap between research and field-level application. Weather forecasting, crop modelling, and digital tools must be made farmer-friendly and accessible, even in remote regions.

Looking Ahead: From Crisis to Opportunity

While climate change presents significant challenges, it also offers an opportunity to reimagine agriculture. By enhancing the understanding of plant water relations and nutrient acquisition, we can design farming systems that are not just resilient but also sustainable and productive in the long run.

Farmers, scientists, and policymakers must come together to create systems that respect ecological boundaries while securing food for a growing population. It is only through such integrated efforts that we can ensure that our fields—though weathered by storms and sun—remain fertile and thriving in the years to come.

Conclusion

As climate change continues to reshape our fields and seasons, farmers everywhere are feeling the pressure. Water doesn't come when it's needed, rains fall too hard or not at all, and soils that once fed crops so well are struggling to keep up. But even in these uncertain times, there is hope growing alongside the challenges.

Farmers are not standing still—they are learning, adapting, and turning to smarter ways of working with nature. From using every drop of water wisely to planting crops that can handle the heat, they are showing resilience and innovation every day. And they're not alone. Scientists, policymakers, and communities are stepping in to support them with new knowledge, better tools, and shared solutions.

This is more than just adapting to climate change. It's about building a future where agriculture is both strong and sustainable—where the land continues to provide, and farming remains a source of pride and livelihood for generations to come. If we walk this path together—with wisdom, compassion, and cooperation—then even in a changing climate, we can grow not just crops, but a better tomorrow.

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"Smart Fats for Smart Eating: Edible Oils and Their Nutritional Counterparts in Plants"

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India uses a diverse range of edible oils, each with unique cooking, health, and regional preferences. Mustard oil, rich in monounsaturated fats and omega-3 fatty acids, is commonly used in northern and eastern India and has natural antibacterial properties. Groundnut (peanut) oil, widely used in western and southern India, is high in monounsaturated fats and vitamin E, offering a neutral taste suitable for frying. Sunflower oil is light and rich in polyunsaturated fatty acids (PUFAs), especially linoleic acid, but less heat-stable and prone to oxidation. Soybean oil, another PUFA-rich oil, is often used in processed foods and provides essential omega-6 fats. Sesame oil, traditional in South Indian cooking, contains lignans and antioxidants, offering anti-inflammatory and heart-protective benefits. Coconut oil, high in saturated fats (mainly medium-chain triglycerides), is stable at high heat and commonly used in Kerala and coastal regions. Palm oil, used in processed foods and some rural areas due to affordability, is semi-solid at room temperature and high in saturated fats. Rice bran oil, emerging as a healthier option, contains oryzanol, tocotrienols, and balanced fatty acids, beneficial for heart health. Olive oil, though not traditional, is increasingly popular in urban households for its antioxidant-rich profile and high monounsaturated fat content, especially suitable for low to medium heat cooking.

These oils differ in their smoke points, fatty acid composition, and health effects. While oils rich in monounsaturated fats (like groundnut, olive, and rice bran) are considered heart-friendly, those high in PUFAs (like sunflower and soybean) are more prone to oxidative damage during high-heat cooking. Saturated-fat-rich oils (like coconut and palm) are more heat-stable but should be used in moderation. Choosing the right oil depends on the cooking method, nutritional needs, and regional taste preferences, with an increasing emphasis on rotating or blending oils to balance nutrition and stability. A study published in the journal *Foods* by Petra Norbert and colleagues (2022) investigated how repeated household-style frying affects the fat quality of five commonly used oils: palm, soybean, sunflower, rapeseed (canola), and extra virgin olive oil. The researchers fried potatoes at 180 °C for 5 minutes, repeating this process up to 10 times using the same oil. They found that healthy polyunsaturated fatty acids (like omega-3 and omega-6) significantly decreased, while harmful trans fats increased with repeated heating. They also measured heart-related health risks using atherogenic and thrombogenic indices, which worsened in most oils after repeated use. Extra virgin olive oil was found to be the most stable and heart-friendly under heat, while sunflower and soybean oils showed the greatest deterioration. The study concluded that repeated heating degrades oil quality, increases harmful compounds, and poses potential health risks, especially with PUFA-rich oils.

Perumalla V. R. M. and Subramanyam conducted a study published in *Toxicology Reports* (2016) on how consuming vegetable oils heated 3 times (to ~160–190 °C) affects health. Using Wistar rats, they demonstrated that repeatedly heated oil showed significantly higher peroxide levels and caused histopathological damage to the jejunum, colon, and liver. The rats exhibited elevated oxidative stress markers, increased blood glucose, cholesterol, and creatinine levels, and decreased protein and albumin—all indicating liver and kidney dysfunction due to oxidative free radicals formed in the oil.

In Journal of Oil Palm Research (Nov 2018), Tan, Loganathan, and Teng at the Malaysian Palm Oil Board heated palm olein, soybean oil, and corn oil five times at 150 °C. They measured changes in fatty acids, peroxide value, free fatty acids, and p-anisidine value. Results showed that oils with higher unsaturation (soybean, corn) degraded faster—palm olein remained the most heat-stable, soybean oil less so, and corn oil the least stable. When scientists heated different types of cooking oils (like palm olein, soybean, and corn oil) several times, they noticed that some oils broke down faster than others. This breakdown is called oxidation, and it creates harmful compounds that can be bad for your health. Now, all oils are made up of different types of fats:

- Saturated fats (like in palm oil) are more stable when heated.

- Unsaturated fats (like in soybean and corn oil) are less stable and break down more easily at high temperatures. So in this study:Palm olein (a type of palm oil) stayed more stable even after being heated many times. That means it didn't form as many harmful compounds.Soybean oil, which has more unsaturated fats, started to degrade faster than palm oil.Corn oil, which has the highest amount of polyunsaturated fats (PUFAs), was the least stable—it broke down the fastest and formed the most harmful substances when heated.If you fry food using corn oil or soybean oil, and especially if you reuse the oil, it can lose its healthy properties and become harmful more quickly than palm oil.

So, when choosing oils for deep-frying or repeated heating, it's better to use ones that are more heat-stable, like palm oil or olive oil, instead of those with lots of unsaturated fats like corn oil.

This study was conducted by Leong X.F., Mustafa M.R., Das S., and Jaarin K. and was published in the journal *Lipids in Health and Disease* in 2010. The researchers wanted to see if heating soybean oil multiple times could affect blood pressure and heart health. They fed rats with fresh soybean oil, oil heated 5 times, and oil heated 10 times. After several months, they found that rats consuming the reheated oil had higher blood pressure, thicker artery walls, and more inflammation in their blood vessels. Specifically, there was an increase in harmful molecules like VCAM-1 and ICAM-1, which can lead to atherosclerosis (hardening of arteries). The study concluded that repeatedly heating soybean oil makes it harmful by creating oxidized compounds that damage blood vessels and increase the risk of hypertension and heart disease.

This study was done by Falade A.O. and Oboh G. and was published in the *International Journal of Food Science* in 2015. The goal was to find out how heating peanut oil at 220°C for 20 minutes affects its quality. They discovered that high heat caused a big increase in peroxide value (a marker of fat oxidation) and in malondialdehyde, a harmful substance that shows fats have gone rancid. They also found that beta-carotene, an important antioxidant in peanut oil, decreased significantly. This means that heating peanut oil at high temperatures causes it to lose its nutrients and form harmful byproducts. The study warned that using peanut oil for deep-frying can reduce its health benefits and may contribute to oxidative stress if consumed regularly.

This study was conducted by Loganathan R., Tan K. W., Nesaretnam K., and others, and the findings were published in 2020. It compared regular palm olein and red palm olein, which contains more antioxidants like carotenoids and vitamin E. The oils were heated using different methods—deep frying, oven baking, and microwave heating—for up to 3 hours. The researchers found that both types of oil remained relatively stable under heat, with low oxidation. However, red palm olein lost more of its natural antioxidants like carotene over time. Despite this, it still performed well overall, and the study concluded that red palm olein could be used for cooking, but long heating reduces its nutrient value, especially its color and vitamin content.

Nutrient / Compound	**Plant Sources (excluding oils)**	**Health Benefits**
Omega-3 Fatty Acids (ALA)	Flaxseeds, chia seeds, walnuts, hemp seeds, soybeans, leafy greens (e.g., purslane)	Supports brain & heart health, reduces inflammation
Monounsaturated Fats (MUFA)	Avocados, peanuts, almonds, cashews, sesame seeds, olives	Improves good cholesterol (HDL), heart-protective
Polyunsaturated Fats (PUFA)	Walnuts, flaxseeds, sunflower seeds, soybeans, pumpkin seeds	Essential for cell function, supports immunity
Vitamin E (Tocopherol)	Sunflower seeds, almonds, spinach, pumpkin, red bell pepper, hazelnuts	Powerful antioxidant, protects cells, skin & eye health
Phytosterols	Whole grains, legumes, nuts (almonds, pistachios), seeds (pumpkin, sunflower), fresh vegetables	Lowers cholesterol absorption in intestines
Lignans (e.g., Sesamin)	Sesame seeds, flaxseeds, sunflower seeds	Antioxidant, hormonal balance, anti-inflammatory
Lauric Acid (MCFA)	Coconut flesh, coconut milk, coconut flour	Antimicrobial, energy-boosting, gut support

Nutrient / Compound	Plant Sources (excluding oils)	Health Benefits
Beta-carotene (Provitamin A)	Carrots, sweet potatoes, pumpkin, spinach, kale, red bell pepper	Supports vision, immune system, and skin
Gamma-Oryzanol	Rice bran (brown rice outer layer), rice bran cereals	Reduces LDL cholesterol, antioxidant action
Polyphenols	Berries, apples, grapes, olives, pomegranate, green tea, dark chocolate, spinach	Anti-aging, anti-inflammatory, protects heart & brain
Tocotrienols	Rice bran, barley, wheat germ, palm fruit	Protects brain, lowers cholesterol, anti-cancer potential
Vitamin K	Spinach, kale, broccoli, collard greens, Brussels sprouts, soybeans	Essential for blood clotting, bone health

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Edible Vaccines: A Green Revolution in Plant-Based Immunity

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Abstract

Edible vaccines are a novel biotechnology-based approach that involves producing antigenic proteins in genetically modified (GM) horticultural crops such as banana, tomato, potato, and lettuce. These antigens, when consumed, stimulate the human immune system and provide protection against infectious diseases like hepatitis B, cholera, and rotavirus. Unlike traditional vaccines, edible vaccines are needle-free, cost-effective, and easy to administer, making them especially valuable in low-income and remote regions where healthcare access is limited. Horticultural crops are preferred because they are often eaten raw, nutritionally rich, widely cultivated, and suitable for mass distribution. However, several challenges remain, including dosage standardization, shelf-life stability, regulatory hurdles, and public acceptance of genetically modified organisms. Despite these limitations, the potential of edible vaccines to transform global health is significant. With further research, policy support, and public awareness, this green technology could serve as a sustainable and accessible tool in preventive healthcare. Edible vaccines have the potential to not only reduce disease burdens but also integrate immunization with everyday nutrition, opening up a new era of plant-based medicine for the future

Key words: Edible vaccines, Horticulture crops, Antigens, Immune and Diseases.

Introduction

Imagine eating a banana or tomato and gaining immunity against deadly diseases like hepatitis or cholera. Sounds like science fiction? Thanks to the wonders of biotechnology, it's becoming science fact. Edible vaccines are an emerging innovation where genetically modified crops produce vaccine proteins, turning common fruits and vegetables into disease-fighting foods. In a world increasingly affected by infectious diseases, scientists are constantly on the lookout for novel, efficient, and cost-effective ways to protect populations. One such promising innovation is the development of edible vaccines—a fascinating blend of plant biotechnology and preventive medicine. This once-distant dream is becoming a tangible reality, especially through the medium of horticultural crops.

Edible vaccines represent a groundbreaking innovation at the intersection of biotechnology, horticulture, and public health. By genetically engineering fruits and vegetables like banana, tomato, or lettuce to produce specific disease-fighting proteins (antigens), scientists have developed a way to deliver vaccines simply through food consumption (Mason *et al.*, 1992; Kumar *et al.*, 2012). This green technology has the potential to revolutionize immunization, especially in developing countries where conventional vaccines are expensive and difficult to distribute (Mason *et al.*, 2002; Tiwari *et al.*, 2009). Cost-effective, needle-free, and easily scalable, edible vaccines offer a sustainable and accessible tool to enhance global immunity—one bite at a time (Rosales-Mendoza *et al.*, 2020).

What are Edible vaccines?

Edible vaccines are vaccines produced in genetically modified (GM) plants, where specific genes from disease-causing microbes such as viruses or bacteria are inserted into the DNA of a plant. These genes code for antigenic proteins—the components that stimulate an immune response in the human body (Mason *et al.*, 1992; Tiwari *et al.*, 2009).

When a person consumes the edible part of the modified plant—such as a banana, tomato, or potato—these antigens are detected by the immune system, which responds by producing antibodies. This "training" of the immune system helps protect the person against future infection by the actual pathogen, functioning similarly to conventional injectable vaccines (Rosales-Mendoza *et al.*, 2020).

Why Horticulture crops are preferred?

Horticultural crops are preferred for edible vaccines because:

- Many are eaten raw, preserving the vaccine proteins.
- They are rich in nutrients, supporting overall health.
- They can be grown locally, reducing distribution costs.
- They are non-invasive and suitable for children, the elderly, and needle-phobic patients.

Edible vaccines related to Horticulture

Crop	Target Disease	Consumption	Advantage	Reference
Banana	Hepatitis B, Cholera	Raw	Child-friendly, sweet, soft	Arntzen (1997); Rybicki (2010)
Tomato	Hepatitis B, Norwalk	Raw/Cooked	Fast-growing, widely consumed	Tacket *et al*. (1998)
Potato	Cholera, Hepatitis B	Cooked	Easy transformation, good yield	Tacket *et al*. (1998)
Carrot	HIV, Anthrax	Raw	Good antigen retention, raw use	Rybicki (2010)
Lettuce	Hepatitis B, Anthrax	Raw	Short cycle, raw use	Yusibov *et al*. (2011)
Pea	Measles, Diarrhea	Raw/Cooked	Dry seed storage, protein-rich	Streatfield (2005)
Soya bean	Rotavirus	Cooked	Protein-rich seed, stable form	Daniell *et al*. (2001)
Papaya	Cysticercosis, HIV	Raw	High expression, tropical suitability	Shahid and Daniell (2016)
Spinach	Early-stage research	Raw	Leafy, fast-growing	Shahid and Daniell (2016)

Advantages

The use of horticultural crops in edible vaccine production offers several benefits:

- **Cost-effective:** Eliminates the need for expensive purification, storage, transportation, and administration associated with traditional vaccines (Mason et al., 2002).
- **Ease of delivery:** No syringes or trained personnel are needed—vaccination is as simple as eating a fruit or vegetable.
- **Safety:** Plant-based systems are free from human or animal pathogens, reducing the risk of contamination (Tiwari *et al*., 2009).
- **Scalability:** These crops can be cultivated on a large scale using existing agricultural systems, particularly in developing countries.
- **Stability:** In some cases, vaccine proteins expressed in plants may remain stable without refrigeration, making them ideal for use in tropical and remote regions.

Challenges

Despite its promise, edible vaccine technology is still at the research and developmental stage. Several technical and social hurdles must be overcome:

- **Dosage control:** Ensuring each unit (e.g., a tomato or banana) contains a uniform and effective amount of antigen is a major challenge.
- **Storage and shelf life:** Vaccine proteins can degrade if not consumed within a certain time frame.
- **Public acceptance:** Genetically modified crops are controversial in many regions, raising questions of safety and ethics.
- **Regulatory approval:** Edible vaccines must meet rigorous testing standards for safety, efficacy, and environmental impact before commercial release (Rukmini *et al*., 2019).

Future Prospects

The global burden of diseases such as diarrhoea, hepatitis, and respiratory infections continues to strain healthcare systems. Edible vaccines could become a game-changer in this context, especially for low-income countries where traditional vaccines are difficult to deliver. With continued research, public education, and regulatory support, edible vaccines using horticultural crops could soon be a cornerstone of preventive healthcare.

Conclusion

Edible vaccines made using fruits and vegetables are a new and exciting idea in health care. By using common horticultural crops like banana, tomato, and lettuce, scientists can create food that helps protect us from serious diseases—just by eating it. This is especially helpful for poor and rural areas where regular vaccines are hard to get. These plant-based vaccines are cheaper, easier to use, and safe because they don't need injections or special storage. However, there are still some problems to solve, like making sure each fruit has the right amount of vaccine and helping people accept genetically modified (GM) crops. In the future, with more research, government support, and public understanding, edible vaccines could become a normal part of how we stay healthy—turning simple fruits and vegetables into powerful tools to fight disease.

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SEAWEED SUPERPOWER - NEXT GENERATION PACKAGING FROM THE DEEP

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Introduction

As plastic pollution wreaks havoc on ecosystems, wildlife, and human health, there has been an increased global urgency for sustainability over the last decade. Billions of tons of conventional plastic food packaging, which is derived from fossil fuels, end up in landfills and in the ocean annually, significantly amounting to damage to the environment. Fewer than 9% of plastics produced are recycled, says the Environmental Protection Agency, highlighting the urgent need for alternatives. One such solution is seaweed, a marine crop that can grow rapidly and is renewable. Seaweed, with its high content of polysaccharides such as agar, carrageenan, and alginate, offers biodegradable and sometimes comestible alternatives to conventional plastics. Focusing on recent developments, this article analyzes the characteristics, production processes, applications, inventions, challenges, and future of seaweed in food packaging.

Why Seaweed for Food Packaging?

Seaweed is an abundant, sustainable resource that grows rapidly in marine environments without taking up land, freshwater, or fertilizers. It is less resource-intensive to cultivate and sequesters carbon dioxide by absorbing it.
The composition of seaweed is depicted in the table below:

Composition	Percentage
Carbohydrates	50%
Minerals	7-37.5%
Lipids	1-3%
Protein	3-14.5%
Water	80%

Seaweed polymers degrade spontaneously within weeks to months without depositing hazardous or toxic microplastics, as compared to petroleum-derived plastics that may take thousands of years to degrade. Seaweed is especially suited for food packaging due to the fact that it also possesses antibacterial, antioxidant, and healthy nutrient properties.

Properties of seaweed food packaging

Seaweed yields three polysaccharides: agar, alginate and carrageenan that have a number of applications as biopolymeric films. Seaweed's usage in packaging is due to its high content of polysaccharides such as:

Alginate: Extracted from brown seaweed, alginate produces rigid, water-insoluble films when mixed with metal cations, with good barrier properties against oils and fats. Its flexibility is based on the mannuronic to guluronic acids ratio, with increased guluronic acid concentration forming stronger bonds.

Carrageenan: Red algae such as *Kappaphycus alvarezii* are the source of carrageenan, a hydrocolloid with gelling, emulsifying, and thickening capabilities. Carrageenan contains antioxidants, which can inhibit lipid oxidation in food packages, extending shelf life. It has weak water vapor barrier characteristics and is brittle.

Agar: Derived from red algae, agar is employed to prepare flexible, biodegradable films and serves as a typical gelatin alternative. Agar possesses very good film-forming ability but tends to be reinforced often to enhance mechanical strength.

Current research, including a 2024 review in Trends in Food Science & Technology, points out that the addition of compounds such as biopolymers (e.g., bacterial cellulose), nanoparticles, or plant essential oils can improve mechanical strength, hydrophobicity, and antimicrobial activity. As an example, the addition of bacterial cellulose to agar films improved tensile strength from 22.10 to 44.51 MPa and decreased water vapor permeability by 25.7%.

Production and Processing

Seaweeds have a high growth rate, enabling easy harvesting without consuming any natural resources. Production of seaweed-based packaging involves the following steps starting from seaweed harvesting, either wild-harvested or cultivated, from coastal areas or aquaculture systems.

Harvesting: Seaweed is picked up from eco-friendly farms, usually from nations such as China, Indonesia, and Korea, which are the world leaders in production (e.g., China produces 59% of seaweed). In India, rich seaweed beds occur around Mumbai, Ratnagiri, Goa, Karwar, Varkala, Vizhingam and Pulicat in Tamilnadu, Andhra Pradesh and Chilka in Orissa. Ethical sourcing is essential, with organizations such as Sway utilizing supplier scorecards to guarantee transparency and environmental standards.

Processing: Seaweed is washed, dried, and processed to yield polysaccharides and fibers. These are fermented or mixed with natural additives to create films, coatings, wraps, or rigid containers. The process requires less energy and chemicals than plastic manufacturing, reducing greenhouse gas emissions.

Customization: Based on the purpose, seaweed materials can be shaped into different forms—films, sachets, trays, or cups—and customized for aspects such as moisture resistance or oxygen permeability.

Applications in Food Packaging

Seaweed packaging has received increased attention in recent years for various food applications:

Edible Packaging: Evoware and Notpla are among the companies that have introduced seaweed wraps, sachets, and cups that are edible. Evoware's Ello Jello cups, which come in flavors such as peppermint and lychee, are for ice cream and are dissolved using hot water, serving as fertilizer if they are thrown away. Notpla's Ooho capsules for water and sauces biodegrade within weeks.

Biodegradable Wraps and Films: Seaweed films substitute for plastic cling film for snacks, sandwiches, and ready meals. Just Eat tested Notpla's seaweed-lined takeaway containers in London that will compost naturally. These are perfect for single-use products that get littered with ease, like candy packaging.

Active Packaging: Seaweed polysaccharides like carrageenan have natural antioxidant and antimicrobial activity. In a 2024 study, κ-carrageenan films containing plant essential oils improved antioxidant activity, whereas species such as *Himanthalia elongata* (sea spaghetti) suppressed gram-positive and gram-negative bacteria, indicating future potential for antimicrobial packaging.

Market Adoption: The big brands of Nestlé and Unilever have also shown interest, with Nestlé collaborating with startups such as Sway for seaweed packaging. Notpla was awarded a deal in 2024 to replace 75 million plastic products with seaweed-based materials in UK venues within three years.

Recent Innovations

The last few years have seen some major breakthroughs:

Material Upgrades: Advances involve mixing seaweed with antimicrobial agents, antioxidants, and essential oils to enhance shelf life and food safety. For example, Sway employs varying species of seaweed to produce flexible, vibrant films.

Commercial Scale-Up: Notpla secured more than $25 million in Series A+ funding in 2024 to substitute 100 million single-use plastics every year by 2026. Startups such as Oceanium and SoluBlue are working on seaweed films, cups, and sachets for food, cosmetics, and more.

Novel Applications: Amazon is backing a commercial-scale seaweed farm between rows of offshore wind turbines in the Netherlands, which suggests possibilities for mass production of seaweed-based packaging.

Challenges

Despite its promise, seaweed packaging faces hurdles include material limitations, cost and scalability, consumer awareness, regulatory hurdles and environmental concerns.

Market Outlook

The seaweed packaging industry is expanding fast. Future Market Insights has estimated its value at US$ 1,224.5 million as of 2033 with a compound annual growth rate (CAGR) of 6.0%. Government interventions, technology, and consumer interest in sustainable choices drive the rise. The food and beverage industry lead, with uses in wraps, sachets, and trays, respectively.

Conclusion

Seaweed-based food packaging is a revolutionary step toward sustainability, providing biodegradable, renewable, and sometimes edible substitutes for plastic. Its special characteristics—antioxidant, antimicrobial, and film-forming—make it the perfect choice for maintaining food quality and safety while minimizing environmental damage. The recent advancements, from AI-optimized cultivation to improved materials, highlight its potential, with Notpla, Evoware, and Sway being among the companies that are taking the lead. But there are challenges to be overcome such as cost, scalability, and regulatory challenges. With research and consumer consciousness increasing, packaging with seaweed can revolutionize the food industry, supporting global targets to halve plastic waste by 2030, according to commitments by 170 nations. Though not the be-all and end-all of plastic, seaweed has the potential to be central to a greener, more sustainable future.

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FEEDING THE FUTURE: SMART FERTILIZATION WITH SLOW-RELEASE NUTRIENTS

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ABSTRACT:

An important development in nutrient management techniques for sustainable agriculture is slow-release fertilizers, or SRFs. Unlike conventional fertilizers that rapidly release nutrients, SRFs are designed to gradually release essential nutrients over an extended period, aligning more closely with plant uptake rates. This controlled nutrient delivery minimizes nutrient losses due to leaching, volatilization, and runoff, thereby enhancing nutrient use efficiency and reducing environmental pollution. SRFs have been widely applied in horticulture, forestry and high-value crop production, offering benefits such as improved crop yield, reduced frequency of fertilizer applications, and better soil health. Advances in coating technologies, biodegradable polymers, and nanomaterials have further improved the efficiency and environmental compatibility of SRFs. SRFs' long-term ecological and agronomic advantages highlight how crucial they are to contemporary, sustainable farming methods.

Keywords: Slow-release fertilizers, Sustainable agriculture, controlled nutrient delivery, Coating technologies.

DEFINITION AND TYPES

Slow-release fertilizers (SRFs) are nutrient sources designed to release nutrients gradually over an extended period, aligning nutrient availability with crop demand. There are several types of slow-release fertilizers, including:

- **Coated Fertilizers:** These are the fertilizers that have a protective coating which controls the release rate of nutrients. The coating materials can be polymeric, sulphur-based, Wax, nanomaterials or resin-based.
  Examples: polymer-coated urea (PCU) and sulphur-coated urea (SCU).
  The polymer coated fertilizers consist of soluble fertilizers encapsulated in a polymer coating. Each fertilizer capsule is called a Prill Polymer coated fertilizers which release nutrients through a semi-permeable membrane formed by the polymer coating.
- **Chemical or Organic Matrices:** These fertilizers contain nutrients embedded in a matrix that slowly dissolves or degrades.
  Example: Osmocote.
- **Controlled-Release Fertilizers (CRF):** CRFs are designed to release nutrients based on environmental conditions such as temperature, moisture, and microbial activity. They are often used in precision agriculture for targeted nutrient delivery.

MECHANISM OF NUTRIENT RELEASE

Diffusion:

- Water penetrates the coating or matrix, dissolving the nutrients inside.
- The dissolved nutrients then diffuse out through the coating or matrix into the surrounding soil.
- Nutrients move from areas of high concentration in the fertilizer to areas of lower concentration in the soil.

Osmosis:

- Water enters the fertilizer granule due to osmotic pressure.

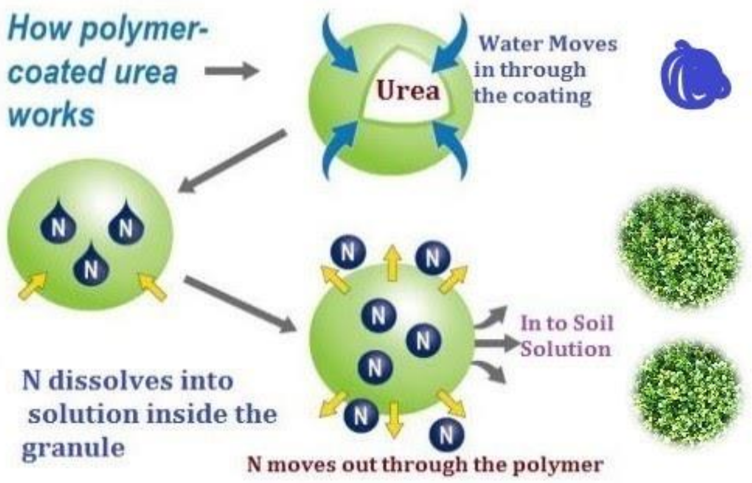
- This influx of water dissolves the nutrients inside.
- The pressure buildup within the granule forces the dissolved nutrients out through the coating.

Degradation:

- The breakdown of coating materials or organic matrices which causes release of nutrients into the soil.

Microbial Activity:

- In organic slow-release fertilizers, microbial decomposition of organic matter occurs that causes gradual release of nutrients.



NEED FOR SLOW-RELEASE FERTILIZERS

- Traditional fertilization practices often lead to inefficiencies in nutrient use, with significant nutrient losses occurring through leaching, runoff, and volatilization.
- Quick releasing fertilizers can be over applied or improperly diluted, which can result in the burning of plants.
- Highly volatile fertilizers like Urea, even when applied in bulk, due to volatization the efficiency is reduced. So, coating could be an alternate.
- Also, in the usage of organic substances like neem for coating materials, it also acts as pest repellents. Thus, it acts as dual and more efficient.
- Nutrient leaching, particularly of nitrogen and phosphorus, can contaminate surface and groundwater, resulting in eutrophication and harming aquatic ecosystems.
- The volatilization of nitrogen fertilizers increases the consequences of climate change by contributing to greenhouse gas emissions.
- Additionally, excessive fertilizer use can cause soil salinity, which impairs fertility and soil structure.
  These challenges highlight the need for more efficient and environmentally friendly fertilization practices in fruit crop production.

SRF'S BASED ON THEIR MAJOR NUTRIENT CONTENT:

Slow-release Nitrogen Fertilizers:

- Pelletized- MagAmp, a 7-40-0 fertilizer.
- Chemically altered- Urea Formaldehyde, a fertilizer that is 38 percent nitrogen, 70 percent of which is water-insoluble.
- IBDU (Isobutylidene diurea) is similar to Ureaform, but contains 32 percent nitrogen, 90 percent of which is insoluble.
- Coated- Osmocote, Nutricote.

Slow-release Phosphorous Fertilizers:

- Hydrochars.
- Struvite- A magnesium ammonium phosphate compound.
- Triple Super Phosphate.

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Slow-release Potassium Fertilizers:

- Potassium magnesium sulphate- with K2O as of 22%, MgO as of 18% and elemental sulphur of 20%.
- Humic acid-coated KCl.
- Polymer-coated potassium chloride.


Polymer coated Urea Fertilizers

Biochar coated Urea

Osmocote

Hydrochars

Nutricote

APPLICATION IN FRUIT CROPS

The application of slow-release fertilizers (SRFs) in fruit crop production has revolutionized nutrient management practices by providing a steady and controlled release of nutrients, thereby enhancing plant growth, increasing yields, and minimizing environmental impact. SRFs are particularly beneficial in fruit crops such as apples, citrus, strawberries, and grapes, which require consistent nutrient availability throughout their growth cycle.

In **Apple** orchards, slow-release fertilizers like polymer coated urea or sulphur-coated urea are applied either at the time of planting or during the early growth stages.

In **Mango**, by using, Urea Formaldehyde (38% N) can be used instead of urea (46%N). Urea Formaldehyde @ 750g/tree enhanced the Nitrogen and potassium contents in leaves, increased fruit set, number of fruit retention per panicle and Yields in some cultivars. (Eman *et al.*,2009).

In Citrus, where nitrogen deficiency can severely affect fruit production and quality, slow-release fertilizers play a crucial role in maintaining optimal nitrogen levels in the soil.

In **Grapes** orchard, a combination of resin-coated and bio-polymer-coated fertilizers were used to provide a sustained release of nutrients, promoting vigorous vine growth, enhancing fruit development, and improved wine quality. The yield and quality of Early sweet grapevines were obtained, due to supplying the vines with phosphorus- coated urea at 25 g N/ vine (Ahmed *et al.*,2019).

At one location of chlorotic vine plants under field conditions coated Fe-EDTA (8% Fe), applied in the amount of 15 g and 30 g per plant increased chlorophyll content as well. It was concluded that coated Fe-EDTA may serve as an Fe fertilizer if the water supply is sufficient.

In **Papaya**, the usage of coated urea, promoted higher growth and yield compared to the conventional urea application.

Similarly, in **Strawberry** cultivation, which is highly sensitive to nutrient imbalances, slow-release fertilizers such as encapsulated nutrients are applied. For ongoing fertilization, consider using a controlled-release fertilizer like Osmocote or applying a balanced NPK fertilizer (e.g., 10-10-10) in early spring and again in autumn.

In **Pear**, the usage of Urea Formaldehyde, Phosphorus coated urea, Sulphur coated urea, increased shoot length, leaf area, leaf N content of the tree (Kandil *et al.*, 2010).

BENEFITS OF SLOW-RELEASE FERTILIZERS:

1) **Steady Nutrient supply:**
SRFs release nutrients gradually over time, matching the plant's growth cycle. It reduces nutrient spikes and crashes, promoting healthier and more consistent plant growth.
2) **Reduced Nutrient Loss:**
Minimizes leaching of nutrients into groundwater and runoff, especially in sandy or porous soils. Less volatilization losses, especially with Urea fertilizers.
3) **Less Frequent Applications:**
Nutrients are available over weeks or months, reducing the need for frequent fertilizing. Thus, it Saves time, labour and costs in large-scale agriculture.
4) **Enhanced soil health and structure:**
The gradual release of nutrients promotes the development of beneficial soil microorganisms and enhances soil organic matter content.
5) **Environmental Benefits:**
By reducing nutrient runoff and leaching, slow-release fertilizers contribute to a more sustainable agricultural system. This can help protect water resources and minimize the negative environmental impacts associated with excess nutrient application.

CONCLUSION:

As agriculture move towards sustainable practices, slow-release fertilizers will play an important role in meeting global food demands while preserving soil and environmental health. The application of slow-release fertilizers presents a promising approach to enhance agricultural productivity while minimizing environmental degradation. By considering nutrient release with plant uptake, SRFs significantly improve nutrient use efficiency and reduce the frequency of fertilizer application. Continued research and innovation in coating technologies and biodegradable materials are expanding the potential and accessibility of SRFs across various cropping systems.

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Biofortification in Vegetables: A Strategy to Combat Micronutrient Deficiencies

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Abstract

Micronutrient deficiencies, also known as "hidden hunger," impact more than two billion people worldwide and contribute to serious health conditions like anemia, weakened immune response, stunted development, and vision impairment. In India, such deficiencies particularly of iron, zinc, and vitamin A are highly prevalent, especially among women and children. Although food availability has increased, the nutrient content of many crops has declined due to rising carbon dioxide levels and intensive farming practices. Biofortification, which enhances the nutrient levels of crops during cultivation through breeding, agronomic practices, or biotechnology, presents a sustainable, cost-effective strategy to improve nutrition. Vegetables are especially well-suited for biofortification because of their natural richness in essential nutrients, widespread and frequent consumption, rapid growth cycles, genetic diversity, and adaptability to various climates. Various approaches to vegetable biofortification include traditional breeding, the use of nutrient-rich fertilizers, genetic modification, and the application of beneficial soil microbes. Proven successes include vitamin A–rich orange-fleshed sweet potatoes, iron-enhanced beans, zinc-fortified spinach and tomatoes, and carrots with higher β-carotene content. These biofortified vegetables have been linked to improved health outcomes in vulnerable populations. Despite their potential, several challenges remain, such as limited genetic variation for certain nutrients, environmental limitations, regulatory concerns over genetically modified crops, and insufficient public awareness. Additionally, access to biofortified seeds for smallholder farmers can be a constraint. Nonetheless, incorporating biofortified vegetables into human or public nutrition and agricultural policies offers a promising food based approach to tackling micronutrient malnutrition both globally and in India, particularly in underserved rural communities.

Key words: Biofortification, Micronutrient Deficiencies, Vegetables, Nutritional Security.

Introduction

Micronutrient deficiencies, also known as hidden hunger, continue to pose a major health challenge worldwide, especially in developing nations. More than 2 billion people are affected by insufficient intake of essential micronutrients such as iron, zinc, and vitamin A, which can lead to serious problems like poor growth, low immunity, mental delays, and greater vulnerability to infections (WHO, 2020; Bailey *et al*., 2015). Despite improved food availability, nutrient levels in many crops, including vegetables, have declined due to factors like increased carbon dioxide and modern farming (Loladze, 2014; Myers *et al*., 2014).

Biofortification is enhancing nutrients in crops during growth through breeding or biotechnology—is a promising, cost-effective way to address this, particularly for rural populations (Bouis & Saltzman, 2017). Vegetables are excellent targets because they are widely consumed, nutrient-rich, grow quickly, and can thrive in diverse climates (Niroula *et al*., 2019).New developments—such as biofortified leafy greens rich in provitamin A—have shown that improving nutrition through vegetables is both feasible and acceptable (Tanumihardjo *et al*., 2021).

This information provides the potential of vegetable biofortification as a tool to fight micronutrient deficiencies. It examines the current methods of integrating biofortified vegetables into both public health and agricultural systems.

Micronutrient Deficiencies: A Global and Indian Perspective

Micronutrient deficiencies, or "hidden hunger," affect over two billion people globally, causing serious health problems like anemia, weakened immunity, and blindness (WHO, 2020; Bailey *et al*., 2015). In India, more than half of women and children suffer from anemia, with zinc and vitamin A deficiencies also widespread (ICMR-NIN, 2020).

Tackling micronutrient malnutrition in India calls for comprehensive strategies that extend beyond supplementation and fortification. Enhancing the nutrient content of commonly consumed vegetables through biofortification presents a promising, sustainable, and food-based approach that can effectively complement current interventions to improve nutritional health at the community level.

Why Vegetables for Biofortification?

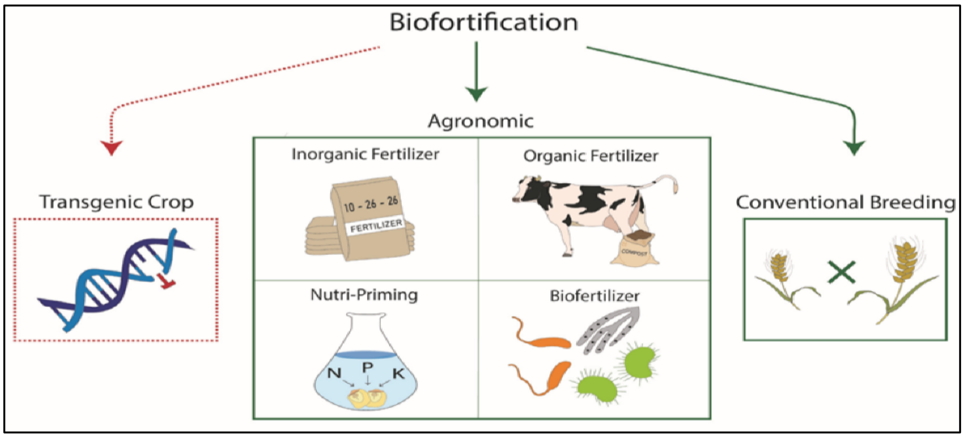
Vegetables are excellent candidates for biofortification due to several key advantages that make them effective in delivering essential micronutrients to a wide range of people:

1. **Rich Nutrient Content:** Vegetables are naturally packed with vital vitamins and minerals like vitamin A, vitamin C, iron, calcium, and zinc. Enhancing these nutrients through biofortification can help address dietary deficiencies (Niroula *et al*., 2019).
2. **Regular Consumption:** People from various age groups and economic backgrounds consume vegetables frequently, ensuring a steady intake of biofortified nutrients for ongoing health benefits (Bouis & Saltzman, 2017).
3. **Short Growth Cycle:** Compared to staple grains, many vegetables grow quickly, enabling faster development and distribution of nutrient-enhanced varieties, which accelerates improvements in nutrition (Pfeiffer & McClafferty, 2007).
4. **Genetic Diversity for Breeding:** Vegetables display a wide range of genetic variation in nutrient content, offering breeders valuable resources to develop improved varieties through both traditional and modern breeding methods (Niroula *et al*., 2019).
5. **Wide Climatic Adaptability:** Vegetables can be cultivated in diverse climates and farming conditions, making biofortification efforts scalable and applicable to many regions, including less-resourced areas (Tanumihardjo *et al*., 2021).
6. **Supplementing Staple Crops:** While biofortified cereals have gained focus, vegetables provide complementary nutrients and health-promoting compounds such as antioxidants and dietary fiber, contributing to a balanced diet (Bouis & Saltzman, 2017).
7. **Cultural and Dietary Acceptance:** Vegetables are already well-integrated into traditional cuisines, facilitating consumer acceptance of biofortified types. Additionally, visible traits like altered colour (e.g., orange-fleshed sweet potatoes) can attract consumer interest when paired with awareness efforts (HarvestPlus, 2022).

Approaches to Biofortification in Vegetables

Biofortification of vegetables can be achieved through several key methods:

1. **Conventional Breeding:** Selecting and crossing vegetable varieties with naturally higher nutrient levels. It's cost-effective but may take longer to develop new varieties (Pfeiffer & McClafferty, 2007).
2. **Agronomic Biofortification:** Applying micronutrient-rich fertilizers or foliar sprays to enhance nutrient uptake during growth. This offers quick results but requires repeated inputs (Cakmak, 2008).
3. **Biotechnology and Genetic Engineering:** Using modern tools to directly modify genes related to nutrient production, enabling faster development of nutrient-rich vegetables. However, regulatory and acceptance issues remain (Bouis & Saltzman, 2017).
4. **Microbial Biofortification:** Employing beneficial soil microbes that improve nutrient absorption by plants, offering an eco-friendly approach (Kumar *et al*., 2020).



Success Stories of Biofortification in Vegetables

- **Orange-Fleshed Sweet Potato (OFSP):** Rich in vitamin A, OFSP has been widely adopted in African countries, helping reduce vitamin A deficiency and related health problems like blindness and child mortality (Low *et al*., 2017).
- **Iron-Fortified Beans:** Developed in Latin America and Africa, these beans contain much higher iron levels than traditional varieties, helping lower anemia rates among vulnerable groups (Bouis *et al*., 2019).
- **Zinc-Enriched Tomatoes and Spinach:** Enhanced zinc levels in these vegetables support better immune function and growth, especially in children (Niroula *et al*., 2019).
- **Vitamin A–Rich Carrots:** Carrots with increased β-carotene are becoming popular as a tasty way to fight vitamin A deficiency (Tanumihardjo *et al*., 2021).

Challenges of Biofortification in Vegetables

Biofortification of vegetables faces challenges such as limited natural genetic variation for some nutrients, which complicates breeding efforts. Agronomic factors like soil and climate can reduce nutrient uptake. Consumer acceptance may be hindered by changes in appearance or taste. Regulatory hurdles and public concerns affect genetically engineered crops. Additionally, lack of awareness limits demand, and ensuring seed availability for small farmers remains difficult.

Conclusion

Biofortifying vegetables presents an effective and sustainable approach to addressing widespread micronutrient deficiencies, particularly in developing countries where hidden hunger persists. Utilizing the inherent nutrient density, fast growth, and genetic diversity of vegetables, biofortification can improve diet quality and health outcomes for diverse populations. While successful cases highlight its nutritional benefits, challenges such as breeding limitations, farming conditions, consumer acceptance, regulatory issues, and seed availability need to be tackled through coordinated efforts among researchers, policymakers, farmers, and communities. Incorporating biofortified vegetables into agriculture and public health initiatives is essential for reducing malnutrition, enhancing food security, and supporting overall health.

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"Pollinators in Peril: Securing the Future of Bees in Agroecosystems"

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Introduction

Pollinators, especially bees, are the unsung heroes of agriculture. Nearly 75% of the world's food crops depend, at least in part, on pollination by insects (Klein *et al*., 2007). These include many fruits, vegetables, oilseeds, and nuts that are vital to human nutrition and livelihoods. However, across the globe and increasingly in India-pollinator populations are declining, threatening agricultural productivity, ecosystem stability, and food security. A multitude of stressors including pesticide overuse, habitat loss, climate change, monoculture practices, and pathogen spillover are driving this crisis. Understanding the importance of pollinators, identifying key threats, and implementing conservation strategies are essential for sustaining India's agrobiodiversity and farming communities.

The Value of Pollinators in Agroecosystems

Pollinators like honey bees (*Apis cerana indica*, *Apis mellifera*), stingless bees (*Tetragonula* spp.), solitary bees (*Xylocopa*, *Nomia*), butterflies, moths, beetles, and hoverflies enable the reproduction of over 250 crop species in India. Research has shown that effective pollination can increase crop yields by 20–60%, improve fruit shape and size, and enhance market value (Klein *et al*., 2007; Ricketts *et al*., 2008).

Pollinators are particularly important for crops like:

- Apple, mango, guava, and pomegranate (fruit set & quality)
- Cucurbits, brinjal, okra (cross-pollination)
- Mustard, sunflower, sesame (oilseed production)
- Coffee and cardamom (export crops)

The estimated economic value of pollination services globally is over $235–577 billion annually (IPBES, 2016; Gallai *et al*., 2009). In India, informal estimates suggest that bee pollination contributes to over ₹1.5 lakh crores of crop value annually.

Key Threats to Pollinators

1. Pesticide Use and Agrochemicals

Neonicotinoids (e.g., imidacloprid, thiamethoxam) and systemic fungicides, commonly used in Indian agriculture, are known to impair bee foraging, memory, and immunity even at sublethal doses (Goulson *et al*., 2015; Choudhary & Sharma, 2008). Over 80% of farmers in surveyed districts apply pesticides during flowering — a critical window when bees are most active.

2. Monoculture and Habitat Loss

The replacement of biodiverse agroecosystems with monoculture crops (e.g., cotton, sugarcane) removes alternative floral resources and nesting habitats. Removal of field margins, hedgerows, and wildflower species further isolates pollinator populations.

3. Climate Change and Weather Extremes

Pollinator emergence and flower availability are tightly coupled. Climate change disrupts this synchrony. Heatwaves, droughts, and erratic rainfall affect:

- Nectar and pollen production
- Bee colony development
- Foraging behavior and success (Kumar *et al*., 2022)

Studies in Himachal Pradesh and Telangana show declining pollination efficiency in apple and sunflower respectively due to climatic mismatches (ICAR–IARI, 2023).

4. Parasites, Diseases, and Poor Management

Pathogens like *Nosema*, *Varroa mites*, and American Foulbrood are exacerbated by poorly managed migratory beekeeping and unscientific apiary practices. Limited access to veterinary care for bees worsens the problem.

Case Studies: Bee-Friendly Farming in India

1. Karnataka: Floral Corridors in Horticulture

KVKs in Chikkaballapur and Tumakuru districts introduced pollinator-friendly strips of sunflower, buckwheat, and basil in tomato and chilli farms. Results showed:

- 32% increase in fruit set
- 25% reduction in pest infestation
- Enhanced wild bee visitation (*Xylocopa* spp. and *Nomia* spp.)

2. Maharashtra: Tribal Apiary Integration

Under the NRLM's Livelihoods Program, tribal women in Gadchiroli were trained in backyard beekeeping using *Apis cerana indica* boxes. Integrated with minor millet and niger seed farming, this improved:

- Household income by ₹15,000–₹25,000/year
- Pollination of niger, guava, and ridge gourd
- Local honey availability and nutrition

The Role of Wild Bees and Native Pollinators

Wild solitary bees such as *Xylocopa* (carpenter bees), *Lasioglossum*, *Nomia*, and *Halictus* species are often more efficient pollinators for open flowers and native crops. They are:

- Active under cloudy or cooler conditions
- Disease-resistant and self-sustaining
- Capable of pollinating deeper or asymmetrical flowers (e.g., brinjal, chilli)

Encouraging soil-nesting zones, shrub cover, and floral diversity is essential to protect wild bee populations.

Conservation and Policy Measures

- **National Beekeeping and Honey Mission (NBHM)** – Promotes training, queen rearing, and scientific apiculture.
- **Mission LiFE (Lifestyle for Environment)** – Encourages biodiversity conservation and reduction in chemical inputs.
- **Pollinator Reserves** – Proposed inclusion in India's Biodiversity Management Committees (BMCs) under the Biological Diversity Act (2002).
- **FAO Global Pollination Project (India Chapter)** – Piloted in Himachal Pradesh to integrate pollinator considerations in apple farming.

Recommendations for Farmers and Policymakers

- **Adopt Bee-Safe Pesticide Practices:** Avoid spraying during flowering or use selective, low-toxicity products (e.g., neem-based).
- **Promote Habitat Diversity:** Establish hedgerows, flowering strips, and native vegetation in field margins.
- **Train Beekeepers Scientifically:** Regular training, queen rearing programs, and disease management are crucial.
- **Support Wild Pollinator Research:** Encourage state agricultural universities and ICAR centers to document regional pollinator species and their ecology.
- **Link Pollination to Market Access:** Create demand for "pollinator-friendly produce" in eco-conscious consumer markets.

Conclusion

Pollinators are essential agents of agricultural productivity and biodiversity conservation. Yet, their survival is increasingly threatened by human-driven changes in landscapes, climate, and farming systems. India, as a biodiversity-rich agrarian nation, stands at a critical juncture. Investing in pollinator conservation is not just a scientific or environmental obligation-it is a necessity for sustainable food production, rural livelihoods, and ecological harmony.

With supportive policies, farmer awareness, and scientific interventions, we can secure the future of bees and ensure resilient agroecosystems for generations to come.

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PRECISION FARMING IN AGRICULTURE

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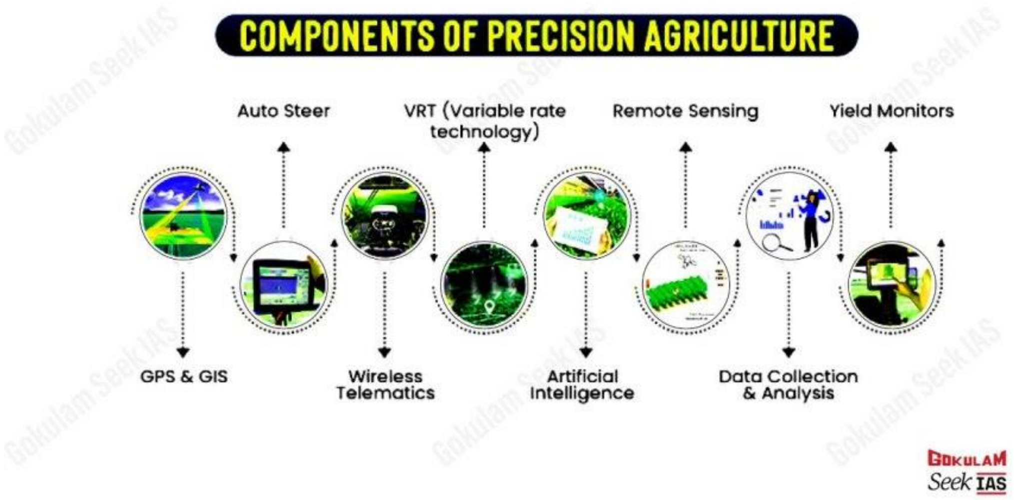
INTRODUCTION

Precision farming emerged in US IN 1980s with researchers like Pierre C. Robert. It is a technology approach that uses data to optimize resource and to improve crop production. It is also known as site- specific crop management. Objective of precision farming is to improve crop yield. It involves planning from selecting the right seed to irrigation management. The term also involves reducing the pest and diseases through spatial target activities.

KEY ASPECTS

1. Information: It mainly deals with the various aspects of spatial and temporal variability data on which the management decisions made.
2. Technology: It uses the technologies like GPS, GIS, remote sensing to gather information about the crop and land parameters.
3. Management: It includes the management decisions to manage variability.



TECHNOLOGIES USED IN PRECISION FARMING

Global positioning system: It allows for mapping of field boundaries, soil types and application of inputs.

Geographic information system: It monitors the soil conditions, crop health, weather pattern and climatic factors.

Remote sensing: It involves soil mapping, crop monitoring, pest and disease detection, yield estimation, monitoring of weeds and crop diseases.

Satellite based technology: Providing real–time data for efficient resource management and optimized crop health.

ADVANTAGES

- The most important advantages of precision farming to increase crop yields.
- It will reduce the input cost of farmers.
- Fertilizers, pesticides and water when and when needed it helps to applying resources and to reduce the waste.

- By applying the right resources at right time can lead to higher quality crops and better marketability.
- It reduces runoff, erosion and reduction in environment pollution.
- It provides more accurate farm records.
- Precision farming can play a crucial role in promoting sustainable agricultural practices and optimize resources use.

DISADVANTAGES

- The initial investment will be high; it is not suitable for all farmers.
- It requires technical skills to operate, maintain the equipment and analyze the data.
- It is complexity to analyze the large volume of data.
- It mostly depends on technology, it will be risky; if the system is failure; it totally disturb the farming operations.
- It is applicable if the farmer is literate. Farmers should have sufficient knowledge about the advanced technologies.

BASIC STEPS IN PRECISION FARMING

1. Assessing variation

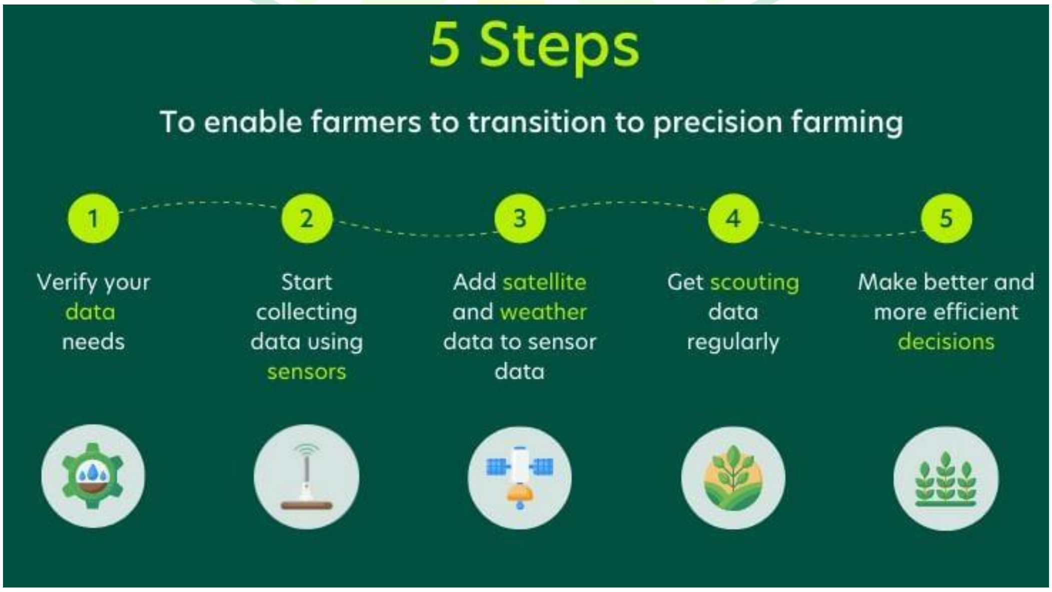
- Variability assessment is the first and most important step. In this process, site condition is assessed by various factors like soil erosion, soil fertility, soil moisture and organic matter.
- Based on the assessment, variability map is established.

2. Managing variation

- Poor site condition warrants more inputs. In this step we have to use the appropriate input application like soil fertility management, fertilizers and appropriate tools.
- Variable rate applicator is the most useful tool in precision farming.

3. Evaluation

- The yield obtained, input and cost involved are evaluated. The yield should be compared with conventional agriculture.
- Precision farming is accepted when the farm income is generated.



FIVE R'S OF PRECISION FARMING

It is often referred to a nutrient Stewardship, it is guide for applying fertilizers, manures at the right time to reduce the wastage of input and maximizes yield. Applying the right input, at the right amount, to the right place, at the right time, and in the right manner

Uses:

1. Variable RateApplication (VRA)

Automatically adjusts seed, fertilizer, and pesticide delivery rates based on real-time or pre-planned field data.

2. Precision Irrigation

Soil moisture sensors, weather forecasts, and automated irrigation work together to provide water precisely when and where crops need it

3. Field Mapping & Monitoring

Drones, satellites, and aerial imaging map crop health using NDVI and other spectral indices

4. GIS & GPS Integration

GPS-guided tractors increase accuracy, minimize overlaps, reduce fuel use, and avoid soil

5. Pest and Disease Control

Remote sensing and AI detect early infections or pest infestations.

6. Robotics & Autonomous Machinery

Self-driving tractors, robotic harvesters, and weed-killing robots reduce labor and improve precision

CONCLUSION

Precision farming refers to where the inputs are precisely used for site condition and crop needs to achieve maximum yield. Precision farming will adaptable when the land holdings are large and farmers will be literate about the technologies. It helps in reducing the environmental pollution and reduces the excessive use of inputs. Precision farming mainly address the variability. Hence it reduces cost of cultivation, maximum yield and it will increase the income

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Rebooting Soil Health: Microbial Inoculants as the Green Surge for Nutrient Revival

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Introduction:

In recent years, farmers across India have noticed a worrying trend—soils are becoming harder, crops are showing nutrient deficiency symptoms despite fertilizer use, yields are stagnating, and water doesn't percolate as easily as it used to. Many call it a "soil fatigue" or "chemical tiredness." But what we are truly witnessing is a biological collapse of the soil ecosystem caused by decades of excessive dependence on chemical fertilizers, monocropping, intensive tillage, and low organic matter application. Soil is not just a medium to hold plants, it is a living, breathing ecosystem filled with microorganisms—bacteria, fungi, actinomycetes, and algae—that regulate the most important soil functions like nutrient cycling, root development, disease suppression, and moisture retention. When this soil life is lost or suppressed, the entire nutrient cycle collapses, forcing farmers to apply more and more fertilizers to get the same yield.

The tragedy is that the natural nutrient suppliers in soil—microbes—have been ignored in modern agriculture. While chemical fertilizers deliver nutrients, they do not build long-term fertility. Continuous use of urea and DAP without replenishing organic inputs or microbial diversity has led to nutrient lock-up (especially phosphorus), micronutrient deficiencies (zinc, boron, sulphur), soil compaction, and declining carbon content. The real solution is not to increase chemical inputs, but to bring back life into the soil. This is where microbial inoculants—also called biofertilizers—play a vital role. These are naturally occurring or lab-cultured beneficial microorganisms that, when applied to seed, soil, or plant roots, stimulate biological activity in the soil and help plants access essential nutrients like nitrogen, phosphorus, and potassium. They not only improve soil health but also reduce input costs and enhance crop resilience under stress.

For example:

- **Rhizobium** forms nodules in legumes and fixes atmospheric nitrogen.
- **Azotobacter and Azospirillum** improve nitrogen availability in cereals.
- **Phosphate Solubilizing Bacteria (PSB)** release locked phosphorus into plant-available forms.
- **Potassium Solubilizing Bacteria (KSB)** enhance K uptake from insoluble minerals.
- **Mycorrhiza (VAM)** expands root surface area for better water and nutrient absorption.

The use of such microbial inoculants, when combined with organic manures and balanced fertilizers, can restore the natural nutrient cycle, improve root growth, increase nutrient use efficiency, and ultimately revive soil fertility. Field trials in Balodabazar districts have shown yield improvements of 15–30% and reduction in fertilizer requirement by 20–25% when biofertilizers were used with recommended practices.

In the face of climate uncertainty, erratic rainfall, and rising input costs, the shift from chemical-heavy farming to biointensive nutrient management is not just desirable—it is essential. Rebooting soil health through microbial inoculants is a practical, farmer-friendly, and sustainable approach to regenerate our soils, reduce environmental impact, and move toward true Atmanirbhar Krishi. The time has come to stop treating soil like dirt—and start nurturing it as a living asset. Let us rediscover the power of invisible allies beneath our feet.

What Are Microbial Inoculants?

Microbial inoculants, also known as biofertilizers or microbial consortia, are preparations that contain live, beneficial microorganisms which, when applied to seeds, soil, or plant roots, enhance plant growth by improving nutrient availability, soil health, and stress tolerance.

Unlike chemical fertilizers that provide direct nutrient input, microbial inoculants activate natural processes in the soil. They help in nutrient cycling, fixation of atmospheric nitrogen, solubilization of locked nutrients (like phosphorus and potassium), and promotion of root growth through hormones and enzymes.

Microbial inoculants are safe, eco-friendly, and cost-effective alternatives or supplements to chemical fertilizers. Their use leads to:

- Better soil microbial activity
- Reduced fertilizer requirement
- Improved nutrient use efficiency
- Sustainable long-term fertility

Types of Microbial Inoculants (with Functions):

1. Nitrogen-Fixing Bacteria

- *Rhizobium*: Symbiotic, forms nodules in legumes
- *Azotobacter*, *Azospirillum*: Free-living N-fixers for cereals and vegetables

2. Phosphate-Solubilizing Bacteria (PSB)

- *Bacillus megaterium*, *Pseudomonas sp.*
- Converts unavailable phosphorus into plant-available form

3. Potassium-Solubilizing Bacteria (KSB)

- *Frateuria aurantia*, *Bacillus mucilaginosus*
- Releases K from silicate and mineral-bound sources

4. Mycorrhizal Fungi (VAM)

- *Glomus spp.*
- Enhances root growth, improves P and micronutrient uptake

5. Plant Growth Promoting Rhizobacteria (PGPR)

- *Pseudomonas fluorescens*, *Bacillus subtilis*
- Improves root development, induces resistance to pathogens

Field-Level Evidence: Microbes at Work

The following field trials were conducted across five crops to assess the role of microbial inoculants in enhancing nutrient use efficiency (NUE), crop productivity, and soil health. The results highlight the multi-dimensional benefits of microbial formulations in both resource-rich and resource-constrained environments.

Farmer 1: Heera Singh Dhruw – Rice

Location: Gudeliya, Bhatapara

Crop: Rice (var. Rajeshwari)

Treatments: RDF vs RDF + Azospirillum + PSB

Treatment	Yield (q/ha)	NUE (%)	Fertilizer Cost (Rs/ha)	Net Return (Rs/ha)
RDF	52.4	38.6	6500	42,300
RDF + Azospirillum + PSB	59.8	47.3	6700	51,700

Scientific Note: In flooded rice fields, there is very little oxygen near the roots. This limits the natural nitrogen availability to plants. However, helpful bacteria like Azospirillum can grow even in such low-oxygen conditions. These bacteria stay around the roots and help fix nitrogen from the air, making it available to the rice crop. Similarly, Phosphate Solubilizing Bacteria (PSB) like Bacillus megaterium help unlock phosphorus in the soil. In wet and acidic conditions, phosphorus often gets stuck in forms that plants can't use (like iron and aluminum-bound phosphate). PSB release natural acids that dissolve this locked phosphorus, making it available to the crop.

“Effect of microbial inoculants on crop Vigor and uniformity, increased Rice yield using Azospirillum and PSB.”

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Farm-level results showed that using these microbes led to more tillers (branches of the rice plant) and greener leaves (as measured by SPAD readings), which means better photosynthesis and plant health. After harvest, the soil had more microbial activity—seen through a 14.2% increase in microbial biomass carbon and 22% higher enzyme activity (dehydrogenase)—indicating improved soil health and fertility.

Farmer 2: Shri Lokesh Dhruw – Chickpea

Location: Gudeliya

Crop: Chickpea (var. JG 14)

Treatments: Control vs RDF + Rhizobium + PSB

Treatment	Yield (q/ha)	Nodules/plant	Fertilizer Cost (Rs/ha)	Net Return (Rs/ha)
Control	12.8	18	3200	20,000
RDF + Rhizobium + PSB	16.5	34	3400	31,800

Scientific Note: In chickpea crops, treating seeds with Rhizobium bacteria (Mesorhizobium ciceri) helped plants form more and bigger root nodules, which are important for natural nitrogen fixation. These nodules also had more leghaemoglobin—a sign that they were actively fixing nitrogen from the air. Adding Phosphate Solubilizing Bacteria (PSB) improved the availability of phosphorus in the soil, which is very important for proper nodule development and function. Using advanced methods, it was found that chickpea plants got about 27.8% more nitrogen from the air compared to untreated plants. Better root growth also helped the plants absorb water and nutrients more efficiently, which led to better yields and good-quality pods. These findings clearly show that using biofertilizers in pulse crops like chickpea can reduce the need for chemical urea fertilizers and promote more sustainable farming.

"Rhizobium nodules on chickpea roots—nature's nitrogen factory"

Farmer 3: Mr. Imran – Soybean

Location: Borsi

Crop: Soybean (var. CG Soya-1)

Treatments: RDF vs RDF + Azotobacter + PSB + KSB

Scientific Note: Azotobacter (specifically A. chroococcum) is a helpful soil bacterium that fixes nitrogen from the air without needing a host plant. It also produces growth-promoting substances like IAA (Indole Acetic Acid), which help the roots grow longer and stronger. Phosphate Solubilizing Bacteria (PSB) release natural enzymes and acids that dissolve locked-up phosphorus in the soil, making it available to plants. This led to a 17.5% increase

"Field-friendly methods of applying microbial inoculants in Soybean crop, increased yield using Rhizobium and PSB" in available phosphorus in the soil (measured as Olsen-P). Potassium Solubilizing Bacteria (KSB) like Frateuria aurantia helped release potassium from minerals like mica and feldspar in the soil. This extra potassium helped in better grain filling and overall crop development. The crop grains had more protein, showing that the plant not only took up more nitrogen but also used it efficiently. After harvest, soil tests showed increased activity of enzymes (measured by FDA hydrolysis), which means the soil had active and diverse beneficial microbes—signs of good soil health.

Farmer 4: Mr. Shivnarayan Sahu – Cauliflower

Location: Purena Khapri

Crop: Cauliflower

Treatments: RDF vs RDF + PGPR + Trichoderma + PSB

Treatment	Yield (q/ha)	Head Weight (kg)	Input Cost (Rs/ha)	Net Return (Rs/ha)
RDF	180	0.96	54,000	78,000
RDF + Bioinoculants	218	1.12	56,000	99,400

Scientific Note: Plant Growth Promoting Rhizobacteria (PGPR) strains like *Pseudomonas fluorescens* enhanced root development and produced ACC deaminase, mitigating stress ethylene under cool conditions. *Trichoderma harzianum* suppressed *Sclerotinia sclerotiorum* and improved soil suppressiveness. Yield improvements were supported by better nutrient uptake (especially P, Zn) and reduced disease severity index (DSI). The average B:C ratio improved from 2.4 to 2.9, showing clear economic viability for adopting bio-inputs in high-value horticulture.

Farmer 5: Shri Daksineshwar – Mustard

Location: Mudhipar

Crop: Mustard (var. DRMR 150-35)

Treatments: RDF vs RDF + Azotobacter + PSB + VAM

Treatment	Yield (q/ha)	Oil Content (%)	Net Return (Rs/ha)
RDF	9.4	37.2	18,600
RDF + Bioinoculants	13.6	39.5	26,900

Scientific Note: The synergistic effect of *Azotobacter* and PSB enhanced early growth and flowering, while VAM (*Glomus spp.*) significantly improved root surface area, P and Zn uptake. Mycorrhizal colonization reached 63%, confirming successful establishment. Increased oil content (by 6.2%) was attributed to balanced macro and micronutrient availability. This reinforces the role of integrated microbial management in **oilseed quality enhancement** and climate-resilient nutrient uptake, particularly in marginal soils.

How to Use Microbial Inoculants in the Field

Proper application of microbial inoculants is essential to ensure maximum survival, colonization, and activity of beneficial microbes in the crop root zone. The method of use varies depending on the crop, type of inoculant, and availability of irrigation. Here are three common and effective methods:

1. Seed Treatment

This is the most economical and widely used method for cereals, pulses, and oilseeds.

- Take required quantity of microbial inoculant (e.g., *Rhizobium*, *Azotobacter*, *PSB*) at 10 g/kg seed.
- Prepare a slurry using jaggery as adhesive.
- Mix well to coat all seeds uniformly.
- Dry in shade for 30 minutes and sow within 24 hours.

Ideal for: Wheat, chickpea, mustard, soybean, maize.

2. Soil Application

For transplanted crops, horticultural plants, or standing field crops.

- Mix 2 kg microbial culture (per acre) with 50 kg well-decomposed FYM or compost.
- Keep the mixture under shade for 12 hours for microbial activation.
- Broadcast evenly in moist soil just before sowing or transplanting.

Ideal for: Rice nursery, cauliflower, tomato, brinjal.

3. Root Dipping or Drip Fertigation

- For vegetable seedlings: Dip roots in a solution containing microbial slurry for 20–30 minutes before transplanting.
- For fruit crops: Apply through drip with water (using water-soluble formulations).

Ideal for: Onion, garlic, citrus, banana, guava.

Mechanisms of Microbial Action

Microbial inoculants improve plant and soil health through a variety of biochemical and physiological mechanisms. Understanding how these microbes function helps in designing better crop-specific and soil-specific strategies.

1. Nitrogen Fixation: Nitrogen-fixing bacteria such as *Rhizobium*, *Azotobacter*, and *Azospirillum* convert atmospheric nitrogen (N_2) into ammonia (NH_3), a form that plants can readily absorb. *Rhizobium* forms symbiotic nodules on the roots of legumes where nitrogenase enzyme facilitates the fixation process in anaerobic conditions. *Azotobacter*, a free-living bacterium, also fixes nitrogen but thrives in aerobic soils and contributes significantly in cereals and vegetables.

2. Phosphate Solubilization: A large fraction of phosphorus in the soil is locked in insoluble forms like tricalcium phosphate, iron phosphate, and aluminum phosphate. PSB (e.g., *Bacillus megaterium*, *Pseudomonas fluorescens*) produce organic acids like gluconic acid, oxalic acid, and citric acid, which lower soil pH and chelate metal ions, thereby releasing plant-available phosphate. This not only improves root uptake but also minimizes the need for synthetic phosphate fertilizers like DAP.

3. Potassium Mobilization: Potassium solubilizing bacteria such as *Frateuria aurantia* secrete organic acids and extracellular enzymes that dissolve silicate minerals and make potassium available to plants. This is especially useful in potassium-deficient soils and under high-yielding crop systems.

4. Mycorrhizal Associations: Vesicular arbuscular mycorrhizae (VAM), especially *Glomus spp.*, form a symbiotic relationship with plant roots. Their hyphae extend beyond the root zone, increasing the effective surface area for nutrient and water uptake. Mycorrhizae are particularly efficient at scavenging phosphorus and micronutrients such as zinc and copper. Additionally, they enhance plant tolerance to drought, salinity, and heavy metals.

5. Hormonal Stimulation and Growth Promotion: Plant Growth Promoting Rhizobacteria (PGPR) like *Pseudomonas* and *Bacillus subtilis* produce phytohormones such as auxins, gibberellins, and cytokinins, which promote root elongation and lateral branching. PGPR also modulate ethylene levels in plants by producing ACC deaminase, an enzyme that breaks down the ethylene precursor. This reduces stress-induced ethylene accumulation and supports better growth under abiotic stress.

6. Biocontrol of Soil Pathogens: Certain microbes like *Trichoderma harzianum*, *Pseudomonas fluorescens*, and *Bacillus subtilis* produce antibiotics, siderophores, and lytic enzymes (e.g., chitinases, glucanases) that inhibit the growth of pathogenic fungi and bacteria. These microbes colonize the root surface and act as a protective shield, reducing the incidence of diseases like root rot, damping-off, and wilt.

7. Enzyme Production and Soil Health Enhancement: Many beneficial microbes produce soil enzymes such as dehydrogenase, phosphatase, urease, and cellulase that accelerate organic matter decomposition and nutrient cycling. Enhanced enzymatic activity reflects increased microbial biomass and active nutrient turnover, leading to improved soil fertility and structure.

8. Induced Systemic Resistance (ISR): Some microbial inoculants trigger the plant's internal defense system through a mechanism called ISR. Unlike conventional pesticides, ISR prepares the plant to respond more effectively to future pathogen attacks without causing environmental toxicity. Together, these mechanisms explain why microbial inoculants are not just passive soil amendments but active agents of soil regeneration, crop nutrition, and environmental sustainability.

Long-Term Vision: Living Soils, Resilient Agriculture

Rebooting soil health is not a one-time act; it is a journey—a continuous commitment to restoring, maintaining, and enhancing the biological vitality of our soils. Fertile soil is not simply a mix of sand, silt, and clay, but a living ecosystem teeming with microbes, earthworms, fungi, and organic matter that collectively govern nutrient cycling, root health, and crop resilience. However, years of overreliance on chemical fertilizers and pesticides have led to soil fatigue, nutrient lock-up, and biological depletion.

In this context, microbial inoculants offer a long-term solution, not as replacements but as enhancers of natural processes. These beneficial microorganisms—such as nitrogen fixers, phosphate solubilizers, potassium mobilizers, and mycorrhizal fungi—work in harmony with the plant root system to unlock nutrients from the soil and make them available to crops efficiently and sustainably. Their application reduces the need for excessive chemical inputs, improves soil structure, enhances water retention, and fosters microbial diversity.

From the perspective of climate resilience, microbial inoculants are climate-smart technologies. They improve carbon sequestration, reduce greenhouse gas emissions (by lowering fertilizer use), and make plants more tolerant to drought, salinity, and heat stress. In the long run, they also help regenerate degraded lands, making them productive again for future generations.

For farmers, this means higher nutrient use efficiency, better returns, and reduced input costs. For the environment, it means healthier soils, cleaner water, and lower carbon footprints.

It's time to stop treating soil as just a substrate and start nurturing it as a living asset. Let us move beyond the "fertilizer-only" mindset and revive nature's nutrient cycle—not with chemicals alone, but with microbes, organic matter, and mindful management.

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Ecofriendly Natural Colour Pigments

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The appearance of colour is mainly due to reflection and emission of different types of light by the objects. Colours affect the persons mood, mental health, productivity, interaction and behaviour. Further colour enhances aesthetic value of an abject, locations and pictures, which is more powerful communication tool that makes it possible to convey thought, concepts and feelings. Different colours have different psychological and emotional effect and are associated with various interpretation. Additionally branding and marketing depends on colours.

Synthetic colours are produced in the laboratory. Dyeing using chemical colour started in late 19th or early 20th centuries. Synthetic colours are extremely attractive, highly intensive, fastness in nature as compared to natural pigments. The synthetic colours are used in everyday life from clothing to food. Related to use of synthetic colour in food resulted in symptoms of hypersensitivity behavioural disturbances, attention deficit in children and also decline in learning performance. The use of synthetic colour in textile and other industry resulted in decreased the passage of sunlight in water bodies, increases biochemical and chemical oxygen demand, prevents photosynthesis and inhibits plant growth and some cases synthetic dyes as mutagenic and carcinogenic effect.

Natural colours are pigments which are derived from planta animals and minerals. The pigments extracted from this are mainly used in food, beverages, cosmetics and also in textile industries. These natural colours are safe for consumption. The main disadvantage is these are less stable because natural colours are sensitive to heat, light and pH changes. The earliest record of use of natural pigments dates back to 5000 BC. The pigments which are extracted from plants, animals and minerals used in cave painting. Later in 1300 BC the Egyptians credited with many pigments. In earlier days the pigments were location based viz., Egyptian blue from Egypt, French ultramarine from France etc. The natural pigments are used to represent specific emotions like saffron symboliser of purity, Red represents sensuality etc. The natural colours provide numerous benefits over synthetic colour: these colours safe to use in food and cosmetics, these are devoid of harmful chemicals these are have health benefits. Further the natural colours are ecofriendly in nature and sustainable as these are derived from renewable sources in this way these colours are having environmental benefits. Balance between health and environment is most important for sustainable life style.

Natural pigments from common plants and their benefits

Sl. No.	Natural Pigments	Colour	Common plant	Main function
1	Lycopene	Red	Tomato, Pink grape fruit, Watermelon, Papaya, Guava	Antioxidant; Anti-carcinogenic activities; Skin protection
2	B-Carotene	Red-Orange	Carrot, Apricot, Asparagus, Chinese cabbage, Chilli, Paprika	Vitamin A; Increase immune system; Inhibit cancer cells; Protects skin against sunburn
3	Betalains	Red-Yellow	Red beet, Dragon fruit, Swiss chard, Cactus flower	Defence and resistance towards pathogen resistance; Antioxidants; Chemo-prevention
4	Anthocyanin	Red/Blue Purple/Green	Red cabbage, Elderberry, Black current, Sweet Potato, Purple carrot, Cheery, Red radish	Antioxidants, Avoid coronary heart disease; Strong in bactericidal; Antiviral and fungistatic activities Protect baby against free radicals; Decrease the risk of heart diseases and cancer
5	Chlorophyll	Green	Green plants, Aloe vera	Improving immune system; High antioxidant; Anti-carcinogen
6	Lutein	Yellow	Peas, Sweet corn, Sweet peppers, Maize, Kiwi fruit, Orange juices, Grapes, Spinach	Protects the neural retina; Delaying the retina and lens in age-related eye diseases and the pigmentary abnormalities

Pigments derived from Insect and Animals and application

Origin	Pigments	Derived Sources	Purpose
Insects	Red animal dyes	Obtain from the exudation of dried bodies	Dyeing, Colorant
Animals	Carminic acid	Cochineal	Dyeing, Colorant
	Kermesic acid	Kermes	
	Lac dye	Laccifer lace/kerria	
	Tyrian purple	Molluscs	

Natural pigments and their uses in food stuffs

Sl. No.	Natural Pigments	Food stuff
1	Annatto	Cakes, Biscuits, Dairy products, Flour, Soft drinks
2	Carotenoids	Meat products, Sauces, Marmalades, Spice blends, Beverages, Milk products
3	Anthocyanins	Confectionary, Fruit preparations
4	Chlorophylls	Dairy products, Soups, Drinks
5	Curcumin	Yoghurt, Baked goods, Dairy products, Ice creams, Salad dressings
6	Carmine	Jams, Gelatines, Baked goods, Dairy products, non-carbonated drinks

Plant sources of colourant potentially used in industries:

Sl.No.	Pigments	Sources
1	Anthocyanins	Elderberry, Black soybean, pomegranate, Cornelian Cherries, Eggplant, Purple cabbage, Hibiscus, Clove, Peony, Purple sweet potato, Purple corn
2	Flavanols	Accacia nilotica bark, Onion shell
3	Curcumin	Turmeric
4	Iridoids	Gardenia jasminoides
5	Carotenoids	Annatto, Marigold, Saffron, Paprika, Tomato
6	Quinones	Lawsonia Alba, Lithospermum erythorhizom, Walnut
7	Indigoid	Indigofera tinctoria, Isatis tinctoria
8	Betalains	Pokeberry, Beetroot, Dragon fruit
9	Melanins	Chestnut shells
10	Tetrapyrrole algae - red	Porphyridium Spirulina

Natural pigments are important related to health and environmental concerns of present-day situation. These pigments offer lower ricks of adverse effect, they inherent the nutritional value, these colourful pigments are also helpful in biological activities like antioxidant, anti-inflammatory and anti-microbial, in addition, the natural pigments are environmentally friendly and promotes circular economy. Present days natural pigments becoming very sustainable because of increase in the consumer demand.

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Practical Applications of Vedic Agriculture Methods: A Case Study on Desi Brinjal (*Solanum melongena*)

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Abstract

Vedic agriculture, deeply rooted in ancient Indian wisdom, offers a holistic and sustainable alternative to chemical-based modern agriculture. This study explores the practical applications of Vedic agricultural methods in cultivating Desi brinjal (Solanum melongena), focusing on seed treatment, soil health, pest management, and yield quality. Through a field experiment conducted over one crop cycle, this research demonstrates how traditional practices such as Panchagavya, Agnihotra, Bijamrita, and lunar sowing patterns positively influence crop health and productivity. The case study emphasizes the role of indigenous seeds and natural preparations in reducing input costs and enhancing nutritional quality, thus making a strong case for reviving Vedic agriculture in the context of food security, sustainability, and soil regeneration.

1. Introduction

Modern agriculture, while contributing significantly to food security, has led to alarming environmental and health challenges including soil degradation, water pollution, and declining crop diversity. In contrast, Vedic agriculture—a system based on the principles of the Vedas, Upanishads, and traditional scriptures like Vrikshayurveda—emphasizes harmony with nature, sustainability, and the cyclical rhythms of the cosmos. This paper presents a practical case study of cultivating the Desi Brinjal (Solanum melongena), a hardy and nutritionally rich indigenous variety, using pure Vedic methods. The study aims to validate ancient techniques through empirical observation and contribute toward the mainstreaming of traditional ecological knowledge in modern farming.

2. Objectives

To implement Vedic agricultural methods in cultivating Desi brinjal.

To assess soil fertility, plant growth, yield, and pest resistance under Vedic practices.

To compare the outcomes with conventional chemical-based farming.

To promote eco-friendly and cost-effective farming for smallholders.

3. Materials and Methods

Vedic Agriculture Practices Based on Krishi Parashara

Introduction to Krishi Parashara:

Krishi Parashara is one of the oldest known texts on agriculture in India, attributed to Sage Parashara, a revered figure in Vedic literature. Composed in classical Sanskrit, it is estimated to have been written between 1500 BCE and 1000 BCE. The treatise provides comprehensive guidance on farming, emphasizing harmony with nature, ethical living, and cosmic rhythms. It covers a wide range of topics including soil classification, crop rotation, manure preparation, rainfall prediction, and seasonal farming—offering a complete science of agriculture based on the Vedic worldview.

Key Vedic Agriculture Practices from Krishi Parashara

1. Soil Science (Bhūmi Vijñāna)

Soil Classification (Bhumi Pariksha):

Parashara categorizes soils based on color, texture, smell, and fertility:

Krishna bhumi (black soil): Good for cotton, sesame, and pulses.

Shweta bhumi (white/light soil): Suitable for barley and wheat.

Rakta bhumi (red soil): Best for millets and oilseeds.

Pandu bhumi (yellow soil): Used for medicinal and aromatic plants.

Fertility Testing:

Soils are tested by sowing seeds and observing early germination; fertility is also assessed by smell and ant activity.

2. Rain Prediction (Megha Lakshana)

Parashara details weather prediction using observations of clouds, wind direction, star constellations, and animal behavior. For instance, the presence of "elephant-shaped clouds" or excessive croaking of frogs signals good rainfall.

3. Ploughing and Land Preparation (Halakarma)

Timing: Land is ploughed three times in summer to aerate and sun-dry the soil, remove weeds, and expose pests.

Plough Material: Ploughs made from specific wood types like khadira and sala are prescribed for durability and soil compatibility.

Number of Oxen: Depending on the soil type, 2–6 oxen are recommended for ploughing.

4. Seed Treatment and Sowing (Bīja Sanskāra)

Bijamrita-like recipes are mentioned using cow urine, milk, honey, ghee, and lime to protect seeds from disease and improve germination.

Auspicious Sowing Days: Seeds are to be sown based on Nakshatra (lunar constellations), especially in the Shukla Paksha (waxing moon).

5. Organic Manure (Mṛda Poshanam)

Use of Gomaya (cow dung): Applied as a basal dose and in slurry form with cow urine.

Nutrient Mixes: Composting with leaves, kitchen ash, and buttermilk.

Panchagavya: Though not directly named, a similar mixture of cow dung, urine, milk, curd, and ghee is described as a rejuvenator for soil and crops.

6. Crop Planning and Rotation (Krama Krishi)

Recommends intercropping and crop rotation to maintain soil fertility and avoid pest cycles.

For example:

After rice: sow pulses or sesame.

After sugarcane: sow legumes to restore nitrogen.

7. Pest and Disease Management (Krimi Nivāraṇa)

Natural repellents made from:

Neem leaves, garlic, and turmeric mixed with cow urine.

Ash dusting and smoke treatment for fungal diseases.

Suggests chanting Vedic mantras while spraying—believed to enhance the energetic field of the crop.

8. Seasonal Agriculture (Ritu-Krishi)

Detailed calendar aligning crops with six Vedic seasons:

1. Vasanta (Spring): Ideal for pulses.
2. Grīṣma (Summer): Fallowing or sesame.
3. Varsha (Monsoon): Paddy, maize, turmeric.
4. Sharad (Post-monsoon): Millets and groundnut.
5. Hemanta (Early winter): Wheat and mustard.
6. Shishira (Late winter): Barley, spinach, leafy greens.

9. Water Management (Jala Niyamanam)

Advocates for rainwater harvesting, bund construction, and check dams.

Preference for well-irrigated fields (Kupa) with limited, slow release irrigation to prevent waterlogging.

10. Ethical Farming and Dharma

Farmer is considered a guardian of dharma and must practice:

Non-violence (Ahimsa) in pest management.

Respect for all life, including the earthworms and ants.

Daily prayers and offerings to nature and ancestors before tilling.

Krishi Parashara provides a highly advanced and spiritually integrated model of farming that is:

Sustainable (no chemicals), Resilient (diverse cropping), Cost-effective (uses local inputs), Holistic (interlinks soil, cosmos, and consciousness).

3.1. Site Selection
Location: A 0.5-acre farm plot in Telangana
Soil Type: Red loamy soil
Season: Kharif (June–October)
Rain-fed conditions with minimal irrigation

3.2. Seed Selection and Treatment
Desi brinjal seeds sourced from a local farmer practicing seed conservation.
Bijamrita used for seed treatment: A mixture prepared with cow dung (250g), cow urine (750ml), lime (10g), and water (20L), fermented for 12 hours. Seeds were soaked for 30 minutes before sowing.

3.3. Sowing Method
Sown on an auspicious lunar day (Shukla Paksha) based on the Panchangam.
Seeds sown in ridges and furrows to ensure optimal aeration and drainage.

3.4. Soil Fertility Management
Application of Jeevamrutha: Prepared with cow dung, cow urine, jaggery, gram flour, and soil from a fertile anthill.
Application of Panchagavya: A fermented bio-nutrient prepared using five cow-derived products—milk, curd, ghee, urine, and dung.
Regular spraying of Ghana Jeevamrutha and cow buttermilk.

3.5. Pest and Disease Management
Dashaparni Ark (a fermented botanical pesticide made from 10 plant leaves like neem, arka, tulsi, etc.)
Agnihotra ash applied to the base of the plant post-harvest.
Ash + cow urine mixture sprayed weekly.

3.6. Control Plot (For Comparative Study)
A nearby plot of the same size was cultivated using chemical fertilizers (NPK), hybrid seeds, and synthetic pesticides for yield comparison.
Application of Vedic Agriculture Methods (from Krishi Parashara) to Desi Brinjal (Solanum melongena) Cultivation
This section illustrates how the traditional practices mentioned in Krishi Parashara can be directly and practically applied to the cultivation of Desi brinjal, a native and climate-resilient variety of eggplant in India.

1. Seed Selection and Treatment (Bīja Sanskāra)
Desi brinjal seeds are chosen from mature, disease-free fruits from the previous season.
Treatment Method:
As per Krishi Parashara, treat seeds using natural antimicrobial agents:
Soak seeds in Bijamrita made with:
250g cow dung
750 ml cow urine
10g slaked lime
1L water
Duration: Soak for 30 minutes to 1 hour before sowing.
Benefits: Protects seeds from fungal diseases, enhances germination, and energizes seeds with microbial and lunar life forces.

2. Land Preparation (Halakarma)
Land is ploughed 3–4 times during summer to solarize and aerate the soil.
Incorporate dried cow dung, ash, and neem leaves during ploughing.
Select south-facing fields with good sunlight as recommended in Krishi Parashara.

3. Soil Fertility Enhancement (Mṛda Poshanam)
Basal Application:
Mix composted cow dung and leaf litter into the soil at least 15 days before sowing.
Apply Panchagavya every 15 days as a foliar spray and soil drench.
Use Jeevamrutha weekly to stimulate microbial activity.

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4. Rainfall and Sowing Time (Ritu-Krishi & Megha Lakṣaṇa)

Based on lunar calendar, sow seeds during Shukla Paksha, on days associated with growth-friendly Nakshatras like Rohini or Mrigashira.

Ideal season: Early monsoon (Varsha Ritu) for rain-fed brinjal.

5. Crop Planning and Spacing

Maintain 2–3 feet spacing between plants to ensure aeration and reduce fungal risk.

Practice intercropping with marigold or basil (tulasi) to deter pests and improve biodiversity.

6. Pest Management (Krimi Nivāraṇa)

Weekly spray of Dashaparni Ark (fermented extract of 10 plants including neem, arka, datura).

Dust agnihotra ash on the base of brinjal plants to prevent root-borne pests.

Use cow urine + neem leaf decoction as a foliar pesticide.

7. Agnihotra and Spiritual Farming Practices

Perform Agnihotra yajna daily or weekly at sunrise/sunset near the field.

Use Agnihotra ash as both fertilizer and pest repellent.

Chant & quot; Bhoomi Sūkta" or Vedic mantras while sowing to sanctify and energize the field.

8. Irrigation and Water Management

Initial watering at sowing time.

Subsequent irrigation twice a week using channel irrigation or drip.

Mulching with straw, dry leaves, or neem to retain moisture and prevent weed growth.

9. Observation and Natural Indicators

As advised in Krishi Parashara, observe:

Worm activity: Indicator of soil fertility.

Cloud color and frog sounds: Natural predictors of rainfall.

Ant movement: Signs of root health.

10. Harvesting and Seed Conservation

Brinjal fruits mature 70–90 days after transplanting.

Harvest when fruits are glossy and firm.

For seed conservation:

Let a few fruits overripe and dry naturally.

Extract seeds, sun-dry, and store in earthen jars layered with ash and neem leaves—as per Krishi Parashara instructions.

Benefits of Applying Krishi Parashara Principles to Brinjal Cultivation

Benefit Outcome

Higher germination rate 90–95%

Improved soil health Increased earthworm activity

Pest resistance Reduced incidence of shoot and fruit borer

Lower input cost No chemicals used

Better fruit quality Firm, aromatic, nutritious

Sustainability No environmental pollution

Farmer empowerment Local input-based, cost-effective

By applying Krishi Parashara's time-tested techniques to Desi brinjal cultivation, farmers can achieve:

Healthier crops

Lower costs

Natural pest control

Revival of native varieties

Spiritual satisfaction and ecological balance

This integration of Vedic wisdom with practical agriculture not only regenerates soil but also reconnects farming with dharma and cosmic consciousness.

4. Results and Observations

Parameter Vedic Plot Conventional Plot

Germination Rate 90% 85%

Soil pH (Post-Harvest) 6.8 (Neutral, improved) 5.9 (Acidic, declined)
Number of Fruits per Plant 38 31
Average Fruit Weight 92g 78g
Incidence of Pests Minimal (2%) Moderate to High (18%)
Taste and Texture Rich, firm, and aromatic Mild flavor, watery texture
Cost of Cultivation ₹10,200 (Low input cost) ₹14,700
Farmer Satisfaction High Moderate

5. Discussion

The results clearly indicate that Vedic methods significantly enhance soil health, pest resistance, and fruit quality. The use of bio-preparations not only minimized the cost of inputs but also restored soil microbiota, crucial for long-term fertility. The agro-lunar calendar and Agnihotra rituals created a spiritually and energetically vibrant field environment, which traditional farmers claim accelerates growth and reduces pest burden. The desi brinjal variety thrived in this natural system without requiring hybrid seed dependency. The spiritual connection, cow-based preparations, and cosmic rhythm-based farming contributed to a holistic and regenerative agro-ecosystem.

6. Benefits of Vedic Agriculture Observed

Soil Regeneration: Improved structure, microbial activity, and organic matter.
Reduced Water Use: Organic mulch and healthy roots retained moisture.
Pest Control: No chemical intervention needed.
Nutritional Quality: Higher in taste, antioxidants, and resilience.
Farmer Empowerment: Low external dependency; indigenous wisdom valued.

7. Challenges and Recommendations

Challenges:
Time-consuming preparation of inputs.
Limited access to indigenous seeds.
Lack of institutional support and scientific validation.
Recommendations:
Establish local Vedic agriculture resource centers.
Encourage farmer training in Jeevamrutha, Agnihotra, and lunar sowing.
Collaborate with agricultural universities for further research.

8. Conclusion

This case study reaffirms that Vedic agricultural methods are not only viable but also superior in several respects compared to chemical farming. The Desi brinjal, when nurtured through these ancient techniques, demonstrated better yield quality, sustainability, and cost-efficiency. Reviving Vedic agriculture can play a crucial role in regenerative farming, food sovereignty, and holistic well-being.

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Fruit Fortification, Possibilities and Challenges

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Fortification is one of the most crucial methods for enhancing the nutrients in food. This procedure may prove to be a highly economical public health intervention. Fortification of fruit products will effectively minimize and prevent diseases linked with nutritional deficiencies because of the excessive consumption of fruit products. For the majority of countries worldwide, the main issues are growing populations, poor food and nutrition, hunger, and vitamin and micronutrient malnourishment. Under nutrition affects 768–828 million people as per the Global Nutrition Report. For the health-promoting effects of fortified products, which help combat nutrient deficiencies that lead to many diseases, the minerals, vitamins, and fiber must be released during digestion and then absorbed in the human stomach before entering the systemic circulation. Fruit fortification is essentially a solution that supplements current treatments and is one of many required to address the intricate issue of vitamin insufficiency. A successful biofortification endeavor requires the application of genetic engineering techniques and cooperation between plant breeders, molecular biologists, and nutrition specialists. Therefore, in order to support researchers working on improving the nutritional properties of food crops and preserve global food and nutritional security, significant resources should be devoted to biofortification programs.

Introduction

Malnutrition, food insecurity, and population growth are the new issues facing the majority of countries worldwide. The frequency of undernourishment has leveled off, according to the report, but the total number of undernourished people is still rising, albeit slowly. The number of hungry people worldwide has been gradually rising for a number of years in a row after a decade of steady decline, underscoring the tremendous task of eradicating hunger by 2030. Hunger is on the rise in practically every sub-region of Africa, with undernourishment rates as high as 22.8 percent in sub-Saharan Africa and, to a lesser degree, Latin America. Despite significant advancements over the past five years, Southern Asia has the greatest rate of undernourishment in Asia, at almost 15%, followed by Western Asia, where the rate is rising at over 12%. The undernourished population is dispersed unevenly among areas, with over 500 million people living in Asia. People who don't regularly have access to enough nourishing food are more likely to suffer from malnutrition and bad health. The prevalence rate is marginally greater for women than for men on all continents. An estimated 2 billion individuals suffer from micronutrient malnutrition, commonly referred to as hidden hunger, primarily in developing nations. Hunger is only one aspect of food insecurity. According to Kul C. Gautam, the former deputy executive director of UNICEF, "hunger as we know it is not caused by the 'hidden hunger' caused by micronutrient deficiencies." Even though you may not feel it in your stomach, it affects your vigor and overall health. This "hidden hunger" is caused by the type of food that is available rather than its amount, and it is directly linked to the fact that people in many impoverished developing nations eat primarily or exclusively low-protein staple crops. It is mainly due to lack of critical micronutrients such as vitamin A, zinc, and iron in the diet. Vitamin A deficiency is predominant in developing countries among children and women which leads to >600,000 deaths each year globally among children <5 year of age. Among the micronutrient malnourishment of population, about 60% of iron, 30% of zinc, 30% of iodine and 15% of selenium are predominant. Hidden hunger impairs the mental and physical development of children and adolescents and can result in lower IQ, stunting, and blindness; women and children are especially vulnerable. Hidden hunger also reduces the productivity of adult men and women due to increased risk of illness and reduced work capacity. Food fortification initiatives and dietary supplements are traditional methods of addressing nutritional deficiencies. Nevertheless, these approaches have inherent drawbacks, such as the frequent failure to reach the target populations, particularly in impoverished rural areas of emerging nations. Therefore, in order to improve human health, the introduction of biofortified horticulture crops with higher nutritional content may be considered a dependable technique for optimal nutrition both in terms of calorie requirements and micronutrient needs.

Approaches of biofortification

Main approaches of biofortification are as follows:

1) Agronomic biofortification

Mineral micronutrient fertilizers are sprayed on leaves or applied to soils to increase the amount of micronutrients in crop sections that may be consumed. The degree of agronomic biofortification success is determined by the mobility of mineral elements in the soil and the plant. The bioavailability of nutrients in manufactured food for humans, the presence and bioavailability of soil nutrients for plant uptake (soil to crop), the allocation of nutrients within the plant and their re-translocation into the harvested food (crop to food), and the physiological state of the human body, which determines the ability to absorb and utilize the nutrients (food to human), are all factors that depend on nutrient bioavailability at different stages.

a) Soil to crop: Bioavailability of micronutrients from soil to crop is influenced by many soil factors (i.e. pH, organic matter content, soil aeration and moisture and interactions with other elements) and by the crop variety that, for example, defines the structure and functioning of rooting systems.

b) Crop to food: Bioavailability from crop to food is influenced by the crop (variety), which defines whether micronutrients are (re-)localized into edible parts of the crop and by food processing.

c) Food to human: A multitude of host-related and diet-related factors influence the bioavailability of micronutrients in food for human consumption. The chemical form and amount of micronutrients consumed, the type of dietary matrix, and the interactions between nutrients and/or food components that either facilitate or hinder absorption in the gastrointestinal tract all influence micronutrient bioavailability, making dietary intake an essential factor. When mineral fertilizer is administered, crop performance is influenced by the type of fertilizer and application technique. The fertilizer formulation is a key factor in determining the micronutrient bioavailability since the structure of the nutrients and their interactions can have favorable, neutral, or even unfavorable effects on yields and nutrient consumption efficiency. Foliar micronutrient supplementation often encourages higher nutrient uptake and efficient distribution in the edible plant portions when compared to soil fertilization. Combining foliar and soil treatment is often the most effective strategy. Foliar pathways are generally more effective in ensuring absorption into the plant because they avoid immobilization in the soil. The disadvantages of foliar application include the fact that nutrients are easily washed away by rain and that it is more costly and difficult to apply. Although higher grain nutritional contents are rare, other techniques for accurately delivering micronutrients include seed priming and fertilizer coating of seeds, which can encourage plant growth and increase yields. The efficiency of agronomic biofortification may be impacted by interactions between macronutrients and micronutrients. Root development, shoot movement, and the relocalization of nutrients from vegetative tissue to the seeds are all positively impacted by a plant's healthy N and P status. As a result, the crop's edible portions absorb and contain higher amounts of micronutrients. Zn and Se have proven to be the most successful agronomic biofortification thus far. Iodine biofortification in strawberries, plums, and nectarine and selenium biofortification in strawberries are a few instances of agronomic approaches in fruit crops.

2) Conventional biofortification

This involves selection of existing varieties containing higher level of nutrients and crossing those high nutrient varieties with high yielding varieties of crops over several generations to develop a new variety with high nutrient content and desirable agronomic traits. This is the most accepted method of biofortification. It offers a sustainable, cost-effective alternative to transgenic- and agronomic-based strategies. Biofortification by breeding can be achieved in crops when genetic diversity is available in the utilizable form within the primary, secondary ortertiary gene pool of the targeted crop. In some cases, this can be overcome by crossing to distant relatives and thus moving the trait slowly into the commercial cultivars. Alternatively, new traits can also be introduced directly into commercial varieties by mutagenesis. For biofortification, using the conventional plant breeding approach to be considered feasible and effective for alleviating micronutrient deficiencies, three conditions should be met:

a. Nutrient density is increased without reducing crop yield.
b. When the crops are consumed, the increase in nutrient levels can make a measurable and significant impact on human nutrition.
c. Farmers are willing to grow the crops and consumers to eat them.

Some examples in fruit crops are:

a) Banana breeding: A large scale screening of several banana germplasm for the identification of high levels of pro vitamin A has been carried out in the Democratic Republic of Congo (DRC) and Burundi by Biodiversity International (BI) in collaboration with Harvest Plus. In this program, they have released five varieties (Apantu, Bira, Pelipita, Lai) rich in provitam in A in Eastern DRC and Burundi.

b) Grape breeding: The Indian Agricultural Institute has released an improved variety, i.e., Pusa Navrang which contains higher amount of total soluble solids (carbohydrates, organic acids, proteins, fats, and minerals) and antioxidants.

3) Transgenic biofortification

In this method, individual genes from the wild relatives or other species that code for increased production of certain nutrients are isolated and transfer them to the plant. Transgenic method is used as an alternative for the development of biofortified crops when there is a limited or no genetic variation in nutrient content among plant varieties or when a particular micronutrient does not naturally exist in crops. The ability to identify and characterize gene function and then utilize these genes to engineer plant metabolism has been a key for the development of transgenic crops. Furthermore, pathways from bacteria and other organisms can also be introduced into crops to exploit alternative pathways for metabolic engineering. Transgenic-based approach has advantages that a useful gene once discovered, can be utilized for targeting multiple crops. Some important genes like phytoene syntheses (PSY), carotene desaturase, nicotinamide syntheses, and ferritin have been utilized in multiple events including multiple crops. Transgenic approaches can also be used for the simultaneous incorporation of genes involved in the enhancement of micronutrient concentration, their bioavailability, and reduction in the concentration of antinutrients which limit the bioavailability of nutrients in plants. In addition, genetic modifications can be targeted to redistribute micronutrients between tissues, enhance the micronutrient concentration in the edible portions of commercial crops, increasing the efficiency of biochemical pathways in edible tissues, or even the reconstruction of selected pathways. Besides, genetic engineering has no taxonomic constraints and even synthetic genes can be constructed and used. Some examples in fruit crops are PVA rich banana, antioxidant rich transgenic apple and beta carotene rich kiwifruit.

Advantages of biofortification:

i. **Effective outreach (Reaching the malnourished in rural areas)**: The biofortification strategy seeks to put the micronutrient-dense trait in the highest-yielding and most profitable varieties targeted to farmers. Biofortification has advantage over many other fortification processes involved in improving nutritional status of people as this is targeted to population through the staple food. Many artificially fortified and processed foods are beyond the reach of poor people and their introduction to daily diet through different programs is time consuming and labour intensive.

ii. **Cost-effectiveness and low cost:** Biofortified seeds include improvement in the variety of crop by introduction of some specific nutritional superior traits into their seed variety. These varieties are capable of producing nutritionally dense staples and are resistant to many environmental pressures so at the same cost of seed, farmer gets nutritionally superior seed for nutritionally rich staple food production.

iii. **Sustainability of biofortification:** Once the crop is introduced with nutritionally superior trait, its seeds and products will contain the same genotype and the cycle will continue without much further investment as compared to other methods of supplementations or artificial fortification.

iv. Change in eating habits and dietary patterns of a population are not essential.

v. A substantial proportion of the recommended dietary allowances (RDA) for different micronutrients can be delivered simultaneously in a continuous manner.

vi. Fortified seed does not incur yield penalty.

vii. Offers important indirect benefits like diseases resistance to nutritionally superior plants,

viii. Overcome malnutrition

ix. Increase in nutritional content

x. Improvement of variability in germplasm

xi. Increased bio-availability (Kuntiz trypsin inhibitor inhibits bioavailability of trypsin so zero Kuntiz trypsin inhibitor varieties of soybean like NRC 127 are good for health)

xii. Reduced off-flavours (low lipoxygenase good in Soybeans because it responsible for off-flavours)

Limitations of biofortification

- The success of agronomical biofortification is highly variable due to the differences in mineral mobility, mineral accumulation among plant species, and soil compositions in the specific geographical location of each crop.
- It is not always possible to target the micronutrient into edible plant parts like seed or fruit and can sometimes result in the accumulation of desired nutrients in the leaves or other non-edible portions of plants; therefore, agronomic biofortification is merely successful in certain minerals and specific plant species.
- Limitations with respect to the amount of genetic variability for the micronutrients in the plant gene pool and the time needed to generate cultivars with the desired trait(s) through breeding.
- Low acceptance of transgenic crops among the consumers.
- Low success rate of the transgenic-based approach in terms of cultivar release due to time required from target trait and gene identification, modification, expression and assessment of agronomical traits to understanding the possible effect on other life forms.

4) Elicitation:

- Elicitors are the substances which induce physiological changes in the plant cells. Plants cells respond to these stressors by activating an array of mechanisms, similar to the defense responses to pathogen infections or environmental factors. They affect the plant metabolism and enhance the synthesis of phytochemical/ plant secondary metabolites.
- Secondary metabolites: They are biosynthetically derived from primary metabolites. They produces product that aid in the growth and development of plants but not required for the plant to survive. They facilitate the primary metabolism in plant. They are major component of plant defense mechanism against herbivores, pest and pathogens.

Challenges:

- The success of agronomical biofortification is highly variable due to the differences in mineral mobility, mineral accumulation among plant species, soil compositions in the specific geographical location of each crop.
- It is not always possible to target the micronutrient into edible plant parts like seed or fruit
- and can sometimes result in the accumulation of desired nutrients in the leaves or other non-edible portions of plants; therefore, agronomic biofortification is merely successful in certain minerals and specific plant species.
- Limitations with respect to the amount of genetic variability for the micronutrients in the plant gene pool and the time needed to generate cultivars with the desired trait(s) through breeding.
- The biggest hurdle in the commercial use of GM crops is the regulatory approval process which is very expensive and time consuming.
- Low acceptance of transgenic crops among the consumers.
- Low success rate of the transgenic-based approach in terms of cultivar release due to time required from target trait and gene identification, modification, expression and assessment of agronomical traits to understanding the possible effect on other life forms.

Possibilities: Future Thrust

- Production of crops with increased iron, vitamin A, zinc and selenium concentration as a lot of people worldwide suffer from micronutrient deficiencies. (Fe-60%, Zn-30%, Se-15%) .
- Transgenic approaches for biofortification from Gene marking and engineering techniques we can identify the specific plant gene or genetic material that control nutrient contents.
- Several transgenic experiments in many agricultural crops targeted protein and micronutrient accumulation are on-going; a successful example is ‘Golden Rice’ for β-carotene.
- Incorporation of elicitors in production technology for enhanced mineral nutrients in fruits.
- Screening of present varieties for their micronutrient responsiveness.
- Improve the transport of minerals from the roots to storage tissues.
- Zinc and Fe fertilization approaches for growth and yield enhancement.
- More knowledge about micronutrient need and fertilization in problematic soils
- Development of affordable customized fertilizers for micronutrient application.

- Application of genetic engineering approaches, collaboration between plant breeders, molecular biologists and nutrition scientists is essential for biofortification to be a successful venture.

Conclusion

Biofortification is an emerging intervention adopted to tackle the underlying problem of global malnutrition by enhancing the concentration of available vitamins and nutrients in food crops already consumed by those suffering from hidden hunger. It is a feasible means of reaching malnourished populations in rural areas by delivering naturally fortified foods to people with limited access to commercially-marketed fortified foods. When eaten regularly, these micronutrient-rich foods work to contribute to body stores of micronutrients, reducing hidden hunger in malnourished communities. Biofortification was mainly targeted on the staple crops which the poor households usually grow and eat. But it has been extended to other non- staple crops including fruits and vegetables in order to benefit greater number of people worldwide. Considering the enormous number of undernourished population, it has become an additional breeding objective in recent years. Application of genetic engineering approaches, collaboration between plant breeders, molecular biologists and nutrition scientists is essential for biofortification to be a successful venture. Therefore, major resources should be allocated to biofortification programmes to encourage the researchers working on the enhancement of nutritional values of food crops in order to maintain the food and nutritional security of the world as a whole.

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Cultivating Abundance: Multi-Layer Farming for the Modern Small Farm

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Multi-layer vegetable farming is a smart, intensive way for small farmers to grow more and earn more. This technique involves carefully arranging different vegetable crops, considering their height, light needs, and growth times, all on the same piece of land. It's about making the most of every inch of space, sunlight, water, and nutrients. For small farms, especially in places like Bihar, India, where land is often limited, this method can significantly increase yields from a small area. It also helps farmers diversify their income, reduce the risk of crop failure, and use resources more efficiently.

Keywords: Multi-layer vegetable farming, small farmers, profitability, sustainable agriculture, vegetable cultivation, crop diversification, resource optimization

Small-scale farmers are the backbone of Indian agricultural production in many regions of India, including Bihar. However, they often grapple with challenges like fragmented landholdings, limited resources, market volatility for single crops, and the impacts of climate change. Traditional monoculture systems for vegetables may not always yield sufficient returns to ensure a prosperous livelihood. Multi-layer vegetable farming presents an innovative and intensive solution, allowing farmers to grow more food and generate higher income from the same piece of land by intelligently utilizing vertical space and creating synergistic plant communities. This method, if implemented effectively, can transform small vegetable farms into highly productive and profitable ventures.

Principles of Multi-Layer Vegetable Farming

The success of multi-layer vegetable farming hinges on understanding and applying ecological principles to crop selection and arrangement:

1. Canopy Architecture and Light Interception: Different vegetable crops have varying needs for sunlight. Taller, sun-loving vegetables (e.g., staked tomatoes, pole beans, some gourds on trellises) form the upper layers, allowing filtered light to reach medium-height, partial-shade tolerant vegetables (e.g., capsicum, chili, okra, brinjal) and ground-level, shade-tolerant leafy greens (e.g., spinach, coriander, lettuce, amaranth) or root crops (e.g., radish, carrots, beetroot, onions, garlic).
2. Root System Stratification: Selecting vegetables with different root depths (deep-rooted, medium-rooted, shallow-rooted) minimizes competition for soil nutrients and moisture. For instance, tomatoes can have deeper roots compared to shallow-rooted leafy greens.
3. Growth Habits and Stature: Combining plants with diverse growth habits-climbers, bushes, spreaders, and erect plants-maximizes spatial utilization. For example, climbing gourds (bitter gourd, bottle gourd, ridge gourd) can be trained on trellises or bamboo structures.
4. Maturity Cycles and Continuous Harvesting: Integrating short-duration vegetables with medium or long-duration ones ensures a continuous harvest and regular income flow, reducing the farmer's reliance on a single harvest period.
5. Companion Planting Benefits: Certain vegetable combinations can offer mutual benefits, such as deterring pests, improving soil fertility (e.g., legumes fixing nitrogen), or enhancing growth, though this requires careful selection.

Benefits for Small Vegetable Farmers

Adopting a multi-layer system for vegetable cultivation can bring numerous advantages:

- **Increased Yield and Higher Income:** This is the most significant benefit. By growing multiple vegetable crops simultaneously in the same space, the total yield per unit area can be increased manifold (often 3-5 times or more compared to monocropping), leading to substantially higher profits.

A View of Multilayer Vegetable Cultivation at Farmer field

Diversified Produce and Reduced Market Risk: Cultivating a variety of vegetables reduces the economic risk if one particular crop faces low market prices or fails due to pests or diseases. This diversification provides a more stable income.

- **Optimal Resource Utilization:**
  - **Land:** Vertical expansion effectively increases the cultivable area on a small plot.
  - **Water:** The dense plant cover reduces soil moisture evaporation, leading to more efficient water use and potentially lower irrigation costs. Some studies suggest water savings of up to 30-50%.
  - **Fertilizers:** Nutrients are utilized more efficiently as different plants have different requirements and rooting patterns. The same amount of fertilizer applied can benefit multiple crops.
  - **Sunlight:** Efficient light harvesting by different canopy layers.
- **Improved Soil Health:** Continuous crop cover protects the soil from erosion. The decomposition of diverse plant residues adds organic matter, improving soil structure, fertility, and water-holding capacity.
- **Weed Suppression:** The dense canopy created by multiple vegetable layers significantly reduces sunlight penetration to the soil surface, thereby suppressing weed growth and reducing the need for manual weeding or herbicides.
- **Pest and Disease Management:** Increased biodiversity can create a more balanced ecosystem, potentially reducing the buildup of specific pests and diseases that often plague monocultures. Some plants can act as repellents for certain pests.
- **Year-Round Production and Employment:** Staggered planting and harvesting of different vegetables ensure continuous farm activity and income throughout the year.
- **Enhanced Household Nutrition**: Access to a variety of fresh vegetables improves the nutritional security of the farmer's family.

Cultivation of Multilayer Vegetables at Farmers Field

Suitable Vegetable Combinations for Multi-Layer Systems

The choice of vegetables depends on local agro-climatic conditions (relevant for Bihar), market demand, and farmer preference. Here are some illustrative models:

- **Model 1 (Gourds, Leafy Greens, Root Crops):**
  - **Top Layer (on trellis/support):** Bitter gourd, Bottle gourd, Ridge gourd, Cucumber, or Pole beans.
  - **Middle Layer:** Bushy plants like Okra, Chili, Capsicum, or Brinjal (Eggplant).
  - **Ground Layer:** Leafy vegetables like Spinach (Palak), Coriander (Dhania), Fenugreek (Methi), Amaranth (Chaulai), or root crops like Radish, Turnip, Onion, Garlic.
  - **Underground:** Ginger or Turmeric (can also be a primary crop with shade-providing layers above).
- **Model 2 (Tomato-based system):**
  - **Top Layer:** Staked Tomatoes or trailing varieties on trellises.
  - **Middle Layer:** Capsicum, Chili.
  - **Ground Layer:** Lettuce, Spinach, Radish, Onion.
- **Model 3 (Fruit-bearing vegetables with shorter crops):**
  - Main Crop (medium height): Brinjal or Okra.
  - Intercrop (ground cover/short duration): Coriander, Spinach, Fenugreek, Radish (harvested before the main crop fully shades them).
- **Specific Examples from Indian Context (relevant for Bihar):**
  - Bitter gourd + Cowpea + Elephant foot yam
  - Pointed gourd + Okra + Cucumber (or Amaranth)
  - Turmeric/Ginger (main underground crop) + Leafy vegetables (short duration surface crop) + Papaya (widely spaced taller crop providing light shade).

Harvesting of fresh vegetables under Multi-Layer Farmers

Economic Viability: A Profitable Venture

Multi-layer vegetable farming has demonstrated significant economic benefits for smallholders. The key drivers of profitability include:

- **Higher Output Value:** The combined value of multiple harvests from the same land far exceeds that of a single crop.
- **Reduced Per-Unit Production Cost:** While initial setup for trellises might be an expense, the cost of land preparation, irrigation, and fertilization is spread across multiple crops, reducing the cost per kilogram of produce.

- **Continuous Cash Flow:** Regular harvests provide a steady income stream, improving the farmer's financial stability and reducing dependence on seasonal earnings.
- **Premium for Diverse/Off-Season Produce:** Ability to supply a variety of vegetables, potentially including some during lean periods, can fetch better market prices.

For instance, farmers in various parts of India practicing 3-to-5-layer vegetable systems have reported net profits increasing by 250% to 500% compared to conventional single-crop farming on the same land area. An initial investment for structures (e.g., bamboo trellises etc.) can range from ₹50,000 to ₹80,000 per acre but can last for several years and the returns often justify this cost within the first year or two.

Summary

Multi-layer vegetable farming stands out as a highly promising and profitable agricultural system for small farmers, especially in land-scarce regions like Bihar. By embracing the principles of vertical space utilization and crop synergism, farmers can significantly increase their yields, diversify income, reduce risks, and practice more sustainable agriculture. While it demands careful planning, skill, and initial effort, the substantial economic returns and enhanced livelihood security make it a worthy endeavour. With appropriate technical guidance, access to quality inputs, and supportive market linkages, multi-layer vegetable farming can empower smallholders to transform their agricultural practices and achieve greater prosperity.

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Role of Meghdoot and Damini in Modernizing Indian Agriculture and Advancing Disaster Preparedness

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Introduction

Timely and accessible weather-related information plays a crucial role in enhancing agricultural productivity and ensuring public safety, particularly in regions vulnerable to weather extremities. In India, the Meghdoot and Damini mobile applications address these needs by leveraging advancements in technology and meteorological science. Meghdoot, a collaborative initiative by the India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM), and Indian Council of Agricultural Research (ICAR), delivers location-specific, weather-based agro-advisories to farmers in vernacular languages. These advisories, issued twice weekly, cover essential aspects of crop and livestock management, enabling farmers to make informed decisions regarding sowing, irrigation, pest control, and harvesting, thereby mitigating production risks and potentially increasing yields. Research has demonstrated positive user responses and observed benefits for farmers using Meghdoot, highlighting its effectiveness in enhancing farming practices.

Complementing Meghdoot's agricultural focus, the Damini app, developed by IITM-Pune and ESSO (Ministry of Earth Sciences), provides crucial, real-time alerts on lightning activity. This application monitors lightning strikes across India and notifies users via GPS notifications about impending lightning within a 20-40km radius, offering valuable warnings up to 30-45 minutes in advance. The app also includes safety instructions and precautions, contributing to a significant reduction in lightning-related casualties across the country. Research suggests that Damini's effectiveness in early warning dissemination, coupled with public awareness campaigns, is vital for mitigating the impacts of thunderstorms and lightning events.

Together, the Meghdoot and Damini applications represent significant advancements in leveraging digital platforms for climate and disaster resilience in India. While Meghdoot empowers farmers with informed agricultural decision-making, Damini enhances public safety during lightning events. Both applications underscore the importance of continuous development, user engagement, and collaboration between scientific institutions and communities to optimize their impact and promote sustainable development.

The Meghdoot and Damini mobile applications are pivotal digital initiatives in India aimed at enhancing weather and disaster preparedness, particularly within the agricultural sector and for public safety. Launched by the Ministry of Earth Sciences and developed through collaborations involving agencies like the Indian Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM), and Indian Council of Agricultural Research (ICAR), these apps represent a significant step towards leveraging technology for weather-related information dissemination and risk mitigation.

A. Meghdoot app

The Meghdoot app is a mobile application developed by the India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM), and Indian Council of Agricultural Research (ICAR) to provide farmers with location-specific, weather-based agricultural advisories. It delivers information about weather forecasts, including temperature, rainfall, wind, and humidity, along with agromet advisories tailored to the farmer's district and crop.

Here's a more detailed explanation:

- **Purpose:**

Meghdoot aims to empower farmers with timely and relevant weather information to make informed decisions about their agricultural practices.

- **Content:**

The app provides observed and forecast weather information, including temperature, rainfall, wind direction, and humidity. It also offers agromet advisories, which are recommendations for farmers based on the weather conditions and their specific crops.

- **Accessibility:**

The app is designed to be user-friendly and is available in multiple languages, making it accessible to a wide range of farmers.

- **Delivery:**

The advisories are issued twice a week (Tuesday and Friday) by Agro Met Field Units (AMFU) and are delivered directly to the farmer's fingertips through the app.

- **Integration:**

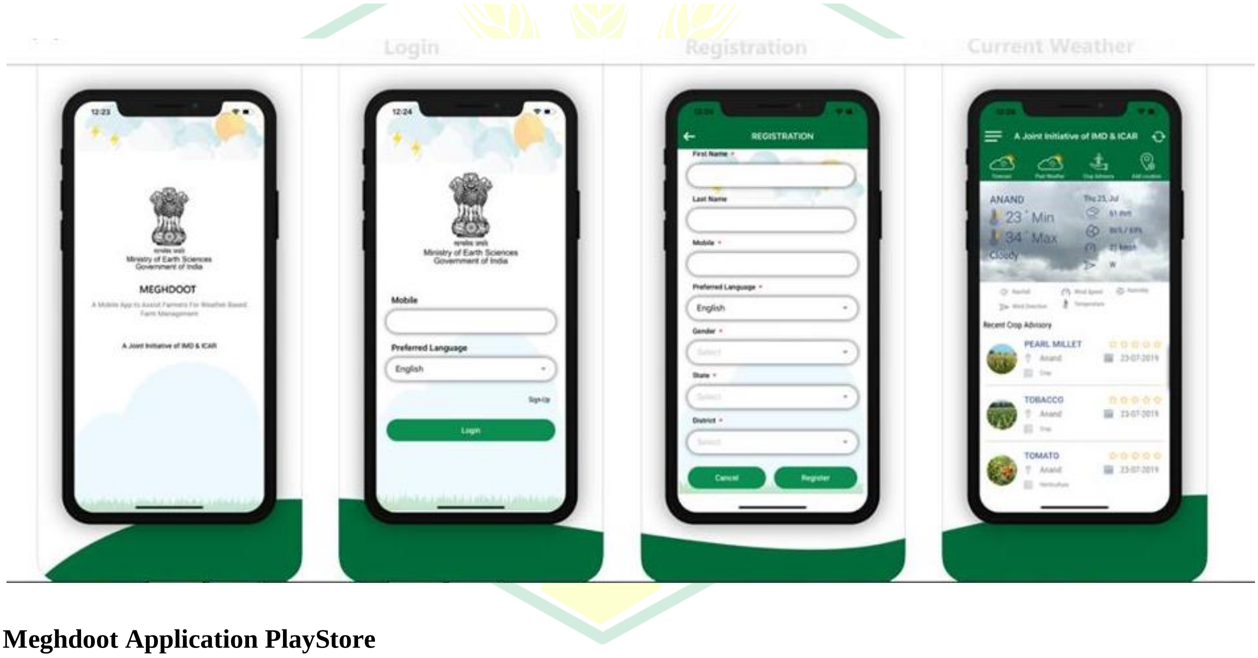
The app is a joint initiative of IMD, IITM, and ICAR, and it aggregates information from various sources, including historical weather data and forecasts, to provide a comprehensive picture to the user.

- **Target Audience:**

The primary target audience is farmers, and the app is designed to be a valuable tool for them to manage their crops and agricultural activities effectively.

- **Availability:**

The app is available for download on both Android and iOS platforms.



Meghdoot Application PlayStore

B. Damini app

The Damini app is a mobile application developed by IITM-Pune and ESSO to monitor lightning activity in India and provide alerts to users based on their location. It offers real-time lightning strike information, potentially helping users take precautions to avoid lightning hazards.

Here's a more detailed breakdown:

Functionality:

- **Real-time Lightning Monitoring:**

The app tracks and displays lightning strikes across India, providing users with a visual representation of lightning activity.

- **Location-Based Alerts:**

Damini utilizes the user's GPS location to send alerts when lightning is detected within a specified radius (e.g., 20km or 40km).

- **Safety Instructions:**

The app includes safety guidelines and precautions for various situations, especially during lightning-prone periods.

Purpose:

- **Early Warning System:**

The primary goal is to provide advance warning of impending lightning activity, allowing individuals to take necessary safety measures and potentially prevent injuries or fatalities.

- **Public Awareness:**

By providing timely information, the app aims to raise awareness about lightning hazards and promote safer practices during thunderstorms.

- **Disaster Management:**

The app contributes to disaster preparedness and management efforts by helping users anticipate and mitigate the risks associated with lightning strikes.

Availability:

- The Damini app is available for download on both Google Play and the App Store.

Conclusion

Both Meghdoot and Damini have been the subject of research and evaluation, demonstrating their potential to empower communities with timely and relevant weather-related information. While Meghdoot plays a crucial role in supporting farmers' livelihoods and crop management, Damini contributes significantly to public safety by providing crucial lightning alerts. Ongoing research continues to explore ways to further optimize their functionalities, improve user adoption, and maximize their overall impact on weather-related decision-making and disaster preparedness in India.

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Weather Parameters and Their Impact on Pests of Agronomic Crops

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Abstract

Weather parameters such as temperature, rainfall, humidity, solar radiation, and wind play a crucial role in determining the population dynamics, distribution, and outbreak patterns of insect pests in agronomic crops. As climate variability increases under global change, understanding the specific influence of these abiotic factors on pest biology and ecology is critical for sustainable pest management. This review synthesizes recent findings on how major weather variables affect key insect pests of cereal, legume, oilseed, and vegetable crops. It also highlights the importance of integrating weather-based pest forecasting models into integrated pest management (IPM) systems for climate-resilient agriculture.

1. Introduction

Agronomic crops form the backbone of global food security, but their productivity is heavily threatened by insect pests. Pest outbreaks are often closely tied to prevailing weather conditions, which affect their development, survival, reproduction, migration, and interactions with host plants. With increasing weather variability and extreme events, the need to understand and predict pest behavior under different weather scenarios is more urgent than ever. This review explores the major weather parameters influencing pest populations and their implications for crop protection.

2. Temperature and Its Influence on Pest Biology

Temperature is one of the most critical environmental factors affecting insect physiology due to their poikilothermic nature. Key effects include:

- **Development Rate**: Higher temperatures generally speed up insect metabolism, reducing generation time and increasing the number of generations per season (voltinism). For example, *Spodoptera frugiperda* and *Helicoverpa armigera* can complete more life cycles under warmer conditions.
- **Geographical Expansion**: Warmer temperatures enable pests to expand into higher latitudes and altitudes.
- **Mortality and Survival**: While moderate warming favors pest survival, extreme heat may exceed lethal thresholds. Overwintering survival is also increased in warmer winters **Example**: *Sitophilus oryzae* (rice weevil) shows optimal development at 27–32°C but suffers increased mortality above 38°C.

3. Rainfall and Moisture Regimes

Rainfall affects pest populations directly and indirectly:

- **Direct Impact**: Heavy rainfall can wash away small-bodied insects (e.g., aphids, whiteflies) and eggs from plant surfaces.
- **Humidity and Fungal Pathogens**: High humidity can increase pest mortality by promoting entomopathogenic fungi.
- **Crop Canopy Microclimate**: Moist environments favor pests like *Spodoptera litura* and *Plutella xylostella*.

However, prolonged dry spells also aid some pests (e.g., *Tuta absoluta*, red spider mites) due to reduced natural enemy activity and weakened host plants.

4. Relative Humidity

Humidity modulates insect physiology and behavior:

- **Reproductive Potential**: High humidity can improve egg hatching and larval survival
- **Dispersal Behavior**: Low humidity may trigger pest migration.
- **Outbreak Potential**: Many sucking pests such as aphids and thrips thrive in high humidity conditions.

Example: *Bemisia tabaci* populations flourish under 60–80% RH, especially when combined with warm temperatures.

5. Wind and Pest Dispersal

Wind acts as a major agent for long-distance dispersal of migratory pests:

- **Migration**: Species like *Helicoverpa armigera*, *Spodoptera frugiperda*, and *Nilaparvata lugens* (brown planthopper) rely on wind currents for seasonal migration.
- **Distribution Patterns**: Wind can also affect horizontal spread across agricultural landscapes

High-speed winds can also reduce pest populations by disrupting their flight or damaging host plants.

6. Solar Radiation and Photoperiod

- **Behavioral Regulation**: Solar intensity influences the activity patterns of many diurnal and nocturnal insects
- **Photoperiodism**: Critical for diapause induction, especially in pests like the cotton bollworm **Plant Physiology**: Changes in solar radiation affect plant metabolism and nutrient composition, indirectly influencing pest feeding behavior.

7. Combined Effects and Weather Extremes

Weather parameters do not act in isolation. Extreme events such as heatwaves, droughts, and unseasonal rains create synergistic effects:

- **Heatwaves** can trigger premature pest emergence or disrupt natural enemy cycles
- **Floods and droughts** alter pest-host dynamics, often leading to outbreaks after recovery
- **Examples of Complex Interactions**:
  - Drought-stressed plants may accumulate nitrogen, attracting pests like aphids Unseasonal rains may reduce pest control efficacy by washing off pesticides

8. Pest Forecasting and Weather-Based IPM

Incorporating weather data into pest forecasting tools is a proactive step toward reducing pesticide use and crop losses:

- **Degree-Day Models**: Help estimate pest emergence and critical development stages
- **Remote Sensing and GIS**: Aid in monitoring and predicting pest outbreaks over large areas
- **Early Warning Systems**: Programs like FAO's FAMEWS for fall armyworm and India's NCIPM pest advisories provide weather-linked pest alerts.

9. Conclusion

Weather parameters profoundly shape the ecology of insect pests in agronomic crops. As climate variability increases, understanding these relationships is vital for forecasting outbreaks and implementing sustainable pest control strategies. Integrating meteorological data into crop protection planning, supported by real-time forecasting tools, will be critical for resilient agronomy in the face of climate change.

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A New Era in Poultry Nutrition: The Promise of Postbiotics

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Introduction:

Once hailed as miracle drugs, antibiotics transformed modern medicine but their overuse has sparked a global race for safer, smarter alternatives like probiotics, prebiotics, synbiotics and postbiotics. Antibiotic overuse in animal agriculture has led to rising concerns about antimicrobial resistance and harmful residues in meat (Ma *et al*., 2021).

Postbiotics, defined as non-viable microbes or their metabolites that provide health benefits, are gaining attention as a safer and more stable alternative to probiotics and antibiotics (Salminen *et al*., 2021). They enhance poultry growth, immunity, and gut health by supporting beneficial gut microbiota, boosting nutrient absorption, and producing antimicrobial compounds like organic acids and peptides. Studies have shown that Lactobacillus plantarum and similar strains can effectively replace antibiotic growth promoters in broiler diets (Chang *et al.*, 2022). Moreover, postbiotics remain active during processing and storage, unlike live probiotics, making them ideal for commercial use. Postbiotics represent a scientifically backed, stable, and safe feed additive that supports poultry performance while addressing public health and food safety concerns.

Components and Functions of Postbiotics: Key components include:

Exopolysaccharides (EPS): Produced by lactic acid bacteria, composed of sugars like glucose, galactose, etc. Exhibit immune-boosting, antibacterial, antioxidant, and anti-inflammatory properties. EPS like β-glucans activate macrophages, aiding in pathogen and cancer defense. These are used as emulsifiers and stabilizers.

Short Chain Fatty Acids (SCFAs): Includes acetate, propionate, butyrate from fiber fermentation. Acetate affects appetite, propionate regulates immune genes and inhibits cholesterol; **butyrate** aids gut repair and lowers inflammation.

Enzymes: Microbial enzymes (e.g., amylase, protease) support nutrient digestion and antioxidant defense. Examples: *L. plantarum*, *L. fermentum* boost antioxidant enzymes like glutathione peroxidase and catalase, useful in prevention of tumors.

Cell-Free Supernatants (CFSs): Contain antimicrobial and anti-inflammatory metabolites (e.g., bacteriocins). Stimulate immune responses, reduce oxidative stress, and offer protection against infections .

Cell Wall Fragments: Include **lipoteichoic acid (LTA)** and peptidoglycans. Act as immune modulators via interaction with host immune receptors. Helps to maintain gut barrier function, though excessive LTA may trigger inflammation, requiring safety evaluation.

Effect of postbiotics on gut health

Postbiotics play a significant role in enhancing intestinal barrier function by promoting mucus secretion from goblet cells, stimulating the release of antimicrobial peptides from Paneth cells, regulating tight junction protein synthesis, and preventing epithelial cell apoptosis. They also modulate the immune system by inducing immunoglobulin A secretion and interacting with gut-associated lymphoid tissue to maintain immune homeostasis, thereby preventing excessive inflammation. Postbiotics exhibit anti-inflammatory effects by reducing pro-inflammatory cytokines like TNF-α and increasing anti-inflammatory mediators, which helps preserve intestinal barrier integrity. For example, fatty acids produced by *Bacteroides thetaiotaomicron* and *Lactobacillus johnsonii* reduce inflammation in colitis models and enhance antifungal activity. These effects contribute to improved intestinal morphology, such as increased villus height and crypt depth, supporting better nutrient absorption and overall gut health.

Immunological Response of Postbiotics

Postbiotics-non-viable microbial products or metabolites, exhibit strong immunomodulatory properties. They upregulate anti-inflammatory cytokines like IL-10, improve T-reg cell responses, and enhance both innate and adaptive immunity. Components like lipoteichoic acid (LTA) and peptidoglycan from cell walls modulate cytokine production, shifting immune balance towards Th1 dominance (Teame *et al*., 2020). Additionally, postbiotics from Streptococcus thermophilus and Lactiplantibacillus plantarum improve IgA/IgM levels, growth hormone expression, and disease resistance in poultry.

Mechanism of action of Postbiotics:

1. Modulating gut microbiota (quorum sensing inhibition),
2. Strengthening intestinal barrier (via SCFAs),
3. Triggering immune responses through pattern recognition receptors (PRRs),
4. Altering systemic metabolism (via microbial enzymes and bile acids),
5. Neuroimmune signaling through serotonin release.

Postbiotics also offer antimicrobial, antioxidant, anti-inflammatory, anticancer, and cholesterol-lowering properties. Bacteriocins from postbiotics inhibit pathogens and may serve in food preservation and pharmaceuticals (Simons *et al*., 2020). Lactobacillus plantarum strains have shown effectiveness across species including broilers, pigs, and rodents.

Compared to probiotics, postbiotics are more stable, not sensitive to heat or oxygen, and have a longer shelf life making them suitable for regions without cold chains. As part of a broader biotic strategy including prebiotics, probiotics, and synbiotics, postbiotics stand out as a safe, efficient, and shelf-stable alternative to antibiotics in animal production. Postbiotics: Promising Effects in Livestock and Poultry.

Promising Effects on Other Animals

Postbiotics have demonstrated significant benefits across various animal species. In lambs, supplementation improved weight gain, feed intake, nutrient digestibility, antioxidant activity, and immune markers, while reducing harmful rumen microbes and enhancing beneficial ones (Izuddin *et al*., 2020). In rats, LAB metabolites increased growth and beneficial gut bacteria, though taste may reduce water intake suggesting powder formulation as preferable. In mice, postbiotic-treated L. casei showed anti-carcinogenic properties. In piglets, L. plantarum metabolites improved growth, gut health, protein digestibility, and reduced diarrhea.

In the poultry industry, postbiotics have improved growth performance, immunity, gut morphology, and egg quality. L. plantarum-based postbiotics helped broilers under heat stress and reduced yolk cholesterol in layers (Humam *et al*., 2019). In broilers, combinations with inulin enhanced feed efficiency, GHR expression, and gut structure. Postbiotics improved immune responses and reduced intestinal pathogens and mortality (Abd El-Ghany *et al.*, 2022). Other notable outcomes include reduced serum cholesterol and fat, improved meat quality, and effective AGP replacement in quails. In layers, S. cerevisiae-based postbiotics helped reduce Salmonella Enteritidis, enhancing food safety (Gingerich *et al*., 2021).

Beneficial Effects of Postbiotics on Meat and Egg Quality

Postbiotics have emerged as effective, natural alternatives to antibiotics in poultry, enhancing meat and egg quality while supporting antibiotic-free production. They improve poultry health and product safety, supporting global food security (Reuben *et al*., 2021).

Postbiotics reduce plasma cholesterol levels in eggs and improve breast meat quality by lowering shear force and increasing pH, especially under heat stress (Humam *et al*., 2019). L. plantarum metabolites enhanced both meat quality and cholesterol profiles in broilers. Postbiotics combined with inulin showed better meat quality than antibiotics.

In laying hens, postbiotic metabolites from L. plantarum increased hen-day egg production and improved overall egg quality. These effects make postbiotics a promising tool to meet the rising global demand for safe, high-quality poultry products (Hussein *et al.*, 2020).

Conclusion

Postbiotics represent a safe, stable, and effective alternative to antibiotics in animal agriculture, particularly in poultry production. They enhance gut health, immunity, growth performance, and product quality, including meat and eggs, while addressing concerns over antibiotic resistance and food safety. Their diverse bioactive components contribute to improved intestinal barrier function, immune modulation, and antimicrobial activity. With proven benefits across multiple animal species and superior stability compared to probiotics, postbiotics offer a promising solution to sustainably meet the increasing global demand for safe and high-quality animal-derived foods.

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Climate Smart Agriculture: A Pathway Towards Sustainable and Profitable Farming in Karnataka

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Abstract

Climate change has become one of the biggest challenges for agriculture in India, particularly in drought-prone states like Karnataka. Irregular rainfall, rising temperatures, and frequent extreme weather events are affecting crop productivity and farm incomes. In this situation, Climate Smart Agriculture (CSA) offers a practical and sustainable approach to address these issues. This article highlights the importance of CSA, its key components and benefits. Despite its potential, the adoption of CSA faces challenges like low awareness, high initial costs, and limited extension support. The article concludes by suggesting policy recommendations to promote CSA in Karnataka, aiming to make farming systems more resilient, sustainable, and profitable for rural communities in the state.

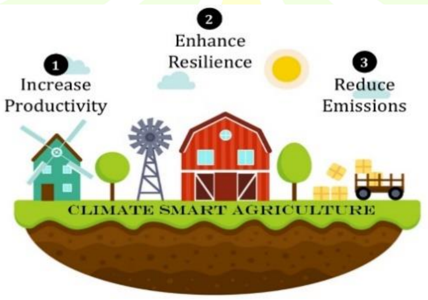
Keywords: Climate Smart Agriculture, Farm Risk Management, Sustainable Farming

Introduction

Agriculture is not just the backbone of India's economy but also a way of life for millions of people in rural areas. In Karnataka, agriculture plays a crucial role in providing livelihoods and ensuring food security. However, the sector is increasingly facing challenges due to climate change. Irregular rainfall, rising temperatures, droughts, and floods are making farming risky and less profitable. In this situation, Climate Smart Agriculture (CSA) is emerging as an important approach to make agriculture more resilient, sustainable, and profitable.

Climate Smart Agriculture is an integrated method to manage landscapes—cropland, livestock, forests, and fisheries—in such a way that it helps achieve three main goals:

1. Increase agricultural productivity.
2. Improve resilience to climate risks.
3. Reduce greenhouse gas emissions wherever possible.



This article highlights the importance of CSA, its components, benefits, challenges, and policy support needed in the context of Karnataka's agriculture.

Why Climate Smart Agriculture is Important for Karnataka

Karnataka is a drought-prone state where nearly 70% of cultivated area depends on rainfall. In recent years, the state has faced both severe droughts and floods in different regions, affecting crops, livestock, and the incomes of farmers. According to government data, over 54% of the geographical area in Karnataka is vulnerable to drought. Erratic monsoons, water scarcity, soil degradation, and increased pest attacks are major problems for farmers.

Climate change is expected to further worsen the situation in the coming decades. Crops like paddy, ragi, maize, and pulses are sensitive to changing weather conditions. A decline in crop yields can lead to food insecurity and distress among farming communities. Therefore, adopting CSA practices is no longer optional but necessary for safeguarding the livelihoods of farmers and achieving long-term sustainability.

Components of Climate Smart Agriculture

CSA is not a single technology or practice but a combination of different strategies tailored to local conditions. The main components of CSA include:

1. Climate Resilient Crop Varieties: Development and promotion of drought-tolerant, flood-tolerant, and heat-resistant crop varieties can help maintain productivity even under extreme weather conditions.
2. Water-Smart Practices: Use of micro-irrigation systems like drip and sprinkler, rainwater harvesting, farm ponds, and improved water management practices reduce water wastage and increase water-use efficiency.
3. Soil Health Management: Practices like integrated nutrient management (INM), organic farming, mulching, and reduced tillage improve soil fertility and moisture retention, helping crops withstand climate stresses.
4. Agroforestry: Integrating trees with crops and livestock provides shade, reduces soil erosion, improves soil fertility, and offers additional income through timber, fodder, and fruits.
5. Livestock Management: Improved feeding, breeding, shelter, and healthcare services for livestock can help reduce animal deaths and increase productivity during adverse climate events.
6. Diversification of Farm Activities: Combining agriculture with allied activities like dairy, poultry, fisheries, and horticulture helps spread risk and ensures stable income for farmers.
7. Use of ICT Tools and Early Warning Systems: Mobile apps, weather advisories, market information systems, and crop insurance services help farmers take timely decisions and reduce risks.

Benefits of Climate Smart Agriculture

CSA offers several benefits for farmers, the environment, and the economy:

- Enhanced Productivity: By using improved seeds, better water management, and good agronomic practices, farmers can achieve higher yields even in challenging conditions.
- Risk Reduction: Adoption of drought-tolerant crops, soil conservation methods, and livestock shelters protects farmers from losses during droughts and floods.
- Environmental Protection: CSA reduces greenhouse gas emissions by promoting renewable energy, reducing the use of chemical fertilizers, and improving carbon sequestration through agroforestry and organic farming.
- Improved Livelihoods: Diversification of farm activities and value addition increases income and employment opportunities in rural areas.
- Better Resource Use Efficiency: Technologies like drip irrigation and precision farming optimize the use of water, fertilizers, and pesticides, reducing wastage and production costs.

Challenges in Adopting Climate Smart Agriculture

Despite its advantages, CSA adoption in Karnataka faces several barriers:

- Limited Awareness: Many farmers, especially small and marginal farmers, are not aware of CSA practices and their benefits.

• High Initial Investment: Technologies like drip irrigation, solar pumps, and weather stations require significant upfront costs, making it difficult for poor farmers to adopt them.

• Lack of Technical Support: Inadequate extension services and shortage of trained manpower limit the dissemination of climate-smart technologies.

• Institutional and Policy Gaps: Absence of region-specific CSA policies and financial incentives discourages farmers from adopting sustainable practices.

• Market Risks: Even if farmers adopt CSA, they often face problems in marketing their produce and getting fair prices, which affects the overall profitability.

Policy Recommendations for Promoting CSA in Karnataka

For the effective implementation of CSA, strong policy support is necessary. The following measures can help scale up CSA in the state:

1. Awareness and Capacity Building: Organize training programmes, farmer field schools, and demonstration plots to educate farmers about CSA technologies.
2. Financial Assistance and Subsidies: Provide subsidies for micro-irrigation, solar pumps, and climate-resilient seeds, especially for small and marginal farmers.
3. Strengthening Extension Services: Recruit and train more agricultural officers, Krishi Vigyan Kendra (KVK) staff, and NGO workers to guide farmers in adopting CSA practices.
4. Developing Market Linkages: Support farmers in marketing climate-smart products through Farmer Producer Organizations (FPOs), online platforms, and contract farming arrangements.
5. Promoting Climate-Responsive Insurance: Expand the coverage and efficiency of crop insurance schemes like Pradhan Mantri Fasal Bima Yojana (PMFBY) to protect farmers against climate risks.
6. Research and Development: Encourage agricultural universities and research institutions and innovative farmers to develop new climate-resilient crop varieties and farming techniques.

Conclusion

Climate Smart Agriculture is a promising pathway for making Karnataka's agriculture more resilient, sustainable, and profitable in the face of climate change. It offers practical solutions to address the challenges of water scarcity, soil degradation, crop failure, and livelihood insecurity. However, its success depends on creating awareness, providing financial support, improving extension services, and ensuring strong policy backing.

For Karnataka, which has a rich tradition of farming but is highly vulnerable to climate risks, CSA is not just an option but a necessity. Agricultural economists, policymakers, extension officers, and farmers must work together to promote and adopt climate-smart practices for securing the future of farming and rural livelihoods in the state.

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Water Apple: A Potential Fruit And An Alternative to Apple

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Introduction:

Water apple *Syzygium aqueum*, a tropical fruit belonging to the *Myrtaceae* family, is gaining attention for its potential health-promoting properties. Traditionally consumed for its refreshing taste and hydrating effects, water apple is now being studied for its rich phytochemical and dietary fibre content, making it a promising candidate in functional food and nutraceutical applications.

Water apples, also known as rose apples, are rich in water and low in calories, fats, and carbohydrates. They contain various nutrients including vitamins (like Vitamin C and A), minerals (like calcium, iron, magnesium, and potassium), and antioxidants. Specifically, they are known for their high water content and low fat and calorie count, making them a healthy snack option.

Nutritional Breakdown (per 100g serving, approximate):

- **Water:** 93g
- **Carbohydrates:** 5.7g (including 1.5g dietary fiber)
- **Protein:** 0.6g
- **Fat:** 0.3g
- **Vitamin C:** 156mg
- **Vitamin A:** 22mg
- **Calcium:** 29mg
- **Potassium:** 123mg

From a biochemical standpoint, water apple is a reservoir of bioactive compounds including polyphenols, flavonoids, tannins, and alkaloids**,** which exhibit antioxidant, anti-inflammatory, and antidiabetic effects. Notably, its dietary fibre fraction, both soluble and insoluble, plays a crucial role in modulating glycemic response, enhancing gut health**,** and improving lipid metabolism. In India, it is most likely to occur in moist deciduous forests up to an altitude of 1500 m. It generally grows in warmer parts like Andhra Pradesh, Assam, Orissa, Maharashtra, West Bengal, Punjab, Rajasthan and Tamil Nadu. Watery Rose Apple has many medicinal uses like fever treatment, detoxifies liver, headaches, digestive issues, diabetes, lowers cholesterol levels, skin diseases and prevention against specific types of cancers. The Watery Rose Apple fruit is rich in fibres, calcium, magnesium, potassium and vitamin C.

The fibre matrix of water apple may act as a carrier for various bioactive molecules, influencing their release, bioaccessibility, and physiological actions. Furthermore, the presence of enzymatic inhibitors like alpha-amylase and alpha-glucosidase inhibitors suggests a possible role in glucose regulation and postprandial blood sugar control. Biochemical assays such as DPPH radical scavenging, Folin–Ciocalteu for total phenolics, and fibre composition analysis provide quantifiable insights into these functional constituents.

Pharmaceutical applications of water apple

Antidiabetic Functional Food

The presence of dietary fibre and natural α-amylase and α-glucosidase inhibitors helps regulate postprandial blood glucose levels, making it suitable for diabetic-friendly diets.

Prebiotic and Gut Health Enhancer

The soluble fibre in water apple promote the growth of beneficial gut microbiota, aiding digestion and improving intestinal health through fermentation into short-chain fatty acids (SCFAs).

Antioxidant Therapy

High levels of phenolic compounds and flavonoids contribute to free radical scavenging activity, potentially reducing oxidative stress linked to aging, inflammation, and chronic diseases.

Cardiovascular Protection

Dietary fibre in water apple help in the reduction of LDL cholesterol, improving lipid profiles and lowering the risk of atherosclerosis and heart disease.

Weight Management

Its fibrous matrix increases satiety, delays gastric emptying, and reduces overall caloric intake, supporting obesity prevention strategies.

Natural Ingredient in Nutraceuticals

Can be developed into fibre supplements, capsules, or powders for use in nutraceutical formulations targeting metabolic disorders.

Food Industry Applications

The fibre-rich pulp can be used in functional food formulations like high-fibre biscuits, fruit bars, and dietary fibre-enriched beverages.

Skin and Anti-aging Products (Cosmeceuticals)

The antioxidant-rich extracts have potential in anti-aging creams or serums to combat oxidative skin damage.

Conclusion and future perspectives

Nature has a wide reservoir of compounds that may be used to produce medications against a variety of chronic diseases. A large variety of herbal medications and their ingredients have proven nutraceutical and pharmacological applications. The present review comprehensively discussed the therapeutic and pharmaceutical effects of *S. aqueum* and its active constituents. The plant also has anti aging effects, which are in general, most likely mediated by the antioxidant properties of the plant and its richness of phytoconstituents like polyphenols and flavonoids. The review also suggested that *S. aqueum* has great potential to reap a prime treatment from its bioactive phytoconstituents. Thus, further research is necessary to address the safety pertaining to human health, regarding probiotics as well as formulations for improving potency and stability.

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Vermi Wash: The natural liquid gold and eco-friendly soil conditioner

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Abstract

Vermiwash is the liquid extract obtained from vermicompost in an earthworm-rich medium act as natural liquid gold and eco-friendly soil conditioner. The liquid comprises mainly decomposers like bacteria, mucus, vitamins, various bioavailable minerals, enzymes, and different antimicrobial peptides. The skin of the earthworms secrete many bioactive macromolecules, coelomic fluid, and mucus that help to safeguard the soil microbes against the worm and hence free the environment from the disease. This article aimed at the need for vermiwash, its preparation and utilization on various crops along with the effects of it on major crops to improve their productivity.

Introduction

Despite the first green revolution significantly increasing crop production in India, the widespread application of chemical fertilizers over the years resulted in poor soil health, a decrease in agricultural output, an increase in insect pest and disease situations along environmental pollution.

Organic farming began the second green revolution (Sathe 2004, Sharma 2004). However, the farmers cannot instantly switch entirely to organic farming to feed the country's rapidly growing population. The only solution to this is to pursue sustainable crop production. Utilizing natural substances like composts, sewage sludge, yard waste, food waste, human waste, and animal manure has long been recognized in agriculture as being beneficial for soil fertility conservation and the growth of plants and productivity. Integrating organic materials to soil allows for high microbial populations and activity. They also serve as a great source of nutrients that plants are able to absorb.

Vermiwash is an excellent plant tonic that can be sprinkled on leaves. After the water has passed through the various layers of the worm culture unit, the liquid extract is collected. The decoction includes the earthworm excretory product and the coelomic fluid, which penetrates from the worms' dorsal pores and contains bacteria, vitamins, plant nutrients, and compounds that promote plant growth. Vermiwash is an acronym for this earthworm coelomic fluid.

Preparation of Vermiwash

There are coarse-grained fragments of stone or brick in the base layer. Sand in the following layer helps in water drainage, preserving a moderate level of moisture.Earthworms inoculated with organic soil are found in the middle layer, while cow manure or any other organic waste used as a primary raw material is found in the fourth layer. Decomposed organic matter, such as leaf litter, straw, etc., is an optional raw material that is primarily used to block direct sunlight exposure on the top layer. To avoid dryness and promote the crushing of organic materials, water should be sprinkled regularly. Lastly, pure vermiwash was recovered for the usage.

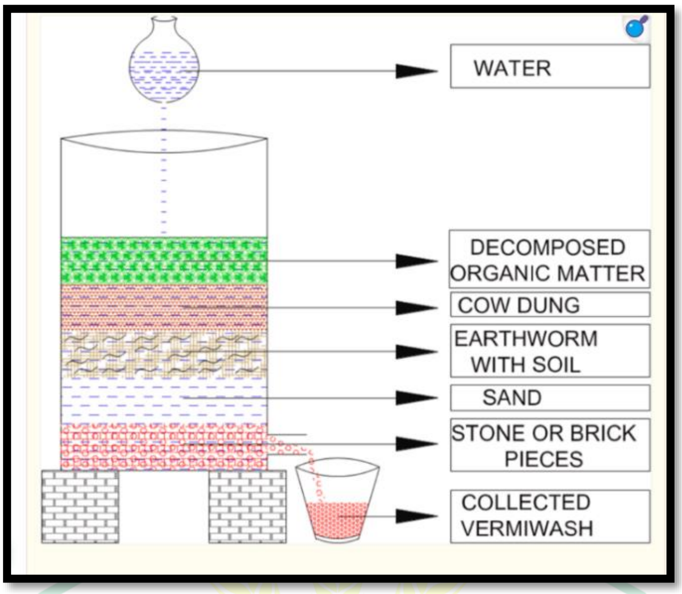
Properties of Vermiwash

- It is a mixture of worm coelomic fluid comprised of growth stimulating hormones like Indole Acetic Acid (IAA), cytokinin, and Gibberellic acid along with some vitamins and essential nutrients.
- It is highly rich in dissolved nutrients and amino acids which are present in available form for plants having non-toxic and ecofriendly properties.
- It is a liquid biofertilizer rich in the primary and secondary nutrients like Nitrogen, Phosphorus, Potassium, Calcium, Zinc, Copper, Iron and Manganese.

Vermiwash serves multiple agricultural purposes such as:

- It acts as a foliar spray to boost plant growth
- Works as a soil conditioner to enhance fertility

- It functions as a natural bio-pesticide for disease control
- It can be used as a root treatment to improve seedling root development.



Composition and Benefits of Vermiwash

Parameters	Content
pH	7.39-7.5
EC	0.008±0.001
Organic carbon	0.25 ± 0.03%
Nitrogen	0.01-0.001%
Phosphorus	1.70%
Potassium	26 ppm
Sodium	8 ppm
Magnesium	160 ppm
Total heterotrophs (cfu/ml)	1.79×10^3
Nitrosomonas (cfu/ml)	1.01×10^3
Nitrobacter (cfu/ml)	1.12×10^3
Total fungi (cfu/ml)	1.46×10^3

Nutrient analysis of Vermiwash, (Source: http//www.erfindia.org/vermiwash.asp)

Effects of Vermiwash

- **On various crops' growth and yield**

  Since ages, earthworms are considered as Farmer's Friend and Vermiwash is the product we get from it. It is an incredible tonic which is ecofriendly, economically enhance the growth and yield of plant. Vermiwash plays a crucial role in soil restoration and environmental conservation. It helps revitalize nutrient-depleted soils by replenishing and expanding the available nutrient pool. Additionally, this liquid extract aids in moisture retention and helps preserve both natural and biological resources.

  It is also considered a natural soil rejuvenation solution. It works to restore the soil's fertility, enhancing its capacity to support plant growth while simultaneously maintaining the ecological balance of the agricultural ecosystem.

- **On enhancing soil properties**

  The usage of vermiwash is not only limited to improving soil fertility and microbial activity but also enhances the accessibility of nutrients to the plants. It is also helpful in root development as sit can easily penetrate if soil properties are better. Liquid vermicompost (vermiwash) is more effective than solid vermicompost because it can quickly reach plant roots and be easily absorbed. When vermicompost is more liquefied, plants can take up its nutrients more readily.

Research has shown that vermiwash and mucus from earthworms (*Eisenia fetida*) can effectively inhibit the growth of *Fusarium graminearum*, a harmful fungus. This inhibition significantly impacts both the quality and production of wheat crops. The liquid form allows for faster and more efficient nutrient and disease-suppressing delivery to plant roots.

- **To reduce insect pests and diseases**
  Vermiwash at 5-10% dilution inhibits the mycelial growth of pathogenic fungi. It is reported that no pathogen can survive in this fluid which can protect the earthworms from the disease caused by pathogen. It helps in enhancing the decomposition by increasing the microbial population into the soil as it provides favourable condition for the microbes It improves the physiochemical properties of the soil such as soil texture , aeration, density and increases the water retention capacity of soil.
- **Increases Plant Disease Resistance:** The beneficial microorganisms in vermiwash protect plants by outcompeting harmful pathogens in the soil. They can also produce natural antibiotics, which help prevent fungal, bacterial, and viral infections, leading to healthier plants.

Overall Impact:

- **Sustainable Agriculture:** Vermiwash supports organic farming practices that promote sustainability by enriching the soil, reducing pollution, and increasing crop yields without harming the environment.
- **Healthier Ecosystems:** By enhancing microbial biodiversity and reducing chemical input, vermiwash contributes to the health of entire ecosystems, from the soil to surrounding wildlife and plant species.
- **Improved Quality of Produce:** As a natural and organic solution, vermiwash helps produce healthier crops that are free from synthetic chemicals, contributing to safer, higher-quality food for consumers.

Recommended Crops

Vermiwash is proven to be beneficial for several crops including cauliflower, bittergourd, cucumbers, melons, squash, leafy greens, flowers and many herbs.

Conclusion

In summary, vermiwash is a valuable liquid containing essential vitamins, plant hormones, enzymes, and both macro and micronutrients. When applied to plants, it promotes healthy and efficient growth. It enhances the soil's physical and chemical characteristics, while also lowering pest infestations. These improvements contribute to better nutrient absorption by plants, leading to improved plant development and increased yield. It is environmental friendly and helpful in sustainable farming practices. It is the result obtained from vermicompost that is applied as a fertilizer by directly incorporating it in the field or as a liquid spray to shield the plant parts from various fungal, and bacterial pathogens and pests, owing to its cellular defence mechanism. . It can be used as an effective input in organic agriculture for both soil health and disease management for sustainable crop production with low cost which could be ensure food security. This article draws special attention to vermiwash preparation, benefits, and how to apply it in the field. Its use in agriculture not only promotes higher yields and healthier plants but also helps protect the planet's resources for future generations.

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Advances in Organic Production Technology of Turmeric

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Introduction:

India is the world's largest producer of turmeric, contributing about 80% of global production. Other significant producers include China, Myanmar, Nigeria, and Bangladesh. Organic turmeric cultivation involves growing turmeric using methods that adhere to organic farming principles, focusing on soil health, natural pest control, and avoiding synthetic pesticides and fertilizers. This approach emphasizes sustainable agriculture practices and minimizes environmental impact. India is the world's largest producer, consumer, and exporter of turmeric. In 2023-24, India's turmeric production was estimated at 10.42 lakh tonnes, with major cultivating states including Maharashtra, Odisha, Tamil Nadu, Madhya Pradesh, West Bengal, and Telangana. The country accounts for approximately 80% of global turmeric production.

Turmeric (*Curcuma longa*) (Family: Zingiberaceae) also known as 'Indian saffron' is used as condiment, dye, drug and cosmetic in addition to its use in religious ceremonies. Turmeric is the dried rhizome of this herbaceous perennial which is native to South Asia particularly India. India is a leading producer and exporter of turmeric in the world. The states of Telangana, Maharashtra, Tamil Nadu, and Andhra Pradesh together contribute 63.4% of India's turmeric production, other important turmeric producers are Orissa, Karnataka, West Bengal, Gujarat, Meghalaya, Assam.

Turmeric enjoys a unique distinction among spices due to its various medicinal properties and versatility. The spice played a great role in the life of ancient people as a wound healer as a medicine for stomach ache, flatulence, poison etc, but recent times, the crop has gained importance of several its documented medicinal properties including its anti cancerous and anti ageing properties and hence find uses in the drug and cosmetic industry.

Organic Cultivation: Organic fcultivation is a method of agriculture that emphasizes ecological balance and sustainability by utilizing natural processes and avoiding synthetic inputs like pesticides and fertilizers. It's chosen for its benefits to the environment, human health, and farm resilience Turmeric as super spice due to its vast array of health properties. But in conventional production there is uncontrolled use of agrochemicals make it inorganic. As we know the consumable part of turmeric is Rhizome. This uncontrollable use of agrochemicals leads to residue stagnation both in soil as well as rhizomes. This is much harmful to health. Exactly reverse was happened in organic farming, as we go for organic manures addition they add organic matter into soil; it leads to nutrient enrichment in soil and by activity of various beneficial soil microbiota turmeric rhizome uptake these nutrients for its development. Hence organically grown turmeric preserves its all-health properties without any adverse effect. Hence best solution is grow only organic turmeric. Prospects of Organic Turmeric If farmers switch towards organic turmeric production; this organic farming offers possibility for Sustainable crop production. Exploiting export opportunities. Meets the domestic and foreign demands. Minimization of cost of production. Provide health benefits and nutritional security. Maintain native soil fertility.

Climate and soil: Turmeric can be grown in diverse tropical conditions from sea level to 1500 m above sea level, at a temperature range of 20-35o C with an annual rainfall of 1500 mm or more, under rainfed or irrigated conditions. Though it can be grown on different types of soils, it thrives best in well-drained red or clay loam soils with a pH range of 4.5-7.5 with good organic status. Soil with good drainage is essential. For certified organic production, at least 18 months the crop should be under organic management i.e. only the second crop of turmeric can be sold as organic. The conversion period may be relaxed if the organic farm is being established on a land where chemicals were not previously used, provided sufficient proof of history of the area is available. It is desirable that organic method of production is followed in the entire farm; but in the case of large extent of area, the transition can be done in a phased manner for which a conversion plan has to be prepared. Turmeric as a best component crop in agri-horti and silvi-horti systems, recycling of farm waste can be effectively done when grown with coconut, arecanut, mango, Leucaena, rubber etc. As a mixed crop it can also be grown or rotated with green manure/ legumes crops or trap crops enabling effective nutrient built up and pest or disease control. When grown in a mixed cultivation system, it is essential that all the crops in the field are also subjected to organic methods of production. In order to avoid contamination of organically cultivated plots from neighboring non-organic farms, a suitable buffer zone with definite border is to be maintained. Crop grown on this isolation belt cannot be treated as organic. In sloppy lands adequate precaution should be taken to avoid the entry of run off water and chemical drift from the neighboring farms. Proper soil and water conservation measures by making conservation pits in the interspaces of beds across the slope have to be followed to minimize the erosion and runoff. Water stagnation has to be avoided in the low lying fields by taking deep trenches for drainage.

- **Land Preparation:**

The land should be well-plowed, and raised beds or ridges and furrows can be prepared to ensure good drainage.

- **Organic Matter:**

Incorporate plenty of organic matter like compost or well-rotted manure to improve soil fertility and structure.

Planting:

- **Rhizomes:**

Healthy, disease-free rhizomes (mother or finger rhizomes) are used for planting.

- **Planting Time:**

In areas with early rainfall, planting can be done during April-May.

- **Spacing:**

Maintain appropriate spacing between plants (e.g., 30cm x 15cm or 45-60cm between rows and 25cm between plants) to allow for healthy growth.

- **Seed Treatment:**

Treat rhizomes with Trichoderma harzianum before planting to protect against fungal diseases.

- **Weeding:**

Regular weeding is essential to prevent competition for nutrients and water.

- **Mulching:**

Mulching with green leaves can help conserve moisture, suppress weeds, and improve soil health.

- **Intercropping:**

Turmeric can be grown as an intercrop with other compatible crops, provided they are also organically grown.

- **Fertilizing:**

Use organic fertilizers like compost, farmyard manure, or green manure to provide nutrients to the crop.

- **Pest and Disease Management:**

Implement natural pest and disease control methods like using neem-based products or introducing beneficial insects.

- **Watering:**

Provide adequate irrigation, especially during dry periods, but avoid waterlogging.

Harvesting and Processing:

- **Harvesting:** The crop is typically harvested 7-10 months after planting when the leaves start to dry.
- **Drying:** The harvested rhizomes are cleaned, boiled, and dried in the sun or using a mechanical dryer.
- **Processing:** Dried rhizomes can be ground into powder or used whole.

Certification:

- **Organic Certification:** To market turmeric as organic, it's crucial to get it certified by a recognized organic certification body.

Benefits of Organic Turmeric Cultivation:

- **Environmental Sustainability:**

Reduces the use of synthetic chemicals, minimizing pollution and soil degradation.

- **Healthier Products:**

Organic turmeric is free from harmful pesticide residues, making it a healthier option.

- **Premium Prices:**

Organic turmeric often fetches a higher price in the market due to consumer demand.

- **Biodiversity:**

Organic farming practices can enhance biodiversity on the farm.

Rhizome Selection

Select well-developed, healthy and disease-free rhizomes for cultivation. Use whole or split mother and finger rhizomes for turmeric planting. The mother rhizome can be divided into two or three pieces, each containing one or two healthy buds and used as seed material.

Seed Rate

- Mother Rhizomes: 800 – 1000 kg per acre
- Finger Rhizomes: 600 – 800 kg per acre
- For inter-cropping: 160 – 200 kg per acre

Nutrient Requirement

Apply organic manures like FYM (8 t/acre) and Neem cake (80 kg/acre) as basal application by broadcasting and then ploughing at the time of field preparation. Also, apply neem cake (80 kg/acre) by top dressing at 45 DAP.

Improved Varieties: Several improved varieties of turmeric have been developed, with some of the most notable including Lakadong, Alleppey, Duggirala, Suguna, Sudarsana, IISR Prabha, and IISR Prathibha. These varieties offer advantages such as higher yields, increased curcumin content, and disease resistance.

- **ISR Prabha:** This variety has a fresh yield of 37.5 t/ha.
- **IISR Prathibha:** This variety has a fresh yield of 39.1 t/ha.
- **Suguna:** This variety has a fresh yield of 29.3 t/ha.
- **Sudarsana:** This variety has a fresh yield of 28.8 t/ha.
- **Rajendra Sonia:** This variety has a yield of 400-450 q/ha.

Organic Certification: Under organic farming, processing methods also should be based on mechanized, physical and biological processes to maintain the vital quality of organic ingredient throughout each step of its processing. All the ingredients and additives used in processing should be of agriculture origin and certified organic. In cases where an ingredient of organic agriculture origin is not available in sufficient quality or quantity, the certification programme authorizes use of non organic raw materials subject to periodic re-evaluation. Labeling should clearly indicate the organic status of the product as “produce of organic agriculture” or a similar description when the standards requirements are fulfilled. Moreover organic and non-organic products should not be stored and transported together except when labeled or physically separated. Certification and labeling is usually done by an independent body to provide a guarantee that the production standards are met. Govt. of India has taken steps to have indigenous certification system to help small and marginal growers and to issue valid organic certificates through certifying agencies accredited by APEDA and Spices Board. The inspectors appointed by the certification agencies will carry out inspection of the farm operations through records maintained and by periodic site inspections. Documentation of farm activities is must for acquiring certification especially when both conventional and organic crops are raised. Group certification programmes are also available for organized group of producers and processors with similar production systems located in geographical proximity.

Harvesting: Depending upon the variety, the crop becomes ready for harvest in 7-9 months after planting during January-March. Early varieties mature in 7-8 months, medium varieties in 8-9 months and late varieties after 9 months. The land is ploughed and the rhizomes are gathered by hand picking or the clumps are carefully lifted with a spade. The harvested rhizomes are cleared of mud and other extraneous matter adhering to them. A good crop may be yield around 20-25 t/ h

Processing Curing: Fresh turmeric is cured for obtaining dry turmeric. The fingers are separated from mother rhizomes. Mother rhizomes are usually kept as seed material. Curing involves boiling of fresh rhizomes in water and drying in the sun. The cleaned rhizomes are boiled in water just enough to immerse them. Boiling is stopped when froth comes out and white fumes appear giving out a typical odour. The boiling should last for 45-60 minutes when the rhizomes turn soft. The stage at which boiling is stopped largely influences the colour and aroma of the final product. Over cooking spoils the colour of the final product while under-cooking renders the dried product brittle. In the improved scientific method of curing, the cleaned fingers (approximately 50 kg) are taken in a perforated trough of 0.9 m x 0.5 m x 0.4 m size made of GI or MS sheet with extended parallel handle. The perforated trough containing the fingers is then immersed in a pan; 100 litres of water is poured into the trough so as to immerse the turmeric fingers. The whole mass is boiled till the fingers become soft. The cooked fingers are taken out of the pan by lifting the trough and draining the water into the pan. The water used for boiling turmeric rhizomes can be used for curing fresh samples. The processing of turmeric is to be done 2 or 3days after harvesting. If there is delay in processing, the rhizomes should be stored under shade or covered with sawdust or coir dust.

Drying: The cooked fingers are dried in the sun by spreading them in 5-7 cm thick layers on bamboo mats or on drying floor. A thinner layer is not desirable, as the colour of the dried product may be adversely affected. During night time, the rhizomes should be heaped or covered with material which provides aeration. It may take 10-15 days for the rhizomes to become completely dry. Artificial drying, using cross-flow hot air at a maximum temperature of 60 degree centigrade also gives a satisfactory product. In the case of sliced turmeric, artificial drying has clear advantages in giving a brighter coloured product than sun drying which tends to undergo surface bleaching. The yield of the dry product varies from 10-30% of fresh produce depending upon the variety and the location where the crop is grown.

Preservation of seed rhizomes: Rhizomes for seed purpose are generally stored by heaping in well ventilated rooms and covered with turmeric leaves. The seed rhizomes can also be stored in pits with saw dust, sand along with leaves of Strychnos nuxvomica (kanjiram). The pits are to be covered with wooden planks with one or two openings for aeration. The rhizomes are to be dipped in litres of water to avoid storage losses due to fungi.

Yield A good crop of turmeric may yield about 20-25 t/ha under organic production.

Conclusion: 0rganic farming is the use of agricultural production system reliant on green manure, compost, biological pest control, and crop rotation to produce crops, livestock and popularity. Organic centered agricultural production system fosters the cycling of the resources to conserve biodiversity and promote ecological balance. The use of green manure, cover crops, animal manure, and soil rotation , to interrupt the habitation of pests and diseases, improve soil fertility, and maximize the soil's biological activity are the primary aspects of organic farmingIndia is major player in conventional turmeric production and processed products too. Also have potential to emerge as largest Organic Producer in global market by 2050. Use of advances management in organic turmeric production can increase its sustainable productivity. Integrated organic management is viable option for increases organic turmeric production. India will have to develop very competitive edge in all aspects including competitive organic production, post harvest and value addition of turmeric, if it has to secure and increase its present position in the international trade of turmeric as in upcoming days due to increased awareness of global troops demand will be only for organic.

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Impact of Maternal Emotional Health on Baby's Brain Development

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Abstract

Maternal emotional health during pregnancy is crucial for optimal foetal brain development. Emotional states such as stress, anxiety, and depression can impact the hormonal environment within the womb, influencing neural connectivity, memory, learning, and emotional regulation in the developing baby. Elevated cortisol levels, commonly associated with maternal stress, can affect key areas of the brain like the hippocampus, amygdala, and prefrontal cortex. The effects may manifest as cognitive delays, behavioural issues, and emotional instability in childhood and beyond. This paper explores the mechanisms through which maternal emotional states affect prenatal brain development and outlines strategies for promoting maternal mental well-being through family support, lifestyle changes, and professional interventions.

Introduction:

The emotional health of a mother during pregnancy plays a critical role in shaping the baby's brain development. The prenatal stage is marked by rapid neurological growth, with billions of neurons forming connections and establishing the foundation for the baby's cognitive and emotional capabilities. The mother's mental state during this time creates a biochemical environment in the womb that can either support or hinder the baby's development.

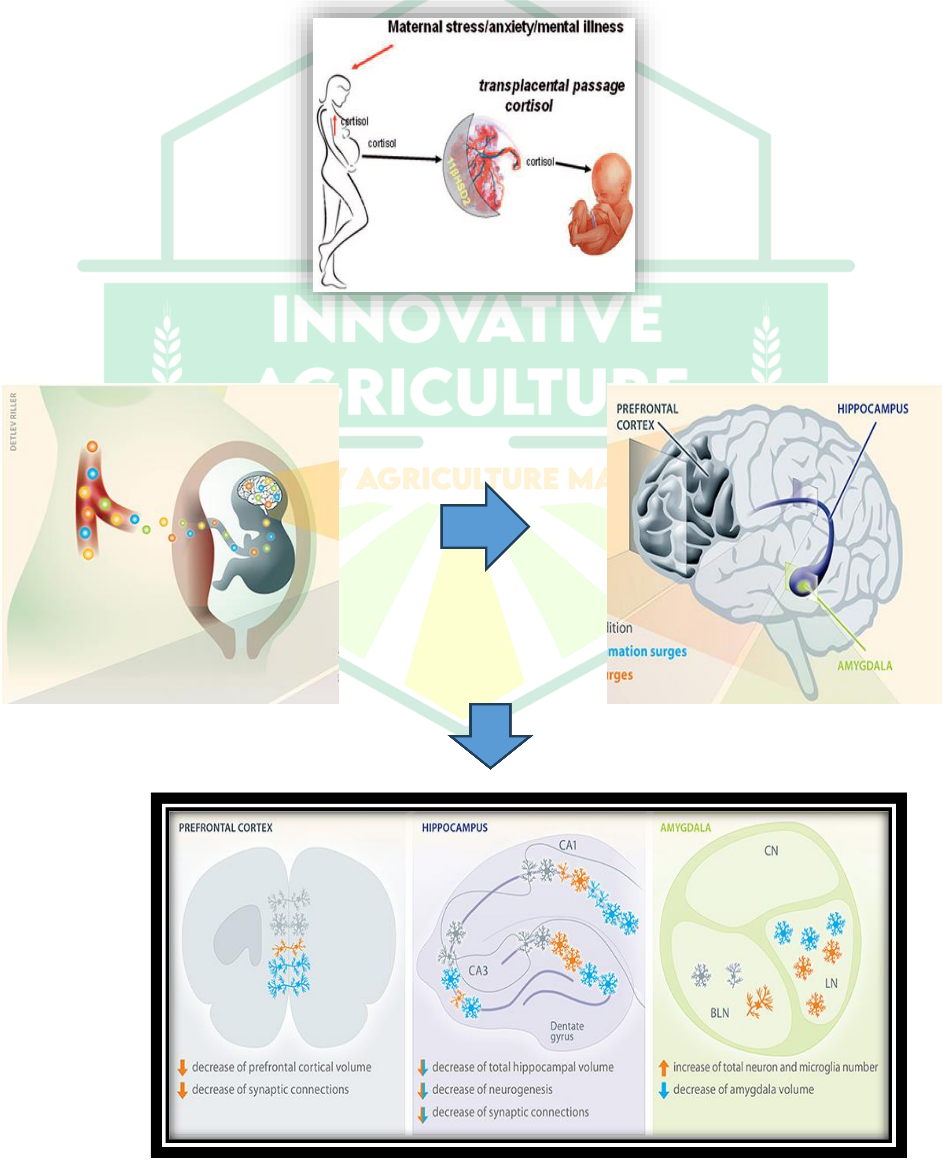
How Emotional Health Impacts Brain Development

1. **Hormonal Transmission Across the Placenta Cortisol and Stress Hormones:** When a mother experiences stress during pregnancy, her body produces the hormone cortisol as part of the body's natural stress response. While cortisol is essential in small amounts for normal development, excessive levels, especially during critical periods of brain development, can have lasting impacts on the foetus.
   - Cortisol crosses the placenta via specialized receptors. While the placenta partially filters cortisol, high maternal stress can overwhelm this protective barrier, exposing the foetus to excessive cortisol levels.
   - Elevated cortisol alters the hormonal environment, disrupting the balance necessary for healthy brain development.

2. **Hippocampus (Memory Formation and Learning):**
   The hippocampus, responsible for memory and learning, is one of the most cortisol-sensitive areas in the foetal brain. Excessive cortisol can impair neuron formation (neurogenesis) and reduce the volume of the hippocampus. This can lead to difficulties in memory retention, learning, and problem-solving abilities in childhood and beyond. Studies have shown that children of mothers with high stress during pregnancy may score lower on memory and cognitive tests by age 7
3. **Anxiety and Neural Connectivity:**
   Anxiety during pregnancy can interfere with the development of neural connections, reducing the efficiency of the baby's brain networks. Long-term exposure to maternal anxiety may predispose the child to cognitive delays and behavioural challenges.

4. **Depression and Foetal Brain Development:**
   Maternal depression is associated with lower levels of serotonin and dopamine, neurotransmitters essential for healthy brain development. Babies born to mothers with untreated depression during pregnancy may show altered brain structure and function, affecting their emotional resilience and social behaviors.
5. **Amygdala (Emotion Regulation):**
   The amygdala, which controls emotional responses like fear and anxiety, is another key area affected by cortisol. High cortisol levels can lead to an overactive amygdala, increasing the child's vulnerability to anxiety disorders, emotional instability, or heightened fear responses. Children born to mothers with untreated prenatal anxiety often show exaggerated fear or difficulty calming down in stressful situations.
6. **Prefrontal Cortex (Decision-Making and Impulse Control):**
   Emotional well-being promotes the formation of neural circuits in the prefrontal cortex, essential for attention, decision-making, and self-regulation.

High cortisol disrupts the development of neural pathways in the prefrontal cortex, which governs decision-making and self-control. This can result in attention deficits and impulsivity in children, often seen in conditions like ADHD.



Strategies to Support Maternal Emotional Health

Creating a Positive Family Environment

- **Open Communication**: Encourage the mother to express her thoughts and feelings without fear of judgment. Families should actively listen and offer emotional support.
- **Shared Responsibilities**: Distribute household and childcare tasks among family members to ease the physical and emotional burden on the mother.
- **Encouragement and Reassurance:** Regular positive reinforcement and reassurance from family members can boost the mother's confidence and reduce anxiety.
- **Conflict-Free Atmosphere**: Minimize family conflicts and stressful situations, creating a peaceful and harmonious home environment.
- **Healthy Lifestyle:** Ensure the mother has access to nutritious meals, adequate rest, and opportunities for light exercise or relaxation.

Stress-Reduction Techniques

- **Mindfulness and Meditation**: Families can encourage the mother to practice mindfulness or meditation to manage anxiety and promote relaxation. Group activities like guided breathing exercises can be helpful.
- **Yoga and Light Exercise**: Prenatal yoga or walking can improve emotional well-being, with family members joining to make it a bonding activity.

Promoting Positive Mental Habits

- **Encourage Self-Care**: Motivate the mother to take time for hobbies, reading, or any activity she enjoys.
- **Affirmations and Positivity**: Family members can regularly share affirmations or reminders of the mother's strengths and capabilities.

Emotional and Social Support

- **Support Network**: Strengthen the mother's social support by fostering connections with extended family, friends, or community groups.
- **Prenatal Support Groups**: Joining pregnancy-focused groups can help the mother share experiences, gain advice, and feel less isolated.
- **Family Bonding Activities**: Organize family outings, movie nights, or simple recreational activities to reduce stress and foster joy.

Access to Professional Help

- **Counselling and Therapy**: If the mother experiences anxiety or depression, seek professional counselling to address these concerns.
- **Education and Awareness**: Educate family members about the psychological changes during pregnancy to foster empathy and understanding.
- **Partner's Role**: A supportive and engaged partner can play a pivotal role in enhancing the mother's emotional health by providing companionship and understanding her needs.

Conclusion

Maternal emotional well-being during pregnancy is vital for healthy foetal brain development. Supportive care and a nurturing environment lay the foundation for the child's lifelong mental and emotional health.

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Climate Change and Its Effects on Crop Pest Dynamics and Natural Enemy Interactions in Agroecosystems

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Abstract

Climate change is exerting profound effects on global agriculture by altering pest dynamics and their interactions with natural enemies. Shifts in temperature, precipitation patterns, and atmospheric carbon dioxide levels are influencing the abundance, distribution, and life cycles of pests, while simultaneously disrupting the ecological balance of agroecosystems. These changes have implications for crop productivity, food security, and sustainable pest management. This paper provides an in-depth analysis of how climate change influences pest outbreaks and natural enemy populations, with an emphasis on the ecological, physiological, and behavioral responses observed in agroecosystems. It also highlights case studies and proposes adaptive strategies for integrated pest management (IPM) under climate-resilient agriculture.

1. Introduction

Climate change poses a formidable challenge to agriculture, particularly through its impact on biotic stress factors such as insect pests, weeds, and pathogens. Among these, insect pests have demonstrated a high capacity to adapt to changing environmental conditions, leading to more frequent and severe outbreaks in various parts of the world. Simultaneously, beneficial organisms that naturally regulate pest populations—such as predators and parasitoids—may be adversely affected, disrupting existing biological control mechanisms. Understanding these dynamics is essential for developing climate-smart agricultural strategies.

The Intergovernmental Panel on Climate Change (IPCC) projects a global temperature increase of 1.5–2°C by the end of the 21st century, with associated shifts in rainfall, humidity, and extreme weather events. These changes have direct and indirect effects on the pest-natural enemy equilibrium in agroecosystems. The present study explores these effects in detail and suggests adaptive measures to mitigate the risks posed by climate-driven pest dynamics.

2. Climate Change and Pest Dynamics

2.1. Temperature-Driven Changes

Temperature is a key determinant of insect physiology, affecting their metabolism, development rate, reproduction, and survival. Rising temperatures can:

- Accelerate insect development and shorten generation time
- Increase the number of pest generations per growing season
- Expand geographic range toward higher altitudes and latitudes
- Enhance winter survival in temperate regions

For example, the diamondback moth (*Plutella xylostella*), a global pest of crucifers, now exhibits increased voltinism (number of generations per year) due to warmer conditions, leading to higher population densities.

2.2. Effects of Elevated CO_2

Increased atmospheric CO_2 alters plant physiology, often reducing nitrogen content and increasing carbon-based compounds like lignin. This can influence herbivore feeding behavior and nutritional efficiency:

- Insect herbivores may increase feeding rates to compensate for reduced leaf quality
- Generalist feeders may adapt better than specialists
- Altered plant volatiles may disrupt host location by pests and natural enemies

Such changes may result in unpredictable pest population dynamics and potentially increased crop damage.

2.3. Altered Precipitation Patterns

Changes in rainfall intensity and distribution affect pest habitats and reproduction cycles:

- Excess moisture may promote fungal pathogens like downy mildew, while drought may favor drought-adapted pests like spider mites
- Heavy rains can wash away eggs or larvae, temporarily reducing pest numbers
- Dry spells may suppress natural enemy activity, giving pests an upper hand

The migratory behavior of pests such as locusts and armyworms is heavily influenced by monsoon patterns and wind currents, both of which are being altered by climate variability.

2.4. Phenological Synchrony Disruption

Climate-induced shifts in phenology—the timing of biological events—can lead to mismatches between pests and their host plants or natural enemies:

- Pests may emerge earlier than the appearance of natural enemies, reducing predation pressure
- Crop flowering and fruiting periods may no longer coincide with natural enemy population peaks

These mismatches can destabilize agroecosystem interactions and favor pest outbreaks.

3. Impact on Natural Enemies

3.1. Predators and Parasitoids

Natural enemies such as lady beetles, lacewings, predatory mites, and parasitic wasps play a vital role in controlling pest populations. Climate change affects them through:

- Temperature and humidity sensitivity
- Changes in prey availability and quality
- Altered foraging behavior and reproduction

For example, parasitoids with narrow thermal tolerance ranges may become less effective under extreme temperatures. Moreover, higher temperatures can reduce egg viability and increase desiccation risks in natural enemies.

3.2. Pollinators and Pest Control

Pollinators like bees also contribute indirectly to pest control by enhancing plant health and resistance. However, climate change has been linked to colony collapse disorder and reduced pollinator activity, which may negatively affect crop resilience.

3.3. Intraguild Interactions

Changing climates can alter intraguild predation, competition, and coexistence patterns among beneficial organisms. This can result in dominance shifts within predator guilds, leading to imbalanced pest suppression.

4. Case Studies

4.1. Fall Armyworm in Africa and Asia

The invasive fall armyworm (*Spodoptera frugiperda*) has spread rapidly across Africa and Asia, partly due to favorable climate conditions. Its proliferation has overwhelmed local natural enemies, requiring the development of new biocontrol and monitoring strategies.

4.2. Aphid Outbreaks in Europe

Warmer winters in Europe have led to increased survival of aphid eggs, causing early-season infestations. Concurrently, the reduced cold period has affected parasitoid diapause, delaying their emergence and lowering their control efficacy.

4.3. Brown Planthopper in Asia

In rice ecosystems of Southeast Asia, rising temperatures and changing rainfall patterns have led to resurgence of the brown planthopper (*Nilaparvata lugens*), a major pest. This has challenged existing biological control methods and increased pesticide dependency.

5. Adaptation and Mitigation Strategies

5.1. Climate-Resilient IPM Approaches

Integrated Pest Management (IPM) must be reoriented to cope with climate-induced pest dynamics. Strategies include:

- **Diversified cropping systems** to reduce pest habitat continuity
- **Use of climate-resilient cultivars** with inherent pest resistance
- **Habitat manipulation** to enhance natural enemy activity
- **Microclimate management** through mulching and intercropping

5.2. Predictive Modeling and Forecasting

Climate-based pest forecasting models can support proactive interventions. These models integrate meteorological data, pest biology, and host phenology to generate early warnings:

- **Simulation models** like CLIMEX and DEGDAY predict pest range shifts
- **Machine learning tools** process big data for real-time forecasting

These systems help stakeholders time pesticide application and natural enemy release more effectively.

5.3. Conservation Biological Control

Preserving and enhancing natural enemy populations through ecological engineering is key. Approaches include:

- Flower strips to provide nectar and pollen
- Insectary plants to support parasitoid development
- Reduced pesticide use to prevent natural enemy mortality

5.4. Use of Biopesticides and Botanicals

Biopesticides such as *Bacillus thuringiensis*, neem extracts, and entomopathogenic fungi offer safer alternatives to synthetic chemicals, maintaining natural enemy populations while controlling pests.

5.5. Technological Innovations

Technologies such as remote sensing, ICT-enabled light traps, and automated pest monitoring systems are proving useful in climate-smart pest management. Drones and AI-powered image analysis enhance early detection capabilities.

6. Policy and Extension Support

Effective climate change adaptation requires robust policy and institutional support:

- **Government incentives** for adopting climate-resilient IPM practices
- **Strengthening of pest surveillance infrastructure**
- **Capacity building for farmers and extension workers**
- **Research funding** for climate-pest interaction studies

Extension services must also integrate climate literacy and pest risk advisory into routine programming.

7. Future Research Directions

To improve understanding and response to climate-driven pest dynamics, future research should focus on:

- Long-term studies on pest and natural enemy phenology across climatic gradients
- Development of dynamic pest forecasting tools incorporating climate projections
- Genomic approaches to breed pest-resistant and climate-resilient crops
- Identification of thermal and ecological thresholds for key pests and beneficials
- Ecosystem modeling to assess the resilience of biological control services

8. Conclusion

Climate change is reshaping pest dynamics and natural enemy interactions in agroecosystems, posing significant challenges to crop protection and food security. Temperature rise, erratic rainfall, and elevated CO_2 are driving shifts in pest phenology, geographic distribution, and population intensity. Concurrently, natural enemies are facing altered habitats, disrupted phenological synchrony, and reduced efficacy.

Addressing these challenges requires a multi-pronged strategy involving adaptive IPM, enhanced surveillance, predictive modeling, and ecological intensification. Strong policy backing, farmer training, and investment in climate-resilient technologies are essential to sustain pest management in the face of a changing climate. With coordinated efforts, it is possible to safeguard agroecosystem health and ensure resilient food production systems.

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Influence of Organic Farming Practices on Soil Biological Properties and Microbial Diversity

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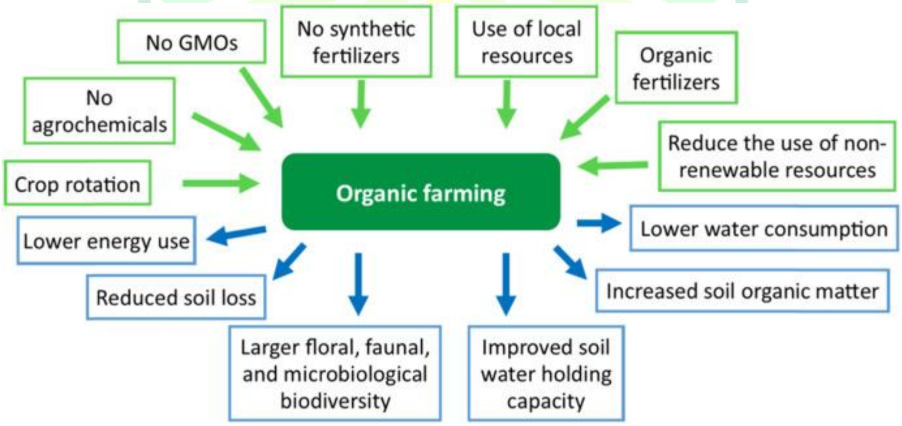
Abstract

Organic farming systems are increasingly recognized as sustainable alternatives to conventional agriculture due to their minimal reliance on synthetic inputs and their emphasis on ecological balance. One of the most significant benefits of organic farming lies in its positive effects on soil biological properties and microbial diversity. This paper explores the influence of organic farming practices on soil health, focusing on microbial biomass, activity, community composition, and functional diversity. It evaluates the key organic techniques—such as compost application, green manuring, crop rotation, and reduced chemical usage—that enhance the soil food web and foster microbial richness. A comprehensive review of empirical studies, mechanisms of microbial enhancement, comparative analyses with conventional systems, and future directions for research are also discussed to underline the critical role of organic farming in sustainable land management.

1. Introduction

Soil is a living system whose biological properties are central to its fertility and function. The soil biota - comprising bacteria, fungi, actinomycetes, protozoa, nematodes, and arthropods—drive nutrient cycling, organic matter decomposition, and disease suppression. The health and diversity of these microbial communities are significantly influenced by agricultural practices. Organic farming, by eliminating synthetic inputs and promoting natural soil amendments, fosters an environment conducive to microbial proliferation and functional resilience.

The increasing interest in sustainable agriculture and climate-smart practices necessitates a deep understanding of how organic methods shape soil biological processes. This paper aims to synthesize current knowledge on the effects of organic practices on soil microbial communities, compare outcomes with conventional systems, and highlight implications for agroecosystem sustainability.



2. Principles and Practices of Organic Farming

Organic farming emphasizes the use of natural inputs and ecological principles to maintain soil and crop health. Key practices include:

2.1 Use of Organic Amendments

- **Farmyard manure (FYM), compost, and vermicompost** enrich soils with organic matter and microorganisms.

- **Biofertilizers** like Rhizobium, Azotobacter, and mycorrhizae enhance nutrient availability and microbial associations.

2.2 Green Manuring

- Incorporation of leguminous crops (e.g., sunn hemp, dhaincha) improves nitrogen content and promotes microbial biomass.

2.3 Crop Rotation and Polyculture

- Diversified cropping systems prevent pest buildup and support varied microbial habitats.
- Rotation of cereals with legumes stimulates rhizosphere activity and symbiotic bacteria.

2.4 Reduced Chemical Input

- Avoidance of synthetic fertilizers and pesticides preserves beneficial soil microflora and prevents toxicity buildup.

2.5 Minimum Tillage

- Conservation tillage preserves soil structure and microbial habitats, especially mycorrhizal networks.

3. Soil Biological Properties Enhanced by Organic Farming

3.1 Microbial Biomass and Activity

Organic amendments supply carbon substrates that act as food sources for soil microbes. Studies show significantly higher microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) under organic regimes compared to conventional ones.

- Increased dehydrogenase and phosphatase enzyme activities are indicators of enhanced microbial activity.
- Enhanced respiration rates and nitrogen mineralization point to active microbial turnover.

3.2 Microbial Diversity

Organic systems support higher taxonomic and functional diversity of microbes:

- **Bacteria:** Including nitrogen-fixers (Azospirillum, Rhizobium), phosphate-solubilizers, and cellulose degraders.
- **Fungi:** Dominated by arbuscular mycorrhizal fungi (AMF) and saprophytes that aid in nutrient mobilization.
- **Actinomycetes:** Involved in the breakdown of complex organics and antibiotic production.

Molecular studies using DNA sequencing and PCR-DGGE techniques confirm richer microbial communities under organic management.

3.3 Soil Enzyme Activities

Organic amendments stimulate key enzymes:

- **Urease**: Assists in nitrogen mineralization.
- **β-glucosidase**: Involved in cellulose degradation.
- **Phosphatases**: Enhance phosphorus solubilization.

These enzymes act as sensitive indicators of soil biological activity and are often higher in organically managed soils.

4. Mechanisms Enhancing Microbial Diversity in Organic Systems

4.1 Carbon Input and Organic Matter Quality

Organic inputs provide a continuous supply of carbon-rich substrates, improving microbial substrate diversity and colonization niches.

4.2 Habitat Heterogeneity

Reduced tillage, mulching, and diverse root architectures provide stable and varied microhabitats for different microbial groups.

4.3 Improved Soil Structure

Organic matter improves soil aggregation and porosity, enhancing oxygen availability and water retention—conditions favorable for microbial proliferation.

4.4 Reduced Chemical Stress

Eliminating chemical fertilizers and pesticides minimizes microbial inhibition and promotes natural feedback cycles in the soil ecosystem.

5. Comparative Studies: Organic vs. Conventional Systems

Numerous long-term field trials (e.g., Rodale Institute, FiBL-DOK trial in Switzerland) demonstrate the advantages of organic farming for soil microbial health:

- **Rodale Institute (USA):** Reported higher soil carbon, microbial biomass, and enzymatic activity in organic plots over a 30-year period.
- **FiBL-DOK Trial:** Found significantly greater microbial respiration, AMF colonization, and microbial biomass in biodynamic and organic systems.

Meta-analyses show that organic systems enhance microbial biomass by 20–50% compared to conventional practices.

6. Benefits of Enhanced Microbial Diversity

6.1 Nutrient Cycling and Soil Fertility

Microorganisms drive mineralization and solubilization of nutrients, ensuring a steady nutrient supply to crops. N-fixers, phosphate solubilizers, and AMF increase nutrient use efficiency.

6.2 Disease Suppression

A diverse microbial community outcompetes pathogens through antibiosis, competition, and induced systemic resistance. Organic soils often show lower incidence of root rot and wilt diseases.

6.3 Soil Carbon Sequestration

Microbial biomass contributes to stable organic matter formation, aiding in carbon storage and climate change mitigation.

6.4 Resilience and System Stability

Soils with diverse microbial communities exhibit greater resilience to drought, flooding, and chemical disturbances.

7. Challenges and Limitations

7.1 Variability in Outcomes

Outcomes vary based on soil type, climate, and management history. Not all organic systems show consistent microbial benefits.

7.2 Time to Realize Benefits

Microbial improvements may take several years to manifest, requiring long-term commitment from farmers.

7.3 Nutrient Imbalances

Overuse of certain organic materials (e.g., high C:N composts) can immobilize nutrients and temporarily reduce crop growth.

7.4 Lack of Standardization

Different definitions and practices under the term 'organic' complicate comparisons and interpretations of results.

8. Future Research Directions

8.1 Microbiome Engineering

Exploring synthetic microbial consortia to enhance nutrient mobilization and crop resilience.

8.2 Genomic and Metagenomic Studies

Using advanced sequencing to understand microbial gene functions and interactions under organic systems.

8.3 Soil Health Indices

Developing standardized indicators for microbial health to guide organic farm management.

8.4 Climate-Smart Organic Systems

Designing organic systems that maximize microbial benefits under changing climatic conditions.

9. Conclusion

Organic farming fosters a biologically active and diverse soil environment through the use of natural inputs, minimal disturbance, and ecological balance. This leads to enhanced microbial biomass, richer microbial diversity, and increased soil enzymatic activity. The soil biota under organic management contribute to improved nutrient cycling, disease suppression, and soil structure, offering a sustainable pathway to long-term agricultural productivity. Although challenges remain, particularly in variability and standardization, the integration of modern tools such as metagenomics and microbiome engineering offers exciting prospects for advancing soil biological health in organic agriculture.

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Genetic Engineering for Insect Resistance in Vegetables

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Introduction

Insects pose a significant threat to vegetable crops, resulting in substantial yield losses and diminished crop quality worldwide. Traditional methods of pest control, such as chemical pesticides, though effective to some extent, have adverse environmental and health implications and often lead to the development of pest resistance. With the rising global demand for safe, sustainable, and high-yielding vegetable production systems, genetic engineering has emerged as a powerful tool for developing insect-resistant crops. This technology not only helps reduce the dependency on chemical pesticides but also ensures a more sustainable agricultural practice. The application of genetic engineering in vegetables for insect resistance includes the transfer of specific genes that either produce toxic compounds to pests or interfere with their biological processes. This paper explores the science, techniques, applications, benefits, challenges, and future directions of genetic engineering for insect resistance in vegetables.

Need for Insect Resistance in Vegetables

- **Economic Impact**: Vegetables like brinjal, tomato, cabbage, and okra suffer heavy losses due to insect pests such as fruit borers, whiteflies, and aphids.
- **Environmental Concerns**: Overreliance on chemical pesticides has caused severe environmental degradation, pesticide residues in food, and resistance development in insects.
- **Health Hazards**: Excessive pesticide use is associated with human health risks, particularly for farm workers and consumers.
- **Sustainability**: Integrated pest management strategies incorporating genetic resistance reduce chemical inputs, supporting sustainable farming practices.

Principles of Genetic Engineering for Insect Resistance

Genetic engineering involves the insertion of specific genes into a plant's genome to confer desired traits. For insect resistance, genes from other organisms, particularly bacteria like *Bacillus thuringiensis* (Bt), are introduced to express proteins that are toxic to target insects but safe for humans and beneficial organisms.

Key Steps:

- Identification of insecticidal gene
- Gene isolation and cloning
- Transformation into plant cells
- Regeneration of whole plants
- Evaluation of insect resistance
- Field trials and biosafety assessments

Mechanism of Bt Technology

Bacillus thuringiensis produces Cry (crystal) proteins during sporulation. These proteins bind to specific receptors in the gut of target insects, creating pores in the intestinal walls, leading to cell lysis and insect death.

Types of Bt Proteins Used in Vegetables:

- Cry1Ac, Cry2Ab: Effective against Lepidopteran pests (e.g., fruit borers)
- Cry3Bb: Used for Coleopteran pests

Mode of Action:

1. Ingestion of Bt protein by larvae
2. Activation in alkaline insect gut
3. Binding to midgut receptors
4. Pore formation and lysis of gut cells
5. Insect starvation and death

Examples of Genetically Engineered Insect-Resistant Vegetables

1. **Bt Brinjal (Eggplant)**:
   - Developed using Cry1Ac gene
   - Controls Fruit and Shoot Borer (*Leucinodes orbonalis*)
   - Commercialized in Bangladesh
2. **Bt Tomato**:
   - Engineered for resistance against fruit borers (*Helicoverpa armigera*)
   - Not yet commercialized widely
3. **Bt Cabbage**:
   - Expresses Cry1Ab gene for resistance to diamondback moth (*Plutella xylostella*)
4. **Bt Okra (Lady's Finger)**:
   - Confers resistance to fruit and shoot borers
   - Trials underway in India
5. **Virus-Resistant Papaya and Squash**:
   - Though viral, these crops demonstrate the versatility of genetic engineering

Methods of Genetic Transformation

- **Agrobacterium-Mediated Transformation**:
  - Widely used in dicot vegetables
  - Involves infection of plant tissues with genetically modified *Agrobacterium tumefaciens*
- **Gene Gun (Biolistic Method)**:
  - Suitable for monocots and recalcitrant species
  - DNA-coated particles are shot into plant cells
- **CRISPR-Cas9 and Genome Editing Tools**:
  - Allow precise modification of plant genome
  - Emerging tool for insect resistance
- **RNA Interference (RNAi):**
  - Silences specific genes in insects by expressing double-stranded RNA in plants
  - Specific, eco-friendly method

Biosafety, Regulations, and Public Perception

- **Biosafety Assessments:**
  - Conducted by national and international agencies (e.g., GEAC in India, USDA, FDA, EFSA)
  - Evaluate allergenicity, toxicity, gene flow, and environmental impact
- **Labeling and Consumer Choice:**
  - GM crops should be clearly labeled to allow informed consumer decisions
- **Public Perception and Misinformation:**
  - Often shaped by lack of awareness or socio-political narratives
  - Education and transparency can improve acceptance
- **Case Study: Bt Brinjal in Bangladesh**
  - Approved in 2013, has reduced pesticide use by over 50%
  - Increased yields and incomes
  - Acceptance driven by farmer field demonstrations and positive outcomes

Benefits of Insect-Resistant Genetically Engineered Vegetables

- **Reduced Pesticide Use:** Significant decline in chemical inputs
- **Increased Yields:** Reduced crop losses, better productivity
- **Improved Food Safety:** Fewer pesticide residues on food
- **Environmental Protection:** Less runoff and pollution
- **Economic Gains for Farmers:** Reduced input costs and higher marketable produce
- **Target-Specific Action:** Minimal impact on beneficial insects (e.g., pollinators)

Challenges and Concerns

- **Resistance Development in Insects:**
  - Continuous exposure may select for resistant pest populations
  - Refugia strategies recommended
- **Gene Flow to Wild Relatives:**
  - May result in unintended consequences in natural ecosystems
- **Regulatory Hurdles and Delays:**
  - Lengthy approval processes
- **Ethical and Social Concerns:**
  - Ownership of technology
  - Corporate control vs public benefit
- **Trade Restrictions:**
  - Some countries restrict imports of GM crops

Integrated Pest Management (IPM) and GE Crops

- Genetically engineered crops should be integrated with:
  - Biological control
  - Cultural practices (crop rotation, intercropping)
  - Mechanical control (traps, barriers)
  - Judicious pesticide use
- Promotes sustainable resistance management and ecosystem balance

Future Prospects and Innovations

- **CRISPR-Cas9**: Precision gene editing without foreign DNA
- **Stacked Traits**: Combining resistance to insects, diseases, and herbicides
- **Synthetic Biology**: Designing novel insecticidal proteins
- **RNAi-Based Crops**: Species-specific, minimal environmental impact
- **Climate-Resilient GE Vegetables**: Combining resistance with tolerance to drought, salinity, and heat

Conclusion

Genetic engineering has revolutionized the approach to insect management in vegetable cultivation. It offers an efficient, targeted, and sustainable solution to pest problems that have long plagued vegetable farmers. The integration of such technology into mainstream agriculture can significantly reduce environmental pollution, minimize health hazards, and contribute to global food security. However, for its wider adoption, public awareness, regulatory transparency, biosafety validation, and ethical considerations must be adequately addressed. Combining genetic resistance with integrated pest management practices ensures the long-term effectiveness and sustainability of this technology. With continuous advancements in genomics, biotechnology, and regulatory frameworks, genetically engineered insect-resistant vegetables promise a healthier, safer, and more productive future for global agriculture.

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Innovative Nursery Management and Propagation Techniques for Quality Plant Production in Horticulture

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Abstract

Nurseries form the backbone of the horticulture sector by providing essential planting material that directly impacts the productivity, quality, and profitability of crops. With increasing demand for high-yielding, climate-resilient, and pest-free plants, it has become crucial to modernize and innovate nursery management and propagation practices. This paper provides an in-depth analysis of recent innovations in nursery management and propagation techniques that contribute to the production of high-quality planting material in horticulture. The paper discusses protected cultivation, automation, micropropagation, plug technology, soilless cultivation, sustainable practices, and challenges in the field. Emphasis is placed on integrating technological advancements with traditional practices to enhance productivity, ensure sustainability, and meet the demands of modern horticulture.

Introduction

The success of any horticultural enterprise depends significantly on the availability of quality planting material. Plant nurseries serve as the primary source of seedlings, saplings, and clones for a wide range of fruit, vegetable, ornamental, and medicinal plants. Traditionally, nurseries relied on open-field propagation and manual practices. However, with the increasing incidence of climate variability, pest and disease outbreaks, and the need for rapid scaling of production, there is a shift towards technologically advanced and sustainable nursery systems.

Nursery management involves a comprehensive approach that includes site selection, layout planning, propagation methods, plant protection, nutrient management, and record-keeping. On the other hand, propagation techniques determine the genetic purity, health, and vigor of the plants. The integration of innovative practices in both these areas leads to the consistent production of robust and true-to-type plants.

Innovative Nursery Management

Importance of Quality Planting Material in Horticulture

Quality planting material is a cornerstone for ensuring:

- Uniformity in plant growth
- Resistance to pests and diseases
- Early maturity and higher yields
- Tolerance to abiotic stresses
- Better post-harvest performance

Poor quality or diseased planting materials often lead to weak crop stands, higher input costs, reduced productivity, and economic losses. Hence, scientific nursery practices that ensure the production of disease-free, genetically true, and vigorous plants are imperative.

Components of Nursery Management

1. **Site Selection and Layout**

An ideal nursery site should have:

- Good drainage
- Access to irrigation water
- Proximity to markets
- Protection from wind and animals

The layout should accommodate propagation units, mother plant blocks, shade houses, potting areas, water tanks, compost pits, and work sheds. Efficient space utilization and workflow optimization are crucial.

2. Nursery Structures

2.1 Open Nurseries

Traditional form where plants are raised in open fields. Susceptible to environmental fluctuations.

2.2 Protected Structures

Includes polyhouses, shade nets, insect-proof net houses, and low tunnels. Benefits include:

- Controlled temperature and humidity
- Protection from insects and pathogens
- Year-round propagation
- Improved rooting and seedling health

3. Nursery Media and Containers

3.1 Growing Media

Soilless media like cocopeat, perlite, vermiculite, peat moss, and rock wool offer better aeration, drainage, and sterility.

3.2 Containers

- Polythene bags
- Root trainers
- Plug trays
- Biodegradable pots

Using the right media and container supports healthy root development and easy transplanting.

4. Irrigation and Nutrient Management

Modern irrigation systems like drip, sprinkler, and misting systems ensure uniform water application and reduce wastage. Fertigation systems deliver nutrients along with irrigation water. Use of water-soluble fertilizers, biofertilizers, and organic amendments supports balanced nutrition.

5. Plant Protection Measures

Integrated pest and disease management (IPDM) using:

- Neem-based products
- Biopesticides (Trichoderma, Pseudomonas)
- Yellow sticky traps
- Regular scouting and roguing

Chemical interventions are minimized to produce safe and eco-friendly planting material.

6. Record-Keeping and Labeling

Proper documentation of source material, propagation dates, treatments applied, and batch performance is essential for traceability and quality assurance.

Innovative Propagation Techniques

1. Micropropagation (Tissue Culture)

Involves growing plants under aseptic conditions using explants. Widely used for banana, orchid, potato, strawberry, and medicinal plants. Stages include:

- Explant preparation
- Multiplication
- Rooting
- Acclimatization

Advantages:

- Rapid multiplication
- Disease-free material
- Uniformity
- Round-the-year production

Challenges include high cost, contamination risk, and need for skilled personnel.

2. Grafting and Budding Techniques

Used in fruit crops like mango, citrus, guava, and apple. Modern innovations include:

- Mechanized grafting (in solanaceous vegetables)
- Multiple grafting on a single rootstock
- Grafting on dwarfing or resistant rootstocks

These enhance plant performance, disease resistance, and orchard management.

3. Plug Tray Propagation

Common in vegetables and ornamentals. Features:

- Uniform germination
- Efficient space utilization
- Reduced transplant shock
- Ease of handling and transport

Plug trays filled with sterile media and raised under controlled conditions ensure high-quality seedlings.

4. Cutting and Layering

Used in crops like grapes, pomegranate, and litchi. Application of rooting hormones (IBA, NAA) and use of mist chambers improve success rates.

5. Use of Root Trainers

Promotes straight and healthy root development. Suitable for forestry species and fruit plants. Enhances survival rate and establishment in the field.

Integration of Technology in Nursery Management

1. Automation and Smart Systems

- Climate sensors (temperature, humidity, light)
- Automated irrigation and fertigation
- Mobile apps for monitoring
- IoT-enabled greenhouses

These systems enhance precision and reduce manual errors.

2. Digital Record Keeping

Use of mobile apps and cloud-based software for:

- Plant tracking
- Inventory management
- Sales and logistics
- Certification and compliance

3. Use of Drones and AI

Emerging applications include:

- Aerial monitoring of large-scale nurseries
- Disease detection
- Growth assessment

Artificial Intelligence is being integrated for predictive analytics and decision-making.

Sustainable Practices in Nursery and Propagation

1. Organic Nursery Practices

- Use of compost, vermicompost, and biofertilizers
- Pest control using neem, garlic extracts, and beneficial microbes
- Avoidance of synthetic chemicals

2. Water and Energy Efficiency

- Rainwater harvesting
- Solar-powered irrigation
- Water recycling systems

3. Waste Management

- Recycling of nursery waste
- Use of biodegradable pots and trays
- Composting of plant residues

Sustainable practices not only conserve resources but also align with consumer preferences for eco-friendly products.

Institutional Support and Standards

1. Nursery Accreditation

Organizations like NHB and ICAR have set quality standards for nurseries. Accreditation ensures:

- Standardization
- Traceability
- Consumer confidence

2. Capacity Building

Training programs, workshops, and exposure visits help nursery operators upgrade their skills. Involvement of KVKs, SAUs, and private institutions is critical.

3. Government Schemes

Schemes like MIDH, RKVY, and NHB subsidies support:

- Establishment of hi-tech nurseries
- Infrastructure development
- Promotion of micropropagation

Case Studies and Successful Models

1. ICAR-IIHR, Bengaluru

Established model nurseries using plug trays, polyhouses, and precision irrigation. Supplies quality vegetable seedlings across South India.

2. Banana Tissue Culture Labs in Maharashtra

Private labs producing millions of tissue culture banana plantlets annually. Accredited and widely accepted by farmers.

3. FPO Nurseries in Punjab

Farmer Producer Organizations running protected nurseries for vegetable seedlings. Enhancing incomes and local availability of quality plants.

Challenges in Implementation

- High initial investment in protected and automated systems
- Skilled manpower shortage
- Risk of disease spread in dense nurseries
- Limited awareness among small-scale farmers

- Marketing and distribution logistics

Future Prospects

- Integration of AI, blockchain, and robotics
- Mobile-based nursery advisory services
- Expansion of export-oriented nurseries
- Custom nursery services (contract propagation)
- Urban and rooftop nurseries using vertical systems

Conclusion

Nursery and propagation practices are undergoing a rapid transformation driven by the need for sustainability, scalability, and quality assurance. Innovative techniques in protected cultivation, automation, and biotechnology are revolutionizing plant production. The future lies in integrating traditional knowledge with modern science, supported by institutional frameworks and farmer awareness. Embracing these innovations will ensure the supply of superior planting material, thus securing the productivity and profitability of the horticulture sector.

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Geospatial Techniques for Assessing Soil Health: A Modern Approach

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Introduction

Soil health is a critical component of sustainable agriculture, environmental management, and climate resilience. It encompasses the soil's capacity to function as a living ecosystem that sustains plants, animals, and humans. In recent years, the degradation of soil due to overexploitation, chemical misuse, erosion, and climate change has become a global concern. Traditional methods of assessing soil health are often labor-intensive, time-consuming, and limited in spatial coverage. The emergence of geospatial technologies offers a modern and efficient approach to monitoring and managing soil health across diverse landscapes.

Geospatial techniques, which include Geographic Information Systems (GIS), Remote Sensing (RS), and Global Positioning Systems (GPS), allow researchers and policymakers to gather, analyze, and visualize spatial data related to soil properties and land use.

What is Soil Health

Soil health refers to the continued capacity of soil to function as a vital living system within ecosystem and land-use boundaries. It includes aspects such as:

- **Physical health:** Soil texture, structure, porosity, bulk density.
- **Chemical health:** pH, nutrient availability, salinity, cation exchange capacity.
- **Biological health:** Microbial biomass, enzyme activity, organic matter content.

A healthy soil supports plant growth, regulates water, stores nutrients, and mitigates pollutants, thereby contributing to food security and ecosystem services.

Role of Geospatial Techniques in Soil Health Assessment

Geospatial techniques provide tools to collect, interpret, and display soil-related data on a spatial scale. They enable the integration of biophysical and socio-economic data for comprehensive decision-making. Key technologies include:

1. Remote Sensing (RS)

Remote sensing uses satellite or airborne sensors to detect and monitor physical characteristics of the Earth. It helps in:

- Identifying land cover and land use patterns.
- Detecting changes in vegetation and erosion trends.
- Estimating soil moisture and organic matter.
- Monitoring crop stress and productivity.

2. Geographic Information System (GIS)

GIS allows for the mapping and analysis of spatial data layers such as soil type, land use, topography, and hydrology. GIS applications in soil health include:

- Soil fertility mapping.
- Erosion risk assessment.
- Site-specific nutrient management.
- Land capability classification.

3. Global Positioning System (GPS)

GPS helps in accurately locating soil sampling points and monitoring field operations. It supports:

- Georeferencing of soil sample data.

- Precision farming applications.
- Ground-truthing of remote sensing data.

Soil Parameters Assessable Through Geospatial Techniques

Geospatial tools can be employed to measure and monitor several soil health indicators, including:

- **Soil Organic Carbon (SOC):** Detected using hyperspectral imagery and linked to land use change.
- **Soil Moisture Content:** Monitored using microwave and thermal remote sensing data.
- **Soil Erosion:** Estimated using Digital Elevation Models (DEMs) and slope analysis.
- **Soil pH and Nutrients:** Mapped using interpolation techniques in GIS from field samples.
- **Compaction and Bulk Density:** Derived from vegetation indices and surface roughness data.

Techniques and Tools Used

1. Satellite Imagery

- Landsat, Sentinel, MODIS, and SPOT are commonly used for land cover classification and change detection.
- Hyperspectral sensors provide detailed spectral information to assess soil properties.

2. Aerial Photography and UAVs

- Drones equipped with multispectral cameras provide high-resolution images for soil and crop monitoring.
- UAVs are increasingly used for real-time monitoring and precision agriculture.

3. Digital Elevation Models (DEMs)

- DEMs help analyze terrain, slope, and watershed characteristics that influence soil erosion and deposition.

4. Spatial Interpolation Methods

- Kriging, IDW (Inverse Distance Weighting), and spline methods are used in GIS to estimate soil parameters at unsampled locations.

Applications in Agriculture and Land Management

1. Precision Agriculture

Geospatial tools allow site-specific soil management, enabling farmers to apply inputs based on the actual need of each zone in a field. This reduces waste, increases efficiency, and maintains soil health.

2. Soil Fertility Mapping

Using GPS-tagged soil samples and GIS, fertility maps can be generated to guide nutrient management practices.

3. Monitoring Degradation and Erosion

Satellite images can detect signs of soil degradation such as salinity, erosion, and desertification, enabling timely intervention.

4. Carbon Sequestration Assessment

Mapping SOC stocks helps assess carbon sequestration potential, vital for climate change mitigation strategies.

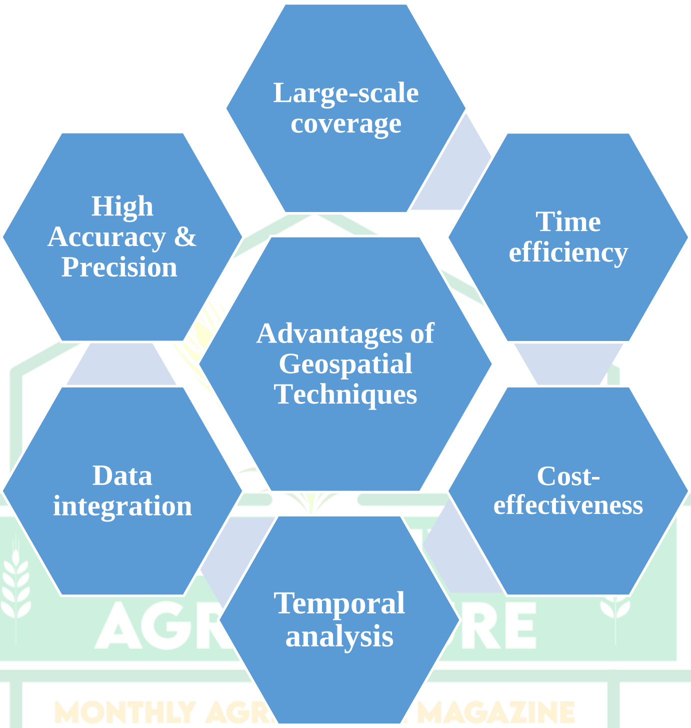
5. Watershed Management

GIS aids in planning watershed projects by analyzing hydrological and soil data to identify priority areas for conservation.


Applications in Agriculture and Land Management

Advantages of Geospatial Techniques

1. **Large-scale coverage:** Ability to assess vast and remote areas.
2. **Time efficiency:** Rapid collection and analysis of data.
3. **Cost-effectiveness:** Reduces need for extensive fieldwork.
4. **Temporal analysis:** Allows monitoring of changes over time.
5. **Data integration:** Combines various datasets for holistic assessment.
6. **High Accuracy & Precision** – Provides detailed and accurate spatial data, essential for planning and decision-making.



Advantages of Geospatial Techniques

Challenges and Limitations

Despite their potential, geospatial techniques face certain challenges:

1. **Data Resolution:** Low-resolution imagery may not capture fine-scale soil variation.
2. **Cloud cover:** Affects the accuracy of optical satellite data.
3. **Ground truthing:** Field validation is necessary for model accuracy.
4. **Technical expertise:** Requires trained personnel and infrastructure.
5. **Cost of equipment and software:** May be high for small-scale farmers or developing nations.

Integration with Emerging Technologies

1. Internet of Things (IoT)

IoT sensors in soil can be connected with geospatial platforms for real-time soil health monitoring.

2. Artificial Intelligence (AI) and Machine Learning (ML)

AI models can analyze satellite data to predict soil properties and classify land degradation with high accuracy.

3. Blockchain for Soil Data Transparency

Blockchain can secure soil data records, improving trust in digital soil information systems.

4. Cloud Computing and Big Data

Cloud platforms like Google Earth Engine enable analysis of massive geospatial datasets for global soil monitoring.

Policy and Future Prospects

Governments and institutions need to integrate geospatial tools into national soil health strategies by:

- Funding remote sensing research.

- Creating open-access soil databases.
- Training field staff in GIS and remote sensing.
- Promoting participatory mapping by farmers.

In the future, digital twin models of soils, combining 3D geospatial visualization and AI, may revolutionize soil health assessment and prediction.

Conclusion

Geospatial techniques have emerged as indispensable tools for modern soil health assessment. By offering spatially explicit, real-time, and integrative insights, they enhance our ability to diagnose soil problems and design targeted interventions. When combined with field data and emerging technologies like AI and IoT, geospatial methods promise a data-driven future for sustainable soil and land management. Strengthening capacity, improving data infrastructure, and promoting interdisciplinary collaboration will be key to unlocking their full potential. As we move towards climate-resilient agriculture and smart farming, geospatial technologies will play a vital role in ensuring soil remains healthy, productive, and protected for generations to come.

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Innovative Tools for Pest Surveillance: Monitoring and Forecasting Insect Populations Using Light Traps and ICT Technologies

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Abstract

Effective pest surveillance is crucial for sustainable crop protection and integrated pest management (IPM). Traditional methods of pest monitoring are often labor-intensive and provide limited real-time data. The integration of innovative tools like automated light traps and Information and Communication Technologies (ICT) has revolutionized pest surveillance by enabling accurate, timely, and location-specific monitoring of insect populations. This paper discusses the principles, design, and application of light traps and ICT-based platforms for pest forecasting. It also highlights their role in data-driven decision-making for timely pest control measures, thereby minimizing crop losses and reducing dependency on chemical pesticides.

1. Introduction

Pests are a major threat to agricultural productivity and food security worldwide. Monitoring pest populations is essential to understand pest dynamics, assess infestation risks, and implement timely management strategies. Conventional pest surveillance methods involve manual scouting and pheromone traps, which are often subjective, labor-intensive, and lack real-time data integration.

Recent advancements in sensor technology, automation, and ICT have led to the development of smart pest surveillance tools that enhance accuracy and scalability. Among these, light traps combined with ICT platforms have emerged as powerful tools for early detection, population monitoring, and forecasting of nocturnal insect pests. These innovations support precision agriculture and enable proactive pest control interventions, reducing reliance on blanket pesticide applications.

Light Traps and ICT Technologies

2. Importance of Pest Surveillance

Pest surveillance plays a critical role in integrated pest management and agricultural biosecurity. Key benefits include:

- **Early warning for pest outbreaks**: Helps detect pest population buildup before reaching economic threshold levels.
- **Timely and site-specific pest management**: Enables localized interventions based on actual field conditions.
- **Reduction in pesticide usage**: Prevents unnecessary pesticide applications, thereby promoting environmental and human health.
- **Enhancement of IPM strategies**: Supports the integration of cultural, mechanical, biological, and chemical control methods.
- **Improved crop yield and quality**: Minimizes crop damage and maintains produce quality by preventing late-stage infestations.

In regions prone to migratory pests such as locusts and armyworms, effective surveillance is essential for regional coordination and cross-border management.

3. Light Traps: Design and Functionality

3.1 Principle of Operation

Light traps function on the principle of phototaxis, where certain insects are attracted to light sources, especially in the ultraviolet (UV) and blue spectrum. Once attracted, insects are trapped using mechanical or adhesive systems or are funneled into a container for later identification and enumeration.

3.2 Types of Light Traps

- **Conventional Light Traps**: Operated manually and typically require daily or weekly inspection. Commonly used in research and extension services.
- **Automated Light Traps**: Integrated with optical sensors, infrared cameras, and data transmission units for continuous, remote operation.
- **Solar-Powered Light Traps**: Utilize solar energy to operate the light source and auxiliary systems, making them ideal for off-grid rural areas.
- **Sticky Light Traps**: Combine light attraction with adhesive surfaces for simplified pest capture and identification.

3.3 Trap Components

A typical automated light trap system includes:

- UV or LED light source
- Catchment funnel or container
- Adhesive surfaces or electric grids (in some models)
- Sensor units and data loggers
- GSM/GPRS modules for wireless data transmission

3.4 Advantages

- **Wide area coverage**: Can attract insects from a significant radius.
- **Cost-effective**: Requires minimal maintenance after installation.
- **Non-selective**: Can capture a wide range of insect species.
- **Data-rich**: Supports statistical analysis and long-term monitoring.

4. ICT Technologies in Pest Monitoring and Forecasting

4.1 Role of ICT in Pest Surveillance

ICT enhances the efficiency and effectiveness of pest monitoring systems through automation and real-time communication. It enables stakeholders, including farmers, extension agents, and researchers, to access pest-related data instantly and make informed decisions.

4.2 Components of ICT-Based Surveillance Systems

- **Sensor Nodes**: Monitor environmental parameters (e.g., temperature, humidity, wind speed) influencing pest dynamics.
- **Imaging Devices**: Capture high-resolution images of trapped insects for species identification.

- **Microcontrollers**: Manage data from sensors and coordinate system functions.
- **GSM/GPRS Modules**: Enable data transfer to cloud servers or mobile devices.
- **Cloud Infrastructure**: Stores and analyzes large volumes of data collected from field traps.
- **Mobile and Web Applications**: Provide user interfaces for data access, pest alerts, and advisories.

4.3 Examples of ICT Platforms

- **eLocust3**: Developed by FAO for real-time locust monitoring, equipped with GPS and satellite communication.
- **CROPMON**: Used in East Africa for real-time crop and pest monitoring using satellite and sensor data.
- **FASAL (Forecasting Agricultural output using Space, Agrometeorology, and Land-based observations)**: India-based platform integrating remote sensing and weather data for crop health and pest risk assessment.
- **Krishi Vigyan Kendra (KVK) apps**: Regional ICT apps delivering customized pest management advisories to farmers.

5. Pest Forecasting Models

5.1 Data Requirements

Effective forecasting relies on integrating multiple data streams, including:

- **Pest trap counts**: Daily or weekly records of specific pest species.
- **Meteorological data**: Temperature, humidity, rainfall, wind direction.
- **Phenological data**: Crop stages and growth conditions.
- **Historical outbreak records**: Past infestation patterns for predictive modeling.

5.2 Forecasting Approaches

- **Statistical Models**: Use regression, correlation, and time-series analysis to establish pest-weather relationships.
- **Machine Learning Models**: Use large datasets to predict pest emergence using algorithms like decision trees, support vector machines, and neural networks.
- **Simulation Models**: Biological models incorporating pest life cycles, development rates, and environmental interactions (e.g., DEGDAY, CROPEST).

5.3 Output and Utility

- Early warnings on likely pest outbreaks
- Estimation of population growth trends
- Identification of intervention windows
- Recommendations on control strategies

These tools support proactive pest management, minimizing economic and ecological damage.

6. Benefits of Integrating Light Traps with ICT Tools

- **Real-Time Monitoring**: Continuous data flow enables prompt responses.
- **Data Accuracy and Precision**: Automated identification reduces observer bias and improves data consistency.
- **High Spatial and Temporal Resolution**: Enables localized and frequent monitoring.
- **Farmer Empowerment**: Through mobile alerts and advisory systems, farmers can take timely action.
- **Reduced Crop Losses**: Early detection allows intervention before severe damage occurs.
- **Lower Environmental Impact**: Targeted pesticide application reduces residues and protects non-target organisms.

7. Challenges and Limitations

Despite their advantages, several challenges hinder the widespread adoption of ICT-based light trap systems:

- **High Initial Investment**: Cost of sensors, solar systems, and software development may be prohibitive for smallholders.
- **Connectivity Issues**: Poor mobile or internet coverage in rural regions limits data transmission.
- **Species Identification Constraints**: Current image recognition algorithms may misclassify morphologically similar species.

- **Maintenance Needs**: Devices require periodic cleaning, calibration, and technical support.
- **Data Ownership and Privacy**: Unclear protocols on who owns the collected data and how it is used can limit stakeholder participation.

8. Future Prospects

8.1 Integration with Other Technologies

- **Weather Forecast Models**: Linking pest surveillance data with short- and long-term weather forecasts for improved predictive power.
- **Remote Sensing and Drones**: Use of aerial imagery to assess crop damage and pest distribution.
- **IoT (Internet of Things)**: Fully networked pest surveillance systems enabling seamless data exchange.
- **AI and Deep Learning**: Improved insect identification and behavioral analysis.

8.2 Customization and Localization

- Designing trap systems tailored to specific agro-ecologies and pest complexes.
- Translation of advisory apps into local languages for better accessibility.
- Inclusion of indigenous knowledge in forecasting systems.

8.3 Policy and Institutional Support

- Government subsidies for digital surveillance tools.
- Public-private partnerships for developing and scaling technologies.
- Capacity building through farmer field schools and extension programs.

9. Case Studies

9.1 Punjab Agricultural University (PAU), Ludhiana

PAU developed solar-powered ICT-enabled light traps equipped with GSM modules and sensors to monitor *Helicoverpa armigera* in cotton fields. These traps transmitted daily pest counts to a central server, triggering SMS advisories to registered farmers. Adoption of this system led to a 30% reduction in pesticide usage and improved yield.

9.2 Tamil Nadu Agricultural University (TNAU) e-Pest Surveillance Program

TNAU deployed automated light traps across sugarcane and paddy belts, integrated with a centralized web portal. Data analysis generated weekly pest forecasts disseminated via mobile apps. Over 50,000 farmers benefited through reduced pest outbreaks and timely spray advisories.

9.3 Maharashtra's Digital Pest Surveillance Network

Under the "Digital Farming" initiative, ICT-based light traps were installed across vegetable-growing zones. Integrated with satellite weather data, the system generated pest heatmaps for extension officers. This supported zonal pest alerts and resource allocation for spraying operations.

10. Conclusion

Innovative pest surveillance tools such as light traps integrated with ICT technologies offer a promising solution for efficient, real-time monitoring and forecasting of insect populations. These tools support data-driven crop protection strategies, reduce over-reliance on chemical pesticides, and promote sustainable agriculture. Despite some challenges in deployment and operation, advancements in automation, AI, and remote sensing are likely to make these systems more accessible and effective. Collaboration between research institutions, government agencies, and agri-tech companies will be key to scaling these innovations for broader impact.

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Insecticide Resistance in Major Agricultural Pests: Mechanisms, Detection Techniques, and Management Approaches

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Abstract

Insecticide resistance in agricultural pests is a critical concern that undermines crop protection strategies and threatens global food security. Overuse and misuse of insecticides have accelerated the development of resistance in many economically significant pest species. This paper explores the key mechanisms by which pests develop resistance to insecticides, outlines advanced detection techniques, and presents sustainable management approaches. Understanding these aspects is crucial for devising integrated and adaptive pest management systems that can delay or mitigate resistance. The review also highlights emerging technologies and the role of policy frameworks, offering insights into a multidimensional approach to address this evolving issue.

1. Introduction

Insect pests cause significant yield losses in agriculture globally. The Food and Agriculture Organization (FAO) estimates that insect pests are responsible for up to 40% of crop losses annually. In response, insecticides have been extensively used to manage pest populations. However, repeated and indiscriminate use of insecticides has led to the development of resistance in numerous pest species, reducing the efficacy of chemical control methods. Insecticide resistance is defined as the heritable ability of a pest population to survive doses of insecticides that would normally be lethal. This phenomenon not only threatens crop productivity but also increases production costs, environmental pollution, and health risks to humans and non-target organisms. Addressing this challenge requires a comprehensive understanding of resistance mechanisms, early detection, and effective, science-based management strategies that align with sustainable agricultural practices.

2. Mechanisms of Insecticide Resistance

Pests can develop resistance through several physiological and biochemical changes. The major resistance mechanisms include:

2.1 Metabolic Detoxification

Metabolic resistance is the most common mechanism and involves enhanced activity of detoxifying enzymes that break down or modify insecticides before they reach their target site. Common enzymes include:

- **Cytochrome P450 monooxygenases (P450s)**: Oxidize a wide range of insecticides, leading to their inactivation.
- **Glutathione S-transferases (GSTs)**: Conjugate reduced glutathione to insecticides, making them less toxic.
- **Carboxylesterases (COEs)**: Hydrolyze ester bonds in insecticides like organophosphates and pyrethroids.

  These enzymes are often overexpressed in resistant populations, significantly reducing insecticide toxicity.

2.2 Target Site Insensitivity

This mechanism involves mutations in the target proteins of insecticides, rendering them less sensitive or completely insensitive to the compound. Examples include:

- **Knockdown resistance (kdr)**: Mutations in voltage-gated sodium channels, leading to pyrethroid resistance.
- **Modified acetylcholinesterase (MACE)**: Reduces sensitivity to organophosphates and carbamates.
- **Nicotinic acetylcholine receptor (nAChR) mutations**: Confers resistance to neonicotinoids.
- **GABA receptor mutations**: Associated with resistance to cyclodiene insecticides.

2.3 Reduced Penetration

Changes in the insect cuticle, such as increased thickness or altered lipid composition, may reduce the rate at which insecticides are absorbed. This delays or prevents the compound from reaching its target site.

2.4 Behavioral Resistance

Behavioral resistance involves changes in insect habits that help avoid exposure to insecticides. Examples include:

- Avoidance of treated surfaces
- Shifting feeding patterns (e.g., nocturnal feeding)
- Moving to untreated plant parts or hiding in the soil

2.5 Microbial Symbiont-Assisted Resistance

Recent studies have shown that gut symbionts in some insects can degrade insecticides, aiding in resistance. For instance, symbiotic bacteria in *Riptortus pedestris* degrade organophosphates.

3. Detection Techniques for Insecticide Resistance

Early detection of resistance is crucial for implementing timely management interventions. Several techniques are used for monitoring resistance in pest populations:

3.1 Bioassay Techniques

These involve exposing insects to a range of insecticide concentrations and measuring mortality. Common bioassay methods include:

- **Topical application assays**: Insecticide is applied directly to the insect's body.
- **Leaf-dip or surface contact assays**: Insects are exposed to treated surfaces.
- **Diet incorporation assays**: Insecticide is mixed with food.
- **Glass vial assays**: Quick screening tool for resistance in field-collected insects.

3.2 Biochemical Assays

These tests measure enzyme activity levels in pests to detect elevated detoxification mechanisms:

- **Enzyme-specific substrates** are used to measure the activity of P450s, GSTs, and esterases.
- Useful for understanding metabolic resistance trends and designing targeted interventions.

3.3 Molecular Techniques

Molecular tools help identify genetic mutations associated with resistance:

- **Polymerase Chain Reaction (PCR)**: Detects specific resistance alleles.
- **Quantitative PCR (qPCR)**: Quantifies gene expression related to detoxification enzymes.
- **Gene sequencing and SNP analysis**: Pinpoint mutations at the nucleotide level.
- **CRISPR-Cas diagnostics**: Emerging tool for rapid and precise resistance detection.

3.4 Insecticide Resistance Monitoring Networks

Global and national networks have been established for resistance surveillance:

- **IRAC (Insecticide Resistance Action Committee)**
- **FAO pesticide resistance monitoring system**
- **National agricultural research institutes** collaborate with universities for regional monitoring.

4. Major Agricultural Pests Exhibiting Resistance

Resistance has been documented in several key pests across crops, posing significant challenges to crop protection.

4.1 *Helicoverpa armigera* (Cotton bollworm)

- A highly polyphagous pest.
- Developed resistance to pyrethroids, organophosphates, and Bt toxins.
- Integrated strategies including refuges and mixed cropping systems are being promoted.

4.2 *Bemisia tabaci* (Whitefly)

- A notorious vector of viral diseases.
- Resistant to neonicotinoids, IGRs, and pyrethroids.
- High reproductive rate and genetic plasticity accelerate resistance.

4.3 *Plutella xylostella* (Diamondback moth)

- Exhibits resistance to almost every class of insecticide.

- Among the first pests to develop field-level resistance to Bt toxins.
- IPM using pheromone traps and parasitoids is proving effective.

4.4 *Spodoptera frugiperda* (Fall armyworm)

- An invasive pest recently spread to Asia and Africa.
- Shows resistance to organophosphates, pyrethroids, and Bt proteins.
- Requires global cooperation and rapid response strategies.

4.5 *Myzus persicae* (Green peach aphid)

- Resistant to organophosphates, carbamates, and pyrethroids.
- Multiple resistance mechanisms make management highly complex.

5. Management Approaches to Combat Insecticide Resistance

Sustainable resistance management involves integrating multiple strategies to reduce selection pressure:

5.1 Insecticide Rotation and Mixtures

- Rotate insecticides with different modes of action to minimize cross-resistance.
- Use mixtures with synergistic effects to enhance efficacy.
- Avoid using same MOA groups consecutively.

5.2 Dose Optimization

- Apply insecticides at recommended dosages and frequencies.
- Avoid under-dosing, which promotes resistance.
- Precision agriculture tools help calibrate applications accurately.

5.3 Integrated Pest Management (IPM)

- Combines cultural, biological, mechanical, and chemical control methods.
- Promotes ecological balance and reduces selection pressure.
- Includes:
  - Pest-resistant crop varieties
  - Natural enemies (predators, parasitoids)
  - Timely sowing and intercropping
  - Trap crops and pheromone traps

5.4 Use of Biopesticides and Botanicals

- Microbial pesticides (*Bacillus thuringiensis*, *Beauveria bassiana*) are safe and effective.
- Botanicals like neem, pyrethrum, and garlic extracts have shown efficacy.
- Reduce pesticide residues and preserve beneficial insects.

5.5 Resistance Monitoring and Forecasting

- Real-time surveillance systems and databases for early detection.
- Decision-support systems (DSS) and mobile apps provide timely advisories.
- Weather-based forecasting models help anticipate outbreaks.

5.6 Farmer Education and Policy Support

- Capacity building through training programs and field demonstrations.
- Policy incentives for adopting IPM and reduced-risk pesticides.
- Strong regulatory frameworks to restrict indiscriminate pesticide use.

6. Case Studies and Regional Insights

6.1 India

- Resistance in *Helicoverpa armigera* prompted the use of non-Bt refuges and biological agents.
- Cotton IPM modules have shown reduced pesticide use and higher yields.
- Farmer Field Schools (FFS) promote participatory learning.

6.2 USA

- Structured refuge strategies in Bt maize reduced resistance in *Ostrinia nubilalis*.
- Resistance monitoring by USDA and university networks informs policy.
- Emphasis on scouting, thresholds, and rotation.

6.3 Africa

- *Spodoptera frugiperda* invasion led to emergency response programs.
- Introduction of egg parasitoids like *Telenomus remus*.
- FAO-led community surveillance initiatives improved awareness.

6.4 China

- Genomic surveillance helped detect resistance alleles in *Plutella xylostella*.
- Government supports mass-rearing of natural enemies.

7. Future Perspectives

- **Genomics and AI Tools:** Integrating genomic data with machine learning for resistance prediction.
- **Gene Editing Technologies:** CRISPR tools for gene knockouts in pests and resistance reversal.
- **Nanoformulations:** Improved insecticide delivery and reduced environmental impact.
- **RNAi-Based Insecticides:** Silencing resistance genes to restore susceptibility.
- **Climate Change Considerations:** Changing weather patterns affect resistance evolution and pest behavior.
- **International Collaboration:** Coordinated efforts for resistance management across borders.

8. Conclusion

Insecticide resistance poses a serious challenge to sustainable agriculture and food security. Its management demands an interdisciplinary approach involving entomology, biochemistry, molecular biology, data science, and policy. By integrating conventional and modern tools—ranging from bioassays and IPM to gene editing and AI forecasting—we can formulate effective strategies. Continued investment in resistance research, farmer education, and regulatory frameworks is essential to slow resistance evolution and ensure effective, long-term pest control.

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Integrating Traditional Knowledge and Modern Breeding Techniques for Climate-Smart Agriculture: A Holistic Approach to Crop Improvement

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Abstract

Climate change presents one of the most pressing challenges to global agriculture, jeopardizing food production, biodiversity, and the livelihoods of millions, especially smallholder farmers in developing countries. Developing climate-resilient crop varieties is essential to adapt to increasing environmental stresses. This paper explores the potential of integrating traditional agricultural knowledge (TK) with modern plant breeding techniques to achieve climate-smart agriculture (CSA). Traditional knowledge—passed down over generations—offers insights into locally adapted practices, varietal diversity, and resource-conserving strategies. When integrated with molecular breeding, genetic engineering, and data-driven approaches, these time-tested systems can contribute significantly to building resilient, productive, and sustainable farming systems. This holistic approach to crop improvement is crucial to address climate variability while safeguarding ecological balance and food sovereignty.

1. Introduction

Global agriculture is undergoing a paradigm shift. In the face of increasing climate variability—rising temperatures, erratic rainfall, soil degradation, water scarcity, and the emergence of new pests and diseases—farmers are struggling to maintain yields and sustain livelihoods. These challenges are projected to intensify in the coming decades, threatening global food security and rural development.

In response, climate-smart agriculture (CSA) has emerged as a critical strategy, aiming to:

1. Sustainably increase agricultural productivity and incomes.
2. Adapt and build resilience to climate change.
3. Reduce greenhouse gas emissions where possible.

Central to CSA is the development and adoption of climate-resilient crop varieties that can withstand biotic and abiotic stresses. While scientific advancements in molecular biology, genomics, and biotechnology have revolutionized crop improvement, these technologies often neglect the depth of knowledge embedded in traditional farming systems. Traditional knowledge (TK) is not only a repository of past agricultural wisdom but a potential enabler for future resilience.

This paper makes a case for a holistic crop improvement strategy that synthesizes the strengths of both traditional knowledge and modern plant breeding technologies. It analyzes the synergies, challenges, and pathways to effectively integrate these systems in the context of climate-smart agriculture.

2. Understanding Traditional Knowledge in Agriculture

2.1. Definition and Characteristics

Traditional knowledge (TK) refers to the knowledge, practices, and innovations developed by indigenous and local communities through generations of interaction with their environment. In agriculture, TK encompasses:

- Seed selection, saving, and exchange
- Crop rotation and mixed cropping
- Organic fertilization and composting
- Indigenous weather forecasting
- Localized pest and disease management using botanicals

These practices are often deeply intertwined with cultural and spiritual beliefs, offering a holistic approach to agricultural sustainability.

2.2. Contributions of TK to Crop Improvement

- **Genetic Diversity:** Farmers maintain and exchange landraces—locally adapted crop varieties—that harbor genetic diversity critical for resilience.
- **Stress Adaptation:** Many traditional varieties show resistance to drought, salinity, or pests and diseases.
- **Knowledge of Micro-environments:** Farmers recognize the suitability of specific varieties to microclimatic niches.
- **Sustainable Practices:** TK often emphasizes low-input, biodiversity-rich farming systems, promoting sustainability.

Example: In India, farmers in the Koraput region of Odisha cultivate over 100 landraces of rice, some of which are resistant to submergence and drought, showcasing the richness of indigenous knowledge systems.

3. Modern Breeding Techniques and Their Role in Climate-Smart Agriculture

3.1. Marker-Assisted Selection (MAS)

MAS allows breeders to identify plants carrying desirable genes using molecular markers. This speeds up breeding cycles by enabling early selection for traits like disease resistance, drought tolerance, or quality parameters.

Example: MAS has been used successfully in rice to develop submergence-tolerant varieties (e.g., Swarna-Sub1), significantly benefiting flood-prone areas in South and Southeast Asia.

3.2. Genomic Selection and GWAS

Genomic selection employs dense molecular markers across the genome to predict performance, enabling rapid development of improved cultivars. Genome-wide association studies (GWAS) help locate genomic regions associated with complex traits like heat tolerance or yield stability.

3.3. Genetic Engineering and CRISPR-Cas9

Transgenic technology allows the insertion of foreign genes, while CRISPR-Cas9 allows precise genome editing without introducing foreign DNA. These tools are promising for developing crops with:

- Drought/heat tolerance
- Pest and disease resistance
- Improved nutritional profiles

3.4. Speed Breeding and Phenomics

Controlled environment facilities allow multiple breeding cycles per year ("speed breeding"). Coupled with high-throughput phenotyping, this greatly accelerates the pace of varietal development.

3.5. Bioinformatics and AI Integration

Data-driven breeding utilizes artificial intelligence and machine learning to predict gene–trait associations and simulate outcomes. These innovations enhance breeding efficiency and precision.

4. Bridging the Gap: Integrating TK with Modern Breeding

A siloed approach to breeding—relying solely on modern tools—can result in varieties poorly suited to local conditions. Similarly, relying only on traditional practices may limit scalability and global applicability. A synergistic model is essential.

4.1. Participatory Plant Breeding (PPB)

PPB involves farmers in the selection and breeding process, ensuring that the developed varieties meet local needs and preferences. Benefits include:

- Faster adoption
- Increased genetic diversity
- Empowerment of farming communities
- Blending of experiential and scientific knowledge

4.2. Utilizing Landraces in Pre-breeding

Traditional varieties often possess valuable alleles for traits such as:

- Drought and heat tolerance
- Resistance to local pests
- Grain quality under marginal soils

Pre-breeding involves transferring these traits from landraces to elite cultivars. Genomic tools help identify the genes controlling these traits, allowing targeted introgression.

Example: Landraces of finger millet in Karnataka, India, were found to possess blast resistance genes absent in commercial varieties.

4.3. Knowledge Co-creation Platforms

Platforms that bring together scientists, extension agents, and farmers foster co-learning. Farmer field schools, community seed banks, and digital documentation platforms can serve as vehicles of integration.

4.4. Indigenous Indicators and Climate Adaptation

Local forecasting systems (e.g., bird migration, wind patterns, and plant flowering) are used by farmers to predict weather events. Incorporating such indicators can complement modern meteorological models in planning agricultural interventions.

5. Advantages of Integrating Traditional & Modern Breeding Techniques:

I. **Climate Resilience** – Combines indigenous stress-tolerant crops with fast-tracked biotech improvements.
II. **Biodiversity Conservation** – Preserves rare landraces while enhancing their traits via genomics.
III. **Sustainability** – Merges organic practices (intercropping, natural pest control) with precision agriculture.
IV. **Cost-Effectiveness** – Uses low-input traditional methods alongside affordable marker-assisted breeding.
V. **Faster Adaptation** – Speeds up development of climate-ready crops using farmer knowledge and gene editing.
VI. **Nutritional Security** – Boosts health benefits by blending traditional nutrient-rich crops with biofortification.
VII. **Farmer Empowerment** – Values indigenous wisdom, ensuring inclusive, culturally relevant solutions.

6. Opportunities for Climate-Smart Integration

6.1. Conserving and Characterizing Agro-biodiversity

- Establish community seed banks
- Digitize indigenous varietal traits
- Use remote sensing and GIS to map landrace cultivation

6.2. Breeding for Multifunctionality

Beyond yield, integrate traits like:

- Carbon sequestration potential
- Nitrogen use efficiency
- Compatibility with organic and low-input systems

6.3. Digital Documentation and AI Applications

Mobile applications and digital platforms can:

- Record traditional practices
- Document field performance
- Match landraces to agro-climatic zones

AI tools can help in correlating this information with genomic and environmental data to guide breeding decisions.

7. Challenges in Integration

7.1. Documentation and Validation

Many traditional practices remain undocumented or anecdotal. Scientific validation is necessary to assess their relevance and scalability.

7.2. Intellectual Property and Benefit Sharing

Use of TK raises ethical concerns related to:

- Biopiracy
- Lack of consent
- Inadequate benefit-sharing mechanisms

Access and benefit-sharing (ABS) frameworks, such as the Nagoya Protocol, must be upheld.

7.3. Institutional Fragmentation

Coordination between research institutions, farmers, and policymakers is often weak. Bridging this gap is essential for effective implementation.

7.4. Capacity Gaps

Both farmers and scientists may lack the capacity or willingness to engage with the other's knowledge systems. Training and sensitization programs are needed to foster mutual respect and collaboration.

8. Policy and Institutional Frameworks

8.1. National Agricultural Policies

CSA and TK should be explicitly included in national breeding and extension frameworks. Budget allocation for community-led breeding programs is essential.

8.2. Role of Agricultural Universities and ICAR

Institutions should promote interdisciplinary research, combining genomics, agronomy, anthropology, and climate science. Curricula should include TK and participatory methods.

8.3. Role of International Organizations

FAO, Bioversity International, and CGIAR centers can promote global exchange of germplasm and best practices. Platforms like the Global Plan of Action for the Conservation and Sustainable Use of Plant Genetic Resources should be strengthened.

9. Future Directions

9.1. Hybrid Knowledge Systems

Build integrated systems that combine:

- Genomic databases with local varietal information
- AI models with farmer observations
- Lab-based trials with on-farm participatory testing

9.2. Climate-Smart Innovation Hubs

Develop regional hubs that test and scale innovations combining TK and science. These can function as incubators for adaptive technologies and training centers.

9.3. Scaling Success

Pilot programs should be scaled through public-private partnerships, policy support, and farmer cooperatives.

10. Conclusion

As the world grapples with the twin challenges of climate change and food insecurity, crop improvement must move beyond narrow, yield-centric goals. Integrating traditional knowledge with modern breeding techniques represents a powerful, inclusive, and sustainable pathway toward climate-smart agriculture.

TK provides invaluable insight into plant resilience, ecosystem management, and local adaptation—qualities that are critical under shifting climate regimes. Modern tools offer speed, precision, and scalability. Together, they can help breed crops that not only survive but thrive in changing environments.

This holistic model demands commitment from all stakeholders—farmers, scientists, policymakers, and institutions—to create a resilient and inclusive agricultural future. By valuing both science and tradition, we can build more adaptive, equitable, and climate-resilient food systems for generations to come.

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Pollinators and Their Crucial Role in Enhancing Fruit Set and Crop Productivity

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Introduction

Pollinators play a pivotal role in maintaining biodiversity and food security through their contributions to plant reproduction and fruit production. Globally, it is estimated that about 75% of major food crops depend to some extent on animal-mediated pollination. In horticulture, pollinators are essential for successful fruit set, seed development, and ultimately for maximizing crop yields and quality. With growing concerns over declining pollinator populations due to habitat loss, pesticide use, and climate change, it is imperative to understand the ecological and economic significance of pollinators in agriculture. This paper explores the role of pollinators in fruit set and crop productivity, mechanisms of pollination, major pollinator species, factors affecting pollination efficiency, and strategies for pollinator conservation.

Types of Pollinators in Horticultural Systems

Pollinators include a diverse array of organisms that assist in the transfer of pollen from the male parts (anthers) to the female parts (stigma) of flowers. The primary pollinator groups include:

- **Bees (Apis spp., Bombus spp., solitary bees):** Most effective pollinators for many fruits and vegetables.
- **Butterflies and moths:** Active during daylight and dusk; important for long-tubed flowers.
- **Flies (hoverflies, syrphids):** Often underestimated but valuable in cool climates.
- **Beetles:** Pollinate crops like magnolias and custard apples.
- **Birds (hummingbirds, sunbirds):** Important in tropical horticultural crops.
- **Bats:** Pollinate certain fruit crops such as bananas, guavas, and durians.

Table 1: Types of Pollinators and Associated Crops

Pollinator Type	Common Associated Crops
Honey bees	Apple, Almond, Guava
Bumblebees	Tomato, Blueberry
Butterflies	Passionfruit, Zinnia
Flies	Carrot, Fennel
Birds	Papaya, Banana
Bats	Guava, Mango, Durian

Mechanisms of Pollination

Pollination in horticultural crops may occur through various mechanisms:

- **Self-pollination:** Pollen is transferred within the same flower or between flowers on the same plant.
- **Cross-pollination:** Pollen is transferred between different plants, which enhances genetic diversity and often leads to higher fruit quality.
- **Assisted pollination:** Manual or artificial transfer of pollen is employed in crops where natural pollination is inadequate.

- **Biotic pollination:** Involves animals (primarily insects and birds) that actively transfer pollen while foraging.

Pollination is essential for fertilization, leading to fruit and seed development. Inadequate pollination results in poor fruit set, malformed fruits, or reduced yields.

Table 2: Effects of Pollination on Fruit Development

Fruit Parameter	Poor Pollination	Effective Pollination
Fruit Set (%)	Low	High
Fruit Weight (g)	Light	Heavy
Fruit Shape	Non uniform	Uniform
Shelf Life (days)	Short	Extended
Seed Number	Few	Optimal

Pollination Deficit and Its Impact on Productivity

A **pollination deficit** occurs when the quantity or quality of pollination is insufficient to maximize crop yields. Consequences include:

- Low fruit set and yield.
- Increased fruit drop.
- Poorly developed or misshapen fruits.
- Reduced seed viability.

Studies have shown that inadequate pollination can reduce yields by up to 30-50% in pollinator-dependent crops. For instance, in cucurbits, poor bee activity leads to malformed fruits and low market value.

Factors Affecting Pollinator Efficiency

Pollinators, including bees, butterflies, birds, and bats, play a crucial role in ecosystem health and agricultural productivity. However, their efficiency is influenced by multiple environmental and anthropogenic factors:

1. **Habitat Loss & Fragmentation**
   - **Urbanization & Agricultural Expansion**: Reduces natural habitats, limiting nesting sites and floral resources.
   - **Deforestation**: Eliminates critical foraging and breeding grounds for pollinators.
   - **Land-Use Changes**: Conversion of wildlands into monocultures decreases biodiversity, affecting pollinator diets.
2. **Pesticide Exposure**
   - **Neonicotinoids & Systemic Pesticides**: Disrupt nervous systems, impairing navigation, foraging, and reproduction.
   - **Herbicides**: Reduce weed diversity, eliminating important wildflower food sources.
   - **Sublethal Effects**: Even low pesticide doses weaken immunity and reduce lifespan.
3. **Climate Change**
   - **Phenological Shifts:** Changes in flowering times may not align with pollinator activity, causing food scarcity.
   - **Temperature Extremes:** Heatwaves and erratic weather disrupt pollinator behavior and survival.
   - **Range Shifts:** Some species may migrate, while others face extinction due to inability to adapt.
4. **Monoculture Farming**
   - **Limited Floral Diversity**: Large-scale single-crop systems reduce nutritional variety for pollinators.
   - **Pesticide Dependency**: Intensive farming increases chemical use, harming non-target species.
5. **Invasive Species & Diseases**
   - **Competition from Non-Native Species:** Invasive plants may outcompete native flora, reducing food sources.

- **Pathogens & Parasites:** Varroa mites (affecting honeybees) and fungal infections threaten pollinator health.

6. **Light Pollution**
   - Artificial lighting disrupts nocturnal pollinators like moths and bats, affecting their foraging patterns.
7. **Soil Degradation**
   - Poor soil health reduces plant diversity and floral abundance, indirectly affecting pollinators.

Pollinator Conservation Strategies

To mitigate these threats and enhance pollinator populations, a combination of ecological, agricultural, and policy-based approaches is essential:

1. Habitat Restoration & Enhancement

- **Wildflower Strips & Hedgerows**: Provide diverse, continuous forage for pollinators.
- **Pollinator Gardens**: Urban and rural planting of native, nectar-rich flowers.
- **Cover Crops & Agroforestry**: Enhance biodiversity in farmlands (e.g., clover, alfalfa).

2. Sustainable Agricultural Practices

- **Integrated Pest Management (IPM)**: Minimize pesticide use through biological controls and crop rotation.
- **Organic Farming**: Avoids synthetic chemicals, promoting healthier pollinator populations.
- **Diversified Cropping Systems**: Polycultures and intercropping support varied food sources.

3. Nesting & Shelter Support

- **Bee Hotels & Ground Nesting Sites:** Support solitary bees and other cavity-nesting species.
- **Undisturbed Natural Areas:** Protect deadwood, bare soil, and grassy patches for native pollinators.

4. Policy & Community Engagement

- **Government Incentives**: Subsidies for farmers adopting pollinator-friendly practices.
- **Protected Areas & Corridors**: Establish wildlife-friendly zones in agricultural landscapes.
- **Public Awareness Campaigns**: Educate on the importance of pollinators and conservation methods.

5. Climate Adaptation Measures

- **Assisted Migration**: Help pollinators relocate to suitable habitats as climates shift.
- **Drought-Resistant Planting**: Use climate-resilient native plants to ensure year-round forage.

6. Research & Monitoring

- **Citizen Science Programs**: Engage the public in tracking pollinator populations (e.g., iNaturalist, Bumble Bee Watch).
- **Genetic Studies**: Develop disease-resistant bee strains.

Managed Pollination in Commercial Horticulture

In large-scale horticulture, natural pollination may be supplemented by managed pollinators:

- **Honey bees (Apis mellifera):** Widely used in orchards and greenhouse crops.
- **Bumblebees:** Preferred in greenhouse pollination of tomatoes and peppers.
- **Stingless bees and solitary bees:** Increasingly recognized for niche pollination roles.

Management involves hive placement, timing, and ensuring availability of flowering plants for sustaining colonies.

Future Prospects and Research Needs

To strengthen pollination services, future directions include:

- **Pollinator-friendly crop breeding:** Selecting traits that attract and support pollinators.
- **Ecological modeling:** Understanding pollinator movement and ecosystem interactions.
- **Technology in pollination:** Use of drones and robotic pollinators in controlled environments.
- **Citizen science and data sharing:** Involving farmers and communities in monitoring pollinators.
- **Climate-resilient pollination:** Developing adaptive management for changing climates.

Interdisciplinary research integrating entomology, horticulture, ecology, and remote sensing can greatly advance pollinator management.

Conclusion

Pollinators are an indispensable part of sustainable horticulture. Their role in ensuring effective fruit set and enhancing crop productivity cannot be overstated. However, the ongoing threats to pollinator health necessitate urgent and coordinated actions to conserve and promote their populations. Integrating pollinator-friendly practices into mainstream horticultural management, supported by scientific research and policy incentives, is crucial for securing food systems and ecological balance. By valuing and protecting our pollinators today, we invest in the resilience and productivity of tomorrow's agriculture.

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Soil Pollution by Heavy Metals: Sources, Effects, and Remediation

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Abstract

Heavy metal pollution in soil is a pressing environmental issue with significant implications for ecosystem health, agricultural productivity, and human well-being. Industrialization, mining, excessive use of agrochemicals, and improper waste disposal are major sources of heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), chromium (Cr), and nickel (Ni). These toxic elements can persist in the soil for decades, affecting soil microbial activity, nutrient cycling, and plant health. This paper explores the major sources and effects of heavy metal contamination in soils and presents an overview of various remediation techniques, including physical, chemical, and biological methods. Sustainable remediation approaches and policy interventions are also discussed to promote safer and more productive land use.

1. Introduction

Soil is a vital natural resource that supports plant growth, regulates water cycles, and serves as a habitat for numerous organisms. However, rapid industrial and agricultural development has led to the accumulation of hazardous substances, particularly heavy metals, in the soil environment. Unlike organic pollutants, heavy metals are non-biodegradable and tend to accumulate in soil, posing long-term risks to ecological and human health. The remediation of heavy metal-contaminated soils is crucial for ensuring food safety, environmental sustainability, and public health.

2. Sources of Heavy Metals in Soil

2.1 Industrial Activities

Industrial operations such as metal smelting, electroplating, tanning, battery manufacturing, and chemical processing release large amounts of heavy metals into nearby soils. Effluents and emissions from factories contaminate surrounding land through deposition and runoff.

2.2 Mining and Metallurgical Activities

Mining activities disturb large areas of land and generate waste materials rich in heavy metals. Tailings and slag often contain residual metals like arsenic, lead, and mercury, which can leach into the soil and groundwater.

2.3 Agricultural Practices

- **Pesticides and Fertilizers**: Many phosphate fertilizers and pesticides contain cadmium, arsenic, and lead as impurities.
- **Irrigation with Contaminated Water**: Use of wastewater or polluted surface water for irrigation introduces heavy metals into agricultural soils.

2.4 Urban and Domestic Sources

- **Waste Disposal**: Improper disposal of municipal solid waste, electronic waste, and sewage sludge contributes to soil contamination.
- **Vehicular Emissions**: Lead from gasoline (in countries where leaded fuel is still in use) and brake linings contribute to roadside soil pollution.

Figure 1: Main sources of heavy metals in agricultural soils.

2.5 Atmospheric Deposition

Heavy metals can be transported over long distances through the atmosphere and deposited onto soil surfaces via precipitation or dry deposition.

3. Effects of Heavy Metals on Soil and Ecosystems

3.1 Soil Properties and Microbial Activity

Heavy metals alter the physical, chemical, and biological properties of soil. They reduce soil fertility by:

- Disrupting microbial communities
- Inhibiting enzymatic activities
- Reducing organic matter decomposition

3.2 Plant Growth and Productivity

Heavy metals are phytotoxic and affect plants by:

- Inhibiting seed germination and root elongation
- Disrupting photosynthesis and respiration
- Causing oxidative stress and nutrient imbalance

3.3 Food Chain Contamination

Accumulation of heavy metals in edible plant parts poses a risk to human and animal health. Chronic exposure can lead to:

- Kidney and liver damage
- Neurological disorders
- Carcinogenic effects

3.4 Groundwater Pollution

Leaching of heavy metals from contaminated soils can pollute groundwater sources, further extending the environmental and health hazards.

4. Remediation Techniques for Heavy Metal-Contaminated Soils

4.1 Physical Remediation Methods

4.1.1 Soil Excavation and Replacement

Contaminated soil is removed and replaced with clean soil. This method is effective but expensive and may not be feasible on a large scale.

4.1.2 Soil Washing

Involves using chemical solutions to extract heavy metals from the soil matrix. This method requires careful handling of washing solutions and residues.

4.2 Chemical Remediation Methods

4.2.1 Stabilization/Solidification

Chemical agents such as lime, phosphates, and cement are added to immobilize heavy metals and reduce their bioavailability.

4.2.2 Soil Amendments

Use of materials like biochar, zeolites, and clay minerals to adsorb heavy metals and prevent their uptake by plants.

4.3 Biological Remediation Methods

4.3.1 Phytoremediation

Use of metal-accumulating plants (e.g., *Brassica juncea*, *Helianthus annuus*) to extract, stabilize, or volatilize heavy metals.

- **Phytoextraction**: Uptake and accumulation in plant tissues.
- **Phytostabilization**: Immobilization in the root zone.
- **Phytovolatilization**: Conversion to volatile forms.

4.3.2 Bioremediation

Use of microorganisms (bacteria, fungi) to detoxify or immobilize heavy metals through biosorption, bioaccumulation, or enzymatic transformation.

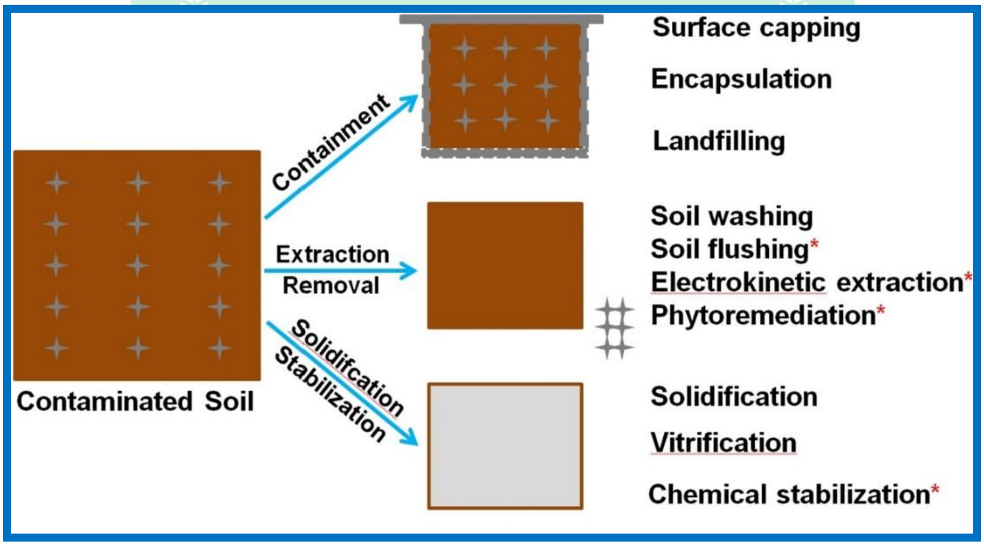

Figure 2: Different remediation techniques for heavy metal-polluted soil

4.4 Electrokinetic Remediation

Application of electric current to mobilize and extract heavy metals from the soil. Effective for fine-textured and low-permeability soils.

5. Sustainable Approaches to Soil Remediation

5.1 Integrated Remediation Strategies

Combining physical, chemical, and biological methods enhances remediation efficiency and sustainability.

5.2 Use of Organic Amendments

Organic materials such as compost, manure, and biosolids improve soil structure, microbial activity, and reduce heavy metal mobility.

5.3 In-situ vs. Ex-situ Remediation

In-situ methods are cost-effective and environmentally friendly, while ex-situ methods offer higher control but at greater expense.

6. Monitoring and Risk Assessment

6.1 Soil Testing and Metal Speciation

Regular monitoring of total and bioavailable heavy metal concentrations helps assess risk and track remediation progress.

6.2 Human Health Risk Assessment

Involves evaluating exposure pathways (inhalation, ingestion, dermal contact) and potential health outcomes.

6.3 Ecological Risk Assessment

Examines the impact of heavy metals on soil organisms, plant communities, and overall ecosystem functions.

7. Policy Interventions and Management Practices

7.1 Regulatory Standards

Establishing permissible limits for heavy metals in soils, crops, and water by national and international agencies (e.g., WHO, FAO, CPCB).

7.2 Land Use Planning

Restricting cultivation of food crops in contaminated areas and promoting alternative land uses (e.g., energy crops, forestry).

7.3 Public Awareness and Education

Raising awareness among farmers, industries, and communities about the sources, risks, and management of heavy metal pollution.

8. Conclusion

Heavy metal contamination of soil is a multifaceted problem that threatens environmental quality, agricultural productivity, and human health. While numerous remediation technologies exist, sustainable management requires an integrated approach that combines technical interventions with policy support and community participation. Continued research, risk assessment, and development of cost-effective, eco-friendly technologies are essential to mitigate soil pollution and ensure long-term land productivity.

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Vermicomposting: A Sustainable Approach to Enhancing Soil Quality

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Abstract

Vermicomposting is an eco-friendly and sustainable method of converting organic waste into nutrient-rich compost using earthworms. This process not only aids in waste management but also enhances soil fertility, structure, and microbial activity. Compared to traditional composting, vermicomposting is faster and produces a superior organic fertilizer. This paper explores the principles, mechanisms, benefits, and applications of vermicomposting in agriculture and environmental sustainability. Additionally, it discusses the challenges, economic viability, policy implications, and future prospects of vermicomposting as a key strategy for improving soil quality and promoting circular economies.

Keywords: Vermicomposting, earthworms, organic waste, soil fertility, sustainable agriculture, circular economy

Introduction

Soil, often regarded as a non-renewable natural resource, plays a fundamental role in supporting agricultural productivity, maintaining ecological balance, and ensuring food security. However, decades of unsustainable agricultural practices, excessive use of chemical fertilizers, and mismanagement of organic wastes have led to significant soil degradation, resulting in the depletion of soil organic matter, reduced microbial activity, and poor soil structure. In the face of these challenges, there is a growing emphasis on adopting sustainable and eco-friendly soil management strategies. Among these, **vermicomposting** has emerged as an effective biotechnological process to recycle organic wastes and enhance soil quality naturally.

Vermicomposting is the process of decomposition of organic materials by earthworms, which convert biodegradable waste into nutrient-rich humus-like material called vermicompost. It not only improves soil physical, chemical, and biological properties but also provides an environmentally sustainable way to manage organic waste. This paper explores the principles, mechanisms, benefits, and applications of vermicomposting in enhancing soil quality, while highlighting its role in sustainable agriculture.

Vermicomposting

Definition and Mechanism

Vermicomposting is a **bio-oxidative process** where earthworms and microorganisms decompose organic waste into stable humus. The steps include:

1. **Ingestion:** Earthworms consume organic matter (food scraps, manure, crop residues).
2. **Fragmentation:** The gizzard mechanically grinds the waste into finer particles.
3. **Enzymatic Digestion:** Gut enzymes (proteases, amylases, cellulases) break down complex compounds.
4. **Microbial Action:** Symbiotic microbes further decompose organic matter.
5. **Excretion:** Earthworms release nutrient-rich **castings (vermicompost)**.

Optimal Conditions for Vermicomposting

- **Temperature:** 15–25°C (earthworms become inactive below 5°C and above 30°C).
- **Moisture:** 60–70% (prevents desiccation or anaerobic conditions).
- **pH:** 6.5–7.5 (neutral to slightly acidic).
- **Aeration:** Requires oxygen for aerobic decomposition (turning the pile helps).
- **Feedstock:** Carbon-to-nitrogen (C:N) ratio of 25–30:1 (e.g., vegetable scraps + shredded paper).

Benefits of Vermicompost on Soil Quality

Vermicompost plays a vital role in improving the **physical**, **chemical**, and **biological** properties of soil, making it an ideal input for sustainable soil management. Below is a detailed breakdown of its multifaceted benefits:

A. Physical Benefits

1. **Improves Soil Structure:**
   Vermicompost enhances the formation of stable soil aggregates, which improve soil tilth and prevent erosion.
2. **Increases Water-Holding Capacity:**
   The humus content in vermicompost enhances the soil's ability to retain moisture, reducing irrigation requirements.
3. **Enhances Soil Porosity and Aeration:**
   Vermicompost particles create spaces in the soil, improving air circulation and promoting healthy root respiration.
4. **Reduces Soil Compaction:**
   Regular application loosens hard soils, especially clay-rich soils, making them more friable and easier to work with.
5. **Improves Root Penetration:**
   Better soil structure and aeration enable deeper and healthier root systems, improving nutrient uptake.

B. Chemical Benefits

1. **Supplies Essential Nutrients:**
   Vermicompost contains macro-nutrients like Nitrogen (N), Phosphorus (P), and Potassium (K), and micronutrients such as Iron (Fe), Zinc (Zn), Copper (Cu), and Manganese (Mn) in plant-available forms.
2. **Increases Soil Organic Matter:**
   Rich in humic substances, vermicompost adds stable organic matter to the soil, enhancing nutrient storage and exchange.
3. **Enhances Cation Exchange Capacity (CEC):**
   Improved CEC allows soil to retain more nutrients and make them available to plants over time.
4. **Buffers Soil pH:**
   Vermicompost helps neutralize acidic or alkaline soils, maintaining an optimal pH range for plant growth.
5. **Reduces Nutrient Leaching:**
   Nutrients in vermicompost are released slowly, minimizing losses due to leaching and increasing fertilizer use efficiency.

C. Biological Benefits

1. **Boosts Microbial Activity:**
   Vermicompost is teeming with beneficial microorganisms such as nitrogen-fixing bacteria, phosphate-solubilizing bacteria, and fungi that support nutrient cycling.
2. **Enhances Enzymatic Activity:**
   Enzymes like dehydrogenase, urease, and phosphatase present in vermicompost accelerate the decomposition of organic matter and nutrient mineralization.
3. **Increases Earthworm Populations:**
   Continuous use of vermicompost creates a favorable environment for native earthworms, further enhancing soil aeration and mixing.
4. **Suppresses Soil-Borne Pathogens:**
   Beneficial microbes and antibiotics present in vermicompost can suppress harmful fungi, nematodes, and bacteria, reducing disease incidence.
5. **Promotes Symbiotic Relationships:**
   Encourages mycorrhizal fungi and rhizobia development, which improve nutrient uptake and nitrogen fixation in legumes.

D. Plant-Related Benefits Linked to Soil Quality

1. **Enhances Seed Germination and Root Development:**
   Growth hormones like auxins, gibberellins, and cytokinins present in vermicompost stimulate faster and healthier plant growth.
2. **Improves Crop Yield and Quality:**
   Better soil health translates into higher productivity, improved nutritional content, and better taste and shelf life of produce.

E. Environmental Benefits (Soil Ecosystem)

1. **Restores Degraded Soils:**
   Vermicompost rebuilds soil fertility in overused or chemically degraded soils, aiding in land reclamation.
2. **Reduces Dependence on Chemical Fertilizers:**
   By providing a complete, natural nutrient source, vermicompost reduces the need for synthetic inputs, minimizing environmental pollution.

Comparative Advantage Over Conventional Methods

Parameter	Vermicompost	Chemical Fertilizers	Traditional Compost
Nutrient Release	Slow-release (6-8 weeks)	Immediate (1-2 weeks)	Moderate (4-6 weeks)
Microbial Activity	10^8-10^9 CFU/g	Suppresses microbes	10^6-10^7 CFU/g
Soil Structure	Improves permanently	No effect	Temporary improvement
Environmental Impact	Carbon-negative	GHG emissions	Carbon-neutral

Applications of Vermicomposting

- **Agriculture:** Boosts crop yields (20-30%) and improves soil fertility for cereals, vegetables, and fruits
- **Organic Farming:** Replaces chemical fertilizers, enhances nutrient uptake, and promotes sustainable practices
- **Urban Waste Management:** Processes food scraps, garden waste, and paper into nutrient-rich compost
- **Landscaping & Turf:** Improves soil structure in parks, golf courses, and lawns
- **Horticulture & Nurseries:** Enhances plant growth in potting mixes and greenhouse cultivation
- **Bioremediation:** Degrades pesticides and binds heavy metals in contaminated soils
- **Hydroponics & Aquaponics:** Provides organic nutrient solutions for soilless farming

- **Home Gardening:** Small-scale composting for eco-friendly urban households
- **Municipal Programs:** Reduces landfill waste through community vermicomposting initiatives
- **Climate Mitigation:** Sequesters carbon and reduces methane emissions from organic waste

Challenges and Limitations

- **Climatic Sensitivity:** Earthworms are vulnerable to extreme temperatures and moisture changes.
- **Labor & Monitoring:** Regular management is essential to maintain compost quality.
- **Knowledge Gap:** Lack of farmer awareness and technical training hinders adoption.
- **Scalability Issues:** Large-scale operations need planning, raw materials, and market access.

Future Prospects and Recommendations

- **Policy Support:** Subsidies and training for rural vermicomposting units.
- **Research & Innovation:** Focus on earthworm species and compost quality.
- **Integration:** Use with biofertilizers and crop rotation.
- **Urban Waste Use:** Promote city-based vermicompost units.
- **Digital Tools:** Mobile apps and online platforms for outreach and marketing.

Conclusion

Vermicomposting represents a practical, sustainable, and ecologically sound method of enhancing soil quality while simultaneously addressing the global challenge of organic waste management. Its ability to improve soil structure, enrich nutrient availability, and promote beneficial microbial activity makes it an indispensable tool for modern, climate-resilient agriculture.

Moreover, it offers a viable economic opportunity for farmers, entrepreneurs, and waste managers alike. Although challenges such as climatic sensitivity, limited awareness, and scalability constraints exist, these can be overcome through targeted policy support, research, education, and infrastructure development.

As agriculture transitions from intensive, input-heavy practices to more regenerative and resource-efficient models, vermicomposting stands out as a nature-based solution that aligns with environmental sustainability, food security, and rural development. Its integration into mainstream agricultural systems can help restore degraded soils, reduce environmental pollution, and ensure long-term productivity for future generations.

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Kitchen Garden: The Nutritional and Livelihood Security

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Food is one of the most fundamental human requirements. India ranked 105th out of 127 countries in the global hunger index (GHI) 2024, which indicates a serious level of hunger with score of 27.3 on a 100 scale. One of the most crucial areas to concentrate in developing countries like India is food security and nutritional diversity. A lot of strategies are required to address the problems of food production and food security. The current social, political and economic landscape as well as the resources available to plan and carry out the intervention will determine which workable strategies are best. Using home labour in the kitchen garden can increase the household's nutritional diversity and food security. Even in the tiny regions surrounding the house when land resources are limited, a difference in life can be made. Small towns and households make use of vacant land to supply their own food needs as well as the needs of the city in which they live.

Kitchen gardening plays an important role for rural families to recover diversified vegetables in their daily diet. The growing of vegetable crops in the backyard of residential houses to meet the requirement of family throughout the year is known as kitchen garden, home garden, nutrition garden or vegetable garden. It is the most ancient type of vegetable gardening and primarily intended for continuous supply of seasonal vegetables and fruits for family use. A number of vegetables are grown in available land for getting a variety of vegetables. Family members do most of works. Nearly five percents of land (250 m^2) is sufficient to provide vegetables throughout year for a family consisting of five members. In rural area, land will not be a limiting factor and scientifically laid out garden can be established. In urban areas, land is a limiting factor and very often crops are raised in limited available area or in terraces of buildings. Cultivation of crops in pots, cement bags, window sills, balconies and roof of buildings is also feasible in cities. That is the path to health and we will be happy and healthy if we grow our own greens. The value of garden produce for a healthy diet long before doctors began prescribing vitamins, minerals and fibre. Vegetables are grown in gardens without the use of pesticides and other chemicals.

Importance of kitchen garden

Vegetables are crucial for a healthy diet due to their rich supply of essential nutrients that support numerous bodily functions. They provide vitamins, minerals, proteins, fibre and antioxidants, contributing to maintain overall well being and helping to prevent chronic diseases. The recommended daily allowance by the Indian Council of Medical Research (ICMR) for an adult person is 300 g of vegetables and 100 g fresh fruits. It includes 125 g leaf vegetables, 100 g roots and tubers and 75 g other vegetables. However, it varies with age of people and nature of work. Vegetables are widely approved for their importance in terms of human nutrition, national economy and health standards. Vegetables due to their short growing seasons, year-round availability, significantly more yield and income per unit area and time, they make excellent choices for home garden. This practice not only ensures a healthy diet but also lowers living expenses and increases family income. Home gardens can aid in the recycling of left over materials, particularly if a compost pit is established.

Advantages of the kitchen garden

- Continuously supply of fresh fruits and vegetables high in nutritive value.
- To reduce the expense of purchasing herbs and vegetables.
- Grow your own vegetables for health benefits.
- Supply fruits and vegetables free from toxic chemicals.
- Vegetables harvested from home garden for better taste than purchased from market.
- Effective utilization of land.
- Making efficient use of kitchen garbage materials and waste water.

- Drained water from kitchen is efficiently utilized.
- Leisure hours of the family members can be spent.
- Induces children on awareness of dignity of labour.
- Housewives in absence of male can be obtained vegetables at any time in emergency even during night hours.
- Increase in vegetable production.

How to make a kitchen garden?

Many people are unable to cultivate the necessary vegetables because there is frequently no tradition of kitchen gardening. Alternatively, they overspend on vegetables or the deficiency in vegetables negatively impacts their health. It is possible that you have failed to establish a kitchen garden. There are several reasons why starting a kitchen garden can be challenging.

For example:

- The crop was damaged by livestock diseases or pests.
- No good seed or seedlings
- Lack of space
- Lack of water
- Lack of fertile soil
- No spare time
- Lack of the right skills

Sites selection and size

The choice for selection of site for a kitchen garden is limited due to shortage of land in homestead. Usually a kitchen garden is established in backyard of house, near water source in an open area receiving plenty of sunlight. Size and shape of vegetable garden depends on availability of land, number of persons in family and spare time available for its care. Nearly 5% of land (225 m^2) is sufficient to provide vegetables throughout year for a family consisting of five members. A rectangular garden is preferred to a square plot or a long strip of land.

Land preparation

Stones, stubbles, bushes and perennial weeds should be removed. Well decomposed farmyard manure or vermicompost about 100 kg is applied and mixed with the soil. As per the requirement nursery bed should be formed.

Sowing and planting

Direct sown crop like okra, cluster bean and cowpea can be sown on one side of the ridges. Transplanted crops like tomato, brinjal, chilli, cabbage, cauliflower and cucurbits can be sown in nursery beds or pots for one month after that seedlings transplanted in the main field. Vegetables such as beet leaf, coriander, fenugreek, spinach, carrot, radish, turnip and beetroot are sown by broadcasting or line sowing. Peas sown in lines are facilitates ease in intercultural operations and harvesting.

Table 1: Crops suitable for kitchen garden

Vegetables	Tomato, Brinjal, Chilli, Okra, Onion, Cabbage, Cauliflower, Knol-khol, Pumpkin, Bitter gourd, Bottle gourd, Ridge gourd, Pointed gourd, Pea, Cluster bean, Cowpea, Carrot, Radish, Beet root, Palak, Curry leaf, Moringa
Fruits	Mango, Banana, Guava, Papaya, Acid lime, Aonla, Pomegranate, Jamun, Ber, Karonda, Jackfruit
Spices	Turmeric, Coriander, Fenugreek, Garlic, Ginger
Flowers	Marigold, Rose, Jasmine, Chrysanthemum, Tuberose, Sunflower, Hibiscus, Periwinkle, Night Jasmine
Medicinal plants	Aloe, Mint, Basil, Ashwagandha, Sarpgandha, Hirda, Behada, Shatavari, Lemon grass

Irrigation

Irrigation should be done when crops required. Drip irrigation is often the most efficient and water-saving method. It delivers water directly to the plant roots, minimizing evaporation and weed growth.

Weeding

Weeding is crucial necessary for maintaining a healthy and productive garden. It is important to remove weeds by hand from surrounding pathways and grass as well, if they are allowed to go to seed. Mulch is an effective way to help prevent weeds in gardens.

Growing of vegetables in pots or boxes

Ordinary earthen pots having diameter of 30-35 cm are ideal for growing vegetables. The wooden boxes should be 75 cm long, 45 cm broad and 50 cm high. The inner and outer sides of the pots or boxes must be painted with some water proof paint. They should be provided legs and handles to handle them easily.

Limitations

- Land is the limiting factor.
- Limited choice of size, shape and location.
- Attack of birds and monkeys, etc.
- Lack of knowledge to the house owners.

Implements used in kitchen garden

- Spade
- Pick-axe
- Hoe
- Hand trowels
- Hand rakes
- Secateur
- Hand sprayer
- Water can

Constraints in adoption of scientific kitchen gardening

A. Input constraints

i. Non-availability of quality planting materials for fruits and vegetables
ii. Lack of irrigation facility due to scarcity of water in area
iii. Unavailability of land for gardening near residential zone
iv. Less availability of well-rotten farm yard manure
v. Specific eco-friendly insecticides are unavailable in market.

B. Technical constraints

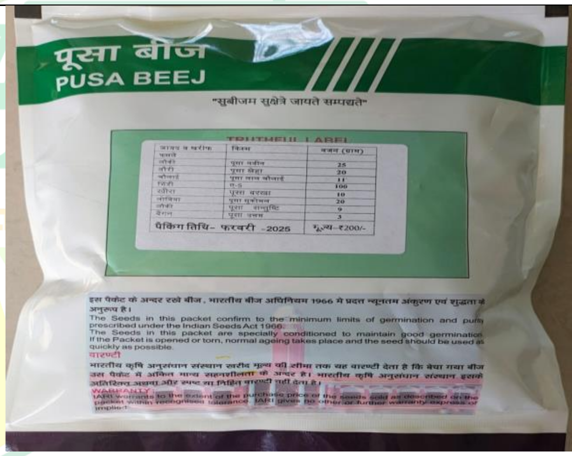
i. Lack of knowledge regarding nutritious fruits and vegetables selection
ii. Lack of knowledge about sowing time, improved varieties and seed rate
iii. Lack of knowledge about seed treatment.
iv. Lack of knowledge insect-pests, diseases and their management
v. Lack of knowledge regarding critical growth stages of crops for irrigation
vi. Lack of knowledge about manures and fertilizers recommendation
vii. Lack of knowledge concerning seed multiplication

Conclusion

The adoption of kitchen gardening package of practices *i.e.*, awareness creation, capacity building, layout and cropping sequence, plays pivotal role in ensuring sustainability, boost economic growth, nutritional and livelihood security of farmer families. Food grains are adequate to supply the body with the necessary amounts of fat, protein and carbohydrates, but not the necessary amounts of vitamins and minerals. In our country, poor and landless peoples are victims of malnutrition, which results in child mortality, morbidity, anemia and other problems. It has been noted that fruits and vegetables provide an adequate amount of vitamins, minerals, proteins and fibre to the human diet.

Table 2: Crop calendar of recommended vegetables in kitchen gardening

Crops	Sowing method	Seed rate	Spacing	Days to maturity
Summer season (March-June)				
Tomato	Transplant	400-500 g/ha	60 cm × 30 cm	110-115 days
Brinjal	Transplant	400-500 g/ha	60 cm × 60 cm	50-60 days
Chilli	Transplant	1.0-1.5 kg/ha	60 cm × 45 cm	95-100 days
Okra	Direct	18-20 kg/ha	45 cm × 20 cm	45-50 days
Bottle gourd	Direct	4-5 kg/ha	2.5 m × 2.0 m	55-60 days
Cucumber	Direct/ Transplant	2.5-3.0 kg/ ha	1.5 m × 60 cm	50-70 days
Cowpea	Direct	20-25 kg/ha	50 cm × 10-15 cm	45-55 days
Monsoon season (July-September)				
Pumpkin	Direct	4-5 kg/ha	200 cm × 90 cm	70-75 days
Bitter gourd	Direct	4-5 kg/ha	200 cm × 80 cm	55-60 days
Cluster bean	Direct	25-30 kg/ha	45-60 cm × 15 cm	90-120 days
Potato	Direct	15-20 q/ha	60 cm × 15-20 cm	70-120 days
Carrot	Direct	5-6 kg/ha	25-30 cm × 10 cm	75-80 days
Radish	Direct	10 kg/ha	45 cm × 6-8 cm	40-45 days
Winter season (October-February)				
Peas	Direct	100-120 kg/ha	30 cm × 5-10 cm	55-60 days
Garlic	Direct	500 kg cloves/ha	15 cm × 7-8 cm	120-150 days
Turnip	Direct	3-4 kg/ha	30-45 cm × 10 cm	40-50 days
Beet root	Direct	7-9 kg/ha	45-60 cm × 10 cm	80-90 days
Spinach	Direct	35-45 kg/ha	30 cm × 10-12 cm	60 days
Coriander	Direct	15 kg/ha	20 cm ×15 cm	30-40 days
Onion	Transplant	8-10 kg/ha	15 cm × 10 cm	150-160 days
Cabbage	Transplant	400-500 g/ha	45 cm × 45 cm	90-100 days
Cauliflower	Transplant	400-500 g/ha	60 cm × 30-45 cm	120-125 days
Broccoli	Transplant	300-400 g/ha	60 cm × 45 cm	90-100 days
Knol-khol	Transplant	1.0 kg/ha	30-40 cm × 20 cm	55-70 days



Glimpse of PUSA nutri kitchen garden kit

Awareness programme about nursery raising

Cabbage in kitchen garden

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Seed Priming with Beneficial Microorganisms: A Sustainable Approach for Enhancing Crop Performance

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Abstract

Seed priming with beneficial microorganisms, also known as bio-priming, is a sustainable, innovative, and environmentally friendly seed treatment method that combines the physical benefits of traditional seed priming with the biological advantages conferred by microbial inoculation. This method not only enhances seed germination and early seedling growth but also imparts tolerance to abiotic and biotic stresses, reduces dependence on chemical inputs, and boosts overall crop productivity. In the face of modern agricultural challenges—such as climate change, soil degradation, and diminishing returns from chemical fertilizers—microbial seed priming offers a promising and eco-conscious strategy. This essay delves into the mechanisms, benefits, microbial agents involved, practical applications, and the role of this technique in sustainable agriculture.

Introduction

In recent decades, global agriculture has been increasingly pressured by growing food demand, climate unpredictability, soil fertility decline, and environmental degradation due to overreliance on chemical fertilizers and pesticides. There is a pressing need for innovative, sustainable agricultural practices that not only ensure productivity but also maintain ecological balance. Among these strategies, microbial seed priming has emerged as a robust and scalable solution.

Seed priming with beneficial microorganisms offers a dual shield to plants—protecting them from abiotic stresses like drought, salinity, and extreme temperatures, and biotic threats such as fungi, bacteria, and nematodes. It achieves this through a complex interplay of physiological fortification, gene expression modulation, and microbial antagonism. These capabilities make microbial seed priming an essential component of climate-resilient, low-input, and sustainable agriculture systems.

Seed priming, by definition, refers to a pre-sowing hydration process that initiates the early physiological processes of germination without the actual emergence of the radicle. When combined with beneficial microorganisms, the process transforms into "bio-priming," which biologically fortifies seeds. These inoculated seeds possess enhanced germination potential, are better equipped to withstand environmental stress, and form symbiotic relationships with soil microbes, leading to improved plant health and yield.

What is Microbial Seed Priming?

Microbial seed priming is a biotechnological advancement where seeds are soaked in a suspension containing beneficial microorganisms and then dried back to original moisture content before sowing. The treatment allows the microbes to colonize the seed coat and become the first biological agents to interact with the soil during germination.

Upon planting, these microbes colonize the rhizosphere (root zone) and interact positively with the developing plant. This interaction enhances seedling vigor, facilitates nutrient uptake, imparts resistance to diseases, and improves tolerance to environmental stresses such as drought and salinity. Unlike synthetic inputs, bio-priming works in harmony with nature, utilizing naturally occurring soil microorganisms that have co-evolved with plants for millennia.

Key Microorganisms Used in Seed Bio-Priming

A wide range of **plant growth-promoting microorganisms (PGPMs)** are used in seed priming, each offering unique benefits. Some of the most commonly used microbial strains include:

Microorganism	Key Benefits
Rhizobium spp.	Symbiotic nitrogen fixation in legumes.
Azospirillum spp.	Enhances root development and nitrogen use efficiency.
Azotobacter spp.	Free-living nitrogen fixer; improves overall plant growth.
Bacillus subtilis	Acts as a biocontrol agent; protects against fungal pathogens.
Pseudomonas fluorescens	Promotes root growth; induces systemic resistance to pathogens.
Trichoderma harzianum	Suppresses soil-borne pathogens; boosts plant vigor.
Arbuscular Mycorrhizal Fungi (AMF)	Improves phosphorus and water uptake; establishes long-term symbiotic relationship.
Phosphobacteria	Solubilizes insoluble phosphates, enhancing phosphorus availability.

These microbes are selected based on the crop, soil condition, and the specific challenges being addressed (e.g., nutrient deficiency, drought, or pathogen load).

Steps Involved in Microbial Seed Priming

The bio-priming process involves several key steps to ensure effective microbial colonization and seed vitality:

1. **Seed Selection**: High-quality, healthy, and disease-free seeds are chosen for priming. Uniformity in seed size and weight ensures consistency in treatment outcomes.
2. **Preparation of Microbial Culture**: A specific strain or a consortium of beneficial microbes is cultured in suitable growth media. The culture is diluted to a desirable concentration, generally in the range of 10^6–10^8 CFU/mL.
3. **Priming Process**:
    - Seeds are soaked in the microbial suspension for 6 to 24 hours depending on crop type and seed size.
    - During this time, the microbes begin colonizing the seed surface and enter natural openings or cracks.
4. **Drying**: After soaking, seeds are shade-dried to their original moisture content. This step ensures that the seeds remain viable and do not begin germination prematurely.
5. **Sowing**: The treated seeds are then ready for field planting. Upon sowing, the microbial partners establish themselves in the rhizosphere and support plant growth from germination onward.

Mechanism of Seed Priming (Mode of Action)

Seed priming is a controlled hydration technique that activates the early metabolic processes required for germination but prevents radicle protrusion. When combined with beneficial microorganisms (bio-priming), it not only enhances seed metabolism but also introduces biological agents that confer added advantages. Below is a detailed explanation of the physiological, biochemical, and microbial mechanisms involved in seed priming:

1. Initiation of Metabolic Processes Without Radicle Emergence

- During priming, seeds absorb a limited amount of water that initiates pre-germinative metabolism without crossing the threshold of full germination.
- Key biochemical activities begin, including:
    - DNA repair
    - Protein synthesis (from stored mRNA)
    - Activation of antioxidant enzymes
    - Mitochondrial repair and energy metabolism

This prepares the seed for rapid and uniform germination once sown.

2. Improved Membrane Integrity

- One of the early events in priming is membrane reorganization.
- Hydration allows repair of damaged cell membranes caused by desiccation during seed storage.

- This enhances the selective permeability of membranes, leading to better solute and nutrient exchange.

3. Enhanced Enzymatic Activity

- Priming activates hydrolytic enzymes such as:
  - Amylase – converts starch into sugars
  - Protease – breaks down stored proteins into amino acids
  - Lipase – mobilizes stored lipids

These enzymes fuel early growth by providing energy and building blocks for embryo development.

4. Stress Tolerance Induction

- Primed seeds show enhanced activity of antioxidant enzymes (SOD, CAT, POD), which help in detoxifying reactive oxygen species (ROS) generated under stress.
- The seeds become better equipped to tolerate abiotic stresses like drought, salinity, and heat due to:
  - Increased accumulation of osmolytes (proline, glycine betaine)
  - Production of heat shock proteins and stress-protective metabolites

5. Microbial Colonization and Rhizosphere Competence

When microbial inoculants are included in the priming solution (bio-priming), several biological mechanisms are triggered:

a. Seed Surface Colonization

- Beneficial microbes colonize the seed coat and micro-pore openings.
- Upon sowing, these microbes proliferate and establish in the rhizosphere, forming a protective and symbiotic microenvironment.

b. Production of Phytohormones

- Microbial strains like *Azospirillum*, *Bacillus*, and *Pseudomonas* synthesize hormones such as:
  - Indole-3-acetic acid (IAA) – enhances root elongation
  - Gibberellins – promote cell elongation and germination
  - Cytokinins – stimulate shoot development

c. Nutrient Solubilization and Fixation

- Phosphobacteria solubilize inorganic phosphates.
- Rhizobium, Azotobacter, and Azospirillum fix atmospheric nitrogen.
- Mycorrhizae improve uptake of water and immobile nutrients like phosphorus and zinc.

d. Induced Systemic Resistance (ISR)

- Some microbes like *Trichoderma* and *Pseudomonas fluorescens* induce systemic resistance in plants.
- This primes the plant immune system for faster and stronger response to pathogen attacks.

e. Biocontrol of Pathogens

- Bio-primed seeds are less susceptible to seed and soil-borne diseases.
- Mechanisms include:
  - Antibiosis: Production of antimicrobial compounds
  - Competition: For nutrients and root space
  - Mycoparasitism: Direct attack on pathogenic fungi by *Trichoderma*

6. Enhanced Root Architecture

- The combined effect of phytohormone production and microbial colonization results in:
  - Increased root length and root hair formation
  - Greater root surface area for absorption
  - Better anchorage and exploration of soil

This leads to improved water and nutrient uptake, even under sub-optimal soil conditions.

Effects of Seed Priming with Beneficial Microbes on Biotic and Abiotic Stress

Seed priming with beneficial microbes (bio-priming) is an effective strategy to improve plant resilience against both biotic stresses (caused by living organisms like pathogens and pests) and abiotic stresses (caused by environmental factors like drought, salinity, temperature extremes, and nutrient deficiencies). The protective and growth-promoting traits conferred by microbial priming are largely due to their biological interactions, induction of systemic tolerance, and modulation of plant physiological responses.

A. Effect on Abiotic Stress Tolerance

Abiotic stresses are major constraints in agriculture that severely affect seed germination, seedling growth, and yield. Microbial seed priming can mitigate such stresses through the following mechanisms:

1. Drought Stress

- **Mechanism**: Beneficial microbes like *Bacillus subtilis*, *Azospirillum*, and Arbuscular Mycorrhizal Fungi (AMF) help in the production of osmoprotectants (e.g., proline, glycine betaine), reduce transpiration, and enhance water uptake.
- **Effect**: Improved root architecture and water-use efficiency; seeds germinate faster and seedlings survive better under limited moisture conditions.

2. Salinity Stress

- **Mechanism**: Microbes such as *Pseudomonas fluorescens* and *Trichoderma spp.* modulate ionic balance by improving Na^+/K^+ ratios and upregulating stress-related genes.
- **Effect**: Enhanced seedling establishment, chlorophyll retention, and reduced oxidative damage under salt stress.

3. Heat and Cold Stress

- **Mechanism**: Primed seeds show increased expression of heat-shock proteins (HSPs) and cold-induced proteins (CIPs) due to microbial signaling.
- **Effect**: Improved germination rate and seedling vigor under temperature extremes.

4. Nutrient Deficiency

- **Mechanism**: Phosphate-solubilizing bacteria (*Phosphobacteria*) and nitrogen-fixers (*Azotobacter*, *Rhizobium*) make essential nutrients more available.
- **Effect**: Efficient nutrient uptake leads to healthier seedlings even in poor soil conditions.

B. Effect on Biotic Stress Resistance

Biotic stresses like fungal diseases, bacterial infections, and nematode attacks can be suppressed by beneficial microbes through several direct and indirect mechanisms:

1. Disease Suppression (Antagonism)

- **Microbes Involved**: *Trichoderma harzianum*, *Bacillus subtilis*, *Pseudomonas fluorescens*
- **Mechanism**:
  - **Antibiosis**: Production of antimicrobial compounds (e.g., antibiotics, lytic enzymes).
  - **Mycoparasitism**: Direct attack and degradation of pathogenic fungi.
  - **Competition**: Occupation of ecological niches and resources, limiting pathogen growth.
- **Effect**: Lower incidence of seed and soil-borne diseases like damping-off, root rot, and early blight.

2. Induced Systemic Resistance (ISR)

- **Microbes Involved**: *Pseudomonas*, *Bacillus*, *Trichoderma*
- **Mechanism**: Triggering of plant immune responses such as:
  - Upregulation of defense-related genes
  - Production of defensive phytoalexins and pathogenesis-related (PR) proteins
- **Effect**: Plants "primed" by microbes can rapidly respond to future pathogen attacks, reducing disease severity.

3. Nematode and Insect Pest Resistance

- **Microbes Involved**: *Paecilomyces lilacinus*, *Pochonia chlamydosporia*, *Bacillus thuringiensis*
- **Mechanism**:
  - Production of nematocidal enzymes and toxins
  - Attraction of natural predators through root exudate modification
- **Effect**: Reduced nematode penetration and pest infestation, improving seedling health and stand establishment.

Microbial Priming Effects on Biotic and Abiotic Stress

Stress Type	Microorganisms	Mechanisms	Observed Benefits
Drought	*Bacillus*, AMF	Osmolyte production, enhanced root growth	Improved water use, survival
Salinity	*Pseudomonas*, *Trichoderma*	Ion regulation, ROS scavenging	Better germination, less salt injury
Heat/Cold	*Bacillus*, *Pseudomonas*	HSP/CIP expression, metabolic adjustment	Stable germination, higher tolerance
Nutrient Deficiency	*Azotobacter*, *Phosphobacteria*, AMF	Nutrient solubilization, symbiosis	Enhanced nutrient uptake, growth
Fungal Pathogens	*Trichoderma*, *Bacillus*	Antibiosis, mycoparasitism	Disease suppression
Bacterial Pathogens	*Pseudomonas fluorescens*	ISR, biofilm formation	Reduced bacterial wilt, blight
Nematodes	*Pochonia*, *Paecilomyces*	Enzyme production, direct attack	Lower nematode population

Advantages of Microbial Seed Priming

Microbial seed priming confers a multitude of agronomic, ecological, and economic benefits:

- **Faster and Uniform Germination**: Bio-primed seeds exhibit quicker and more uniform germination due to improved hydration and microbial stimulation of metabolic activity.
- **Enhanced Seedling Vigor**: Primed seeds show better root and shoot development, leading to robust early growth and competitive advantage in the field.
- **Improved Nutrient Uptake**: Microbes such as mycorrhiza and phosphobacteria enhance the availability and absorption of key nutrients like phosphorus, nitrogen, and iron.
- **Abiotic Stress Tolerance**: Primed seeds show resilience against drought, salinity, and temperature extremes through mechanisms like antioxidant production and osmotic adjustment.
- **Biotic Stress Resistance**: Microbes like *Trichoderma* and *Pseudomonas* offer natural protection against seed and soil-borne pathogens, reducing the need for fungicides.
- **Eco-friendly and Cost-effective**: Bio-priming is inexpensive compared to chemical treatments and aligns with organic and sustainable farming principles.

Real-World Applications and Success Stories

Numerous studies and field trials across different crops have demonstrated the effectiveness of microbial seed priming:

- **Rice**: Bio-priming with *Azospirillum* and *Trichoderma* has significantly increased seedling vigor, root length, and number of tillers per plant, leading to higher yields in paddy fields.
- **Wheat**: Seed priming with *Pseudomonas fluorescens* has been shown to improve salinity tolerance, resulting in better germination and grain filling under saline irrigation.
- **Tomato**: When primed with *Bacillus subtilis*, tomato seeds exhibited lower incidence of early blight and higher fruit quality due to enhanced systemic resistance.
- **Maize**: Priming with Arbuscular Mycorrhizal Fungi enhanced phosphorus uptake and increased biomass accumulation, leading to higher dry matter production and grain yield.

Such results emphasize the scalability of microbial seed priming across diverse agro-climatic zones and cropping systems.

Challenges and Future Prospects

Despite its potential, microbial seed priming faces certain constraints:

- **Strain Compatibility**: Not all microbial strains perform equally across different crops or soils. Tailored strain selection is crucial.
- **Shelf Life and Storage**: Maintaining the viability of microbial inoculants during storage and handling remains a technical challenge.

- **Farmer Awareness**: Adoption is limited by a lack of awareness, technical know-how, and access to quality bio-inoculants in rural areas.

However, the future holds promise. With advances in microbial biotechnology, formulation techniques, and on-farm extension services, bio-priming can become a standard practice. The integration of **next-generation sequencing, metagenomics, and bioinformatics** can further aid in identifying novel beneficial strains and optimizing their interactions with crops.

Conclusion

Microbial seed priming is not merely a seed treatment technique. It is a paradigm shift toward more sustainable, biologically integrated farming systems. By equipping seeds with a microbiological "toolkit" from the outset, we are fostering resilient, efficient, and productive plants that require fewer synthetic inputs. As agriculture moves toward eco-intensification, methods like microbial seed priming will play a central role in ensuring food security while preserving environmental health.

The mode of action of seed priming—especially with beneficial microorganisms—is a synergistic combination of physiological enhancement, biochemical activation, and biological fortification. It initiates germination processes early, boosts microbial interactions, and equips the emerging seedling with tools to thrive in both normal and stressful environments. This integrated approach makes bio-priming a powerful tool for improving crop establishment, yield, and sustainability.

For developing nations, where resource constraints limit the extensive use of agrochemicals, microbial seed priming offers an affordable and practical solution. Its compatibility with organic farming, minimal environmental impact, and multifaceted benefits make it an indispensable technique for the 21st-century farmer.

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Millets as Smart Food: A Sustainable Solution to India's Nutritional and Agricultural Challenges

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India is an agrarian society, with approximately 65 percent of the population engaged directly in agriculture and allied activities, and around 55 percent of the workforce participating in these sectors (Ministry of Cooperation, 2023; Economic Survey, 2024–25). During the Indus Valley Civilization (2600 BCE–1900 BCE), people heavily relied on agriculture, consuming wheat, barley, lentils, and millet. Their diet also included vegetables such as onion, garlic, and radish, while milk and its derivatives—like yoghurt and ghee—formed an essential part of their nutritional intake. Meat was consumed only on special occasions and during religious rituals. Over time, the dietary pattern became more varied with the inclusion of fruits, nuts, and sweets.

However, food habits gradually shifted. Post-Green Revolution, there was a surge in the production and subsidised supply of fine cereals like rice and wheat through the Public Distribution System (PDS), which encouraged the overconsumption of cereals and led to a decline in dietary diversity. This cereal-based, monoculture-driven diet contributed to rising issues of undernutrition and malnutrition across the country.

India's current food and nutritional security status is concerning. In 2023 Global Hunger Index, India ranked 111th out of 125 countries, with a score of 28.7, placing it in the "serious" hunger category. The index captures undernourishment, child stunting, wasting, and mortality—reflecting not only insufficient caloric intake but also widespread micronutrient deficiencies. The National Family Health Survey-5 (NFHS-5) reported that 36 percent of children under five were stunted, 19.00 percent were wasted, 32.00 percent were underweight, and 3.00 percent were overweight—figures that are double those of Sub-Saharan Africa. The 2025 Human Development Report by UNDP rates India’s Human Development Index (HDI) at 0.685 (based on 2023 data), positioning it at 130th out of 193 countries, classified under medium human development Globally, over two billion people suffer from hidden hunger, with nearly half residing in India, largely due to a cereal-centric diet lacking in diversity.

Alongside nutritional challenges, Indian agriculture faces a crisis of income security due to ever-increasing cultivation costs. Small and marginal farmers are the most affected, especially with 60.00 percent of India's cultivated land being rainfed. Climate change-induced droughts and high temperatures lead to frequent crop failures. The Consultative Group on International Agricultural Research (CGIAR) estimates that global production of wheat, rice, and maize could decrease by 13 to 20 percent in the coming decades due to climate change (Gowri & Shivakumar, 2020). Further compounding the problem are global agricultural challenges such as soil degradation, water depletion, and the need for sustainable practices. Meanwhile, Sustainable Development Goals-2030 aim to eliminate all forms of malnutrition by 2030.

To tackle malnutrition, climate change, and poverty, India needs to prioritize "smart food" interventions. The focus must shift from rice, wheat, and maize to highly nutritious and climate-resilient grains such as millets (FAO et al.). Historically, millets were domesticated, cultivated, and consumed extensively during the Indus Valley Civilization. Their area coverage once matched that of rice and wheat. A wide range of millets was grown across diverse agro-climatic regions, including sorghum, pearl millet, finger millet, and small millets such as barnyard, proso, kodo, little, foxtail, and browntop millet, as well as pseudo millets like buckwheat (Kuttu) and amaranth (Chaulai). These grains were known for their superior nutrition and supported farmers with fulfilling and energy-dense meals like ragi muddle (steamed balls of finger millet), bajra roti (millet chapati), and bajra raab (porridge).

However, post-Green Revolution, millet cultivation witnessed a sharp decline. These grains became known as “orphan crops” due to their decreasing popularity. This decline was attributed to several factors: lower remuneration, absence of input subsidies and price incentives, changes in consumer preferences, difficulties in processing, shorter shelf life, and the social stigma attached to millet consumption compared to more "prestigious" grains like rice and wheat. Consequently, communities shifted toward cereals that could feed large populations and yield more per unit area, sidelining coarse grains in the process.

This narrowing of food diversity led to rising health concerns. The consumption of high glycemic index cereals like rice and wheat contributed to increased insulin resistance, excess body fat, and related issues such as high blood pressure. The success of the Green Revolution inadvertently displaced traditional, balanced food systems.

Over the last decade, however, the food revolution has reignited interest in traditional, healthy food options. Growing health consciousness has increased the demand for nutrient-rich foods, reviving interest in millets. The Ministry of Agriculture and Farmers Welfare recognized this trend and, in 2018, declared millets as "Nutri-cereals" due to their rich nutritional composition (7.00–12.00 percent protein, 2.00–5.00 percent fat, 65.00–75.00 percent carbohydrates, and 15.00–20.00 % dietary fiber). That year was celebrated as the National Year of Millets, and the "National Mission on Nutri-Cereals" was launched to promote their cultivation and consumption. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) introduced the term "Smart Food" to refer to food that is "Good for you, Good for the planet, and Good for the farmer." Millets qualify as smart food on all three counts. *Good for you*—they are rich in iron, zinc, calcium, fiber, and protein, making them ideal to combat micronutrient deficiencies, particularly in women and children. *Good for the planet*—they have a low carbon footprint and offer resilience against climate extremes. *Good for the farmer*—millets grow well in marginal environments with minimal water and inputs and serve multiple purposes (food, fodder, biofuel, brewing).

An optimization study found that increasing the area under coarse cereals like bajra and sorghum can improve protein and iron supply, enhance climate resilience, reduce greenhouse gas emissions, and minimize irrigation and energy demands—all while maintaining overall calorie production. Thus, millets offer a sustainable pathway to achieving nutritional security in India, outperforming rice and wheat in marginal growing conditions and boasting a superior nutritional profile.

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"Active Packaging: A Smart Approach to Enhancing Food Shelf-Life and Safety"

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Abstract:

Active packaging represents a significant advancement in food preservation technique, offering intelligent solutions that extend shelf life and enhance safety. By integrating functional components such as oxygen scavengers, moisture absorbers, antimicrobial agents and flavor-release systems into packaging materials, this technology actively interacts with food to maintain its quality and freshness. Intelligent features like sensors, RFID tags, and time-temperature indicators provide real-time information on food condition, improving supply chain transparency and consumer confidence. Innovations in biodegradable polymers and nanotechnology further align active packaging with sustainability goals. Despite its advancement, challenges remain regarding controlled release mechanisms and safety concerns. Continued research is essential to overcome these hurdles and exploring the full potential of smart active packaging in the food industry.

Key words: Active Packaging, Antimicrobial Agents, Shelf-Life Extension, Biodegradable Polymers, Food Safety.

Introduction

Active packaging represents a transformative approach in the food industry, designed to enhance food shelf-life and safety by integrating active and intelligent components into packaging materials. This innovative technology not only extends the shelf life of perishable goods but also maintains their freshness and quality by actively interacting with the food product. The integration of active agents such as oxygen scavengers, moisture absorbers and antimicrobial agents into packaging materials creates a modified atmosphere that inhibits microbial growth and preserves food quality. Active packaging techniques, including absorbers and emitters, play a crucial role in maintaining food quality by preventing deterioration and extending shelf life throughout the supply chain (Kumar et al., 2018).

This approach is increasingly favoured due to its potential to reduce food waste, enhance product safety and meet consumer demands for convenience and sustainability. Key aspects of active packaging are explored in detail as follows.

Active Packaging Technologies

i. **Oxygen Scavengers and Moisture Absorbers**: These components are crucial in maintaining the optimal environment within the packaging, preventing oxidation and moisture-related spoilage, which are common causes of food degradation (Priyanka et al., 2024) (Kuswandi et al., 2020). These technologies not only enhance the safety and quality of food products but also contribute significantly to reducing waste along the supply chain (Priyanka et al., 2024).

ii. **Antimicrobial Agents**: The incorporation of natural extracts and antimicrobial agents into packaging materials helps in reducing bacterial colonies, thereby extending the shelf life of perishable foods like meat, fish, fruits and vegetables (Nasution et al., 2023) (Nasution et al., 2023). This innovative approach not only addresses the challenges of food preservation but also aligns with sustainability goals by minimizing food waste and enhancing safety (Priyanka et al., 2024) (Mexis & Kontominas, 2014).

iii. **Flavor-Release Systems**: These systems are designed to maintain or enhance the sensory attributes of food products, ensuring that the flavor remains intact throughout the product's shelf life (Priyanka et al., 2024). Furthermore, active packaging systems are continuously evolving, with innovations such as active nanocomposites that incorporate oxygen scavengers and antimicrobial properties, enhancing food safety and quality even further (Bodbodak & Rafiee, 2016).

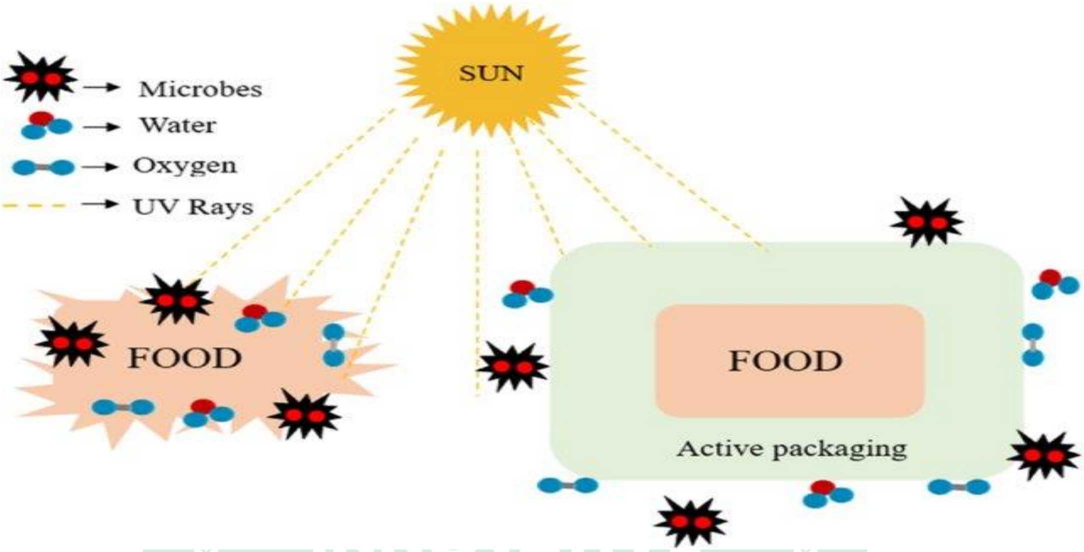

Fig. 1: Schematic representation of active packaging. (Source: Ashfaq et al. 2022)

Intelligent Packaging Features

i. **Sensors and Indicators**: Intelligent packaging systems are equipped with sensors and indicators that provide real-time information on food quality, such as freshness, temperature and microbial load. This information is crucial for both retailers and consumers to ensure food safety and quality (Fazliddinovich, 2022). These advancements in intelligent packaging not only facilitate better inventory management for retailers but also empower consumers to make informed choices regarding food safety and quality.

ii. **Time-Temperature Indicators (TTIs) and RFID Tags**: These tools are used for tracking and monitoring the conditions of food products throughout the supply chain, ensuring that they remain within safe temperature ranges and are not exposed to conditions that could compromise their quality (Kuswandi et al., 2020). These technologies not only enhance food safety and quality but also play a vital role in reducing food waste through improved supply chain management and consumer awareness (Kaushani et al., 2022) (Heising et al., 2017).

Material Innovations

Biodegradable Polymers: The use of biodegradable materials like polylactic acid (PLA) in active packaging aligns with the growing consumer demand for sustainable and environmentally friendly packaging solutions. These materials can be combined with natural active agents to enhance their performance (Nasution et al., 2023) (Nasution et al., 2023). Moreover, the development of biodegradable halochromic films as freshness indicators offers a promising avenue for reducing food waste and enhancing sustainability in packaging solutions (Yu et al., 2023). The integration of these innovative materials not only addresses the environmental concerns associated with traditional plastics but also contributes to the overall sustainability of food packaging systems.

Nanotechnology: The integration of nanotechnology in packaging materials enhances their functionality, providing antibacterial properties and improving the overall storage shelf life of food products (Mousavi & Mahmoudpour, 2024). This ongoing research into intelligent packaging highlights its potential to significantly reduce food waste and improve consumer safety by ensuring optimal storage conditions throughout the supply chain (Yu et al., 2023) (Shao et al., 2021).

Challenges and Future Prospects

While active packaging offers numerous benefits, there are challenges related to the interaction of packaging materials with food, the potential transfer of harmful substances, and the need for precise control over the release of active agents. Developing smart active packaging systems that can respond to environmental changes and release functional molecules on demand is crucial to overcoming these challenges (Zhanbolat & Tungyshbaeva, 2024) (Du et al., 2023). The future of active packaging looks promising, with ongoing research focused on improving material safety, enhancing response sensitivity and developing more effective stimuli-responsive mechanisms (Du et al., 2023).

Conclusion:

Active packaging is a smart approach that significantly enhances food shelf-life and safety by integrating advanced technologies into packaging materials. However, it is essential to address the challenges associated with material interactions and the controlled release of active agents to fully realize the potential of this innovative technology. As the demand for sustainable and safe food packaging solutions continues to grow, active packaging is poised to play a pivotal role in the future of the food industry.

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Chitosan: A Natural Weapon for Sustainable Plant Disease Management

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Introduction

Global agriculture is at a crossroads, facing mounting pressures from population growth, climate change, and the urgent need for increased food production. By 2050, the world's population is projected to reach 9.8 billion, necessitating a 35–56% rise in food output, particularly in developing nations (FAO, 2017). At the same time, crop losses due to plant pathogens—including fungi, bacteria, viruses, and nematodes—remain a significant challenge, accounting for nearly 20% of total agricultural production losses in India alone (Sarwar, 2022). Traditional reliance on synthetic pesticides has contributed to serious environmental concerns, including the evolution of resistant pathogens, pollution, and negative impacts on non-target organisms and human health.

In this context, **chitosan**, a natural biopolymer derived from the deacetylation of chitin, has gained prominence as a sustainable alternative. Sourced from crustacean shells, fungal cell walls, and insect exoskeletons, chitosan possesses a unique set of biochemical properties—including antimicrobial, antifungal, and elicitor activities—that make it a versatile and effective agent for integrated plant disease management. It functions not only by inhibiting pathogen growth but also by stimulating plant defense mechanisms and enhancing overall crop resilience and productivity.

This article provides a comprehensive overview of chitosan's role in modern agriculture, detailing its mechanisms of action, application methods, advantages, limitations, and the latest advancements up to 2025. As noted by Gómez-Rivera et al. (2024), *"Chitosan represents a novel tool for sustainable crop protection strategies against a broad spectrum of plant pathogens."*

What is Chitosan?

Chitosan is a naturally occurring linear polysaccharide derived from the deacetylation of **chitin**, a compound widely found in the exoskeletons of marine crustaceans like shrimp and crabs, as well as in fungi and insect cuticles. Recognized for its **non-toxic, biodegradable, and biocompatible** nature, chitosan stands out as an environmentally safe material with diverse applications, particularly in agriculture and biomedicine.

The discovery of chitin dates back to 1811 when it was first isolated from mushrooms by the French chemist Henri Braconnot. Several decades later, in 1859, chitosan was described by Rouget. However, it wasn't until the 1950s that its detailed molecular structure was clarified through advancements in X-ray diffraction and enzymatic analysis (Rinaudo, 2006). Chemically, chitosan has the molecular formula $(C_6H_{11}NO_4)_n$, and it is known to dissolve in weak acidic solutions such as acetic acid, which enhances its versatility in formulation.

The functional properties of chitosan—such as its biological activity, antimicrobial action, and plant defense elicitation—are strongly influenced by key factors including its molecular weight**,** the degree of deacetylation, and the form in which it is applied, whether as nanoparticles, sprays, films, or gels. These attributes not only determine its solubility and interaction with plant surfaces but also affect its efficiency in plant disease management and crop protection.

Extraction of Chitosan

Chitosan can be extracted via:

1. Chemical Methods:

- **Demineralization:** Using hydrochloric acid (HCl) to remove calcium carbonate.
- **Deproteinization:** Using sodium hydroxide (NaOH) to remove proteins.
- **Deacetylation:** Further treatment with concentrated NaOH (40–50%) converts chitin into chitosan.

2. Biological Methods:

- Use of lactic acid-producing and protease-producing bacteria to remove minerals and proteins, respectively.
- Deacetylation using chitin deacetylase enzyme.

These processes yield high-purity chitosan with desirable physicochemical and antimicrobial properties (Badawy & Rabea, 2011).

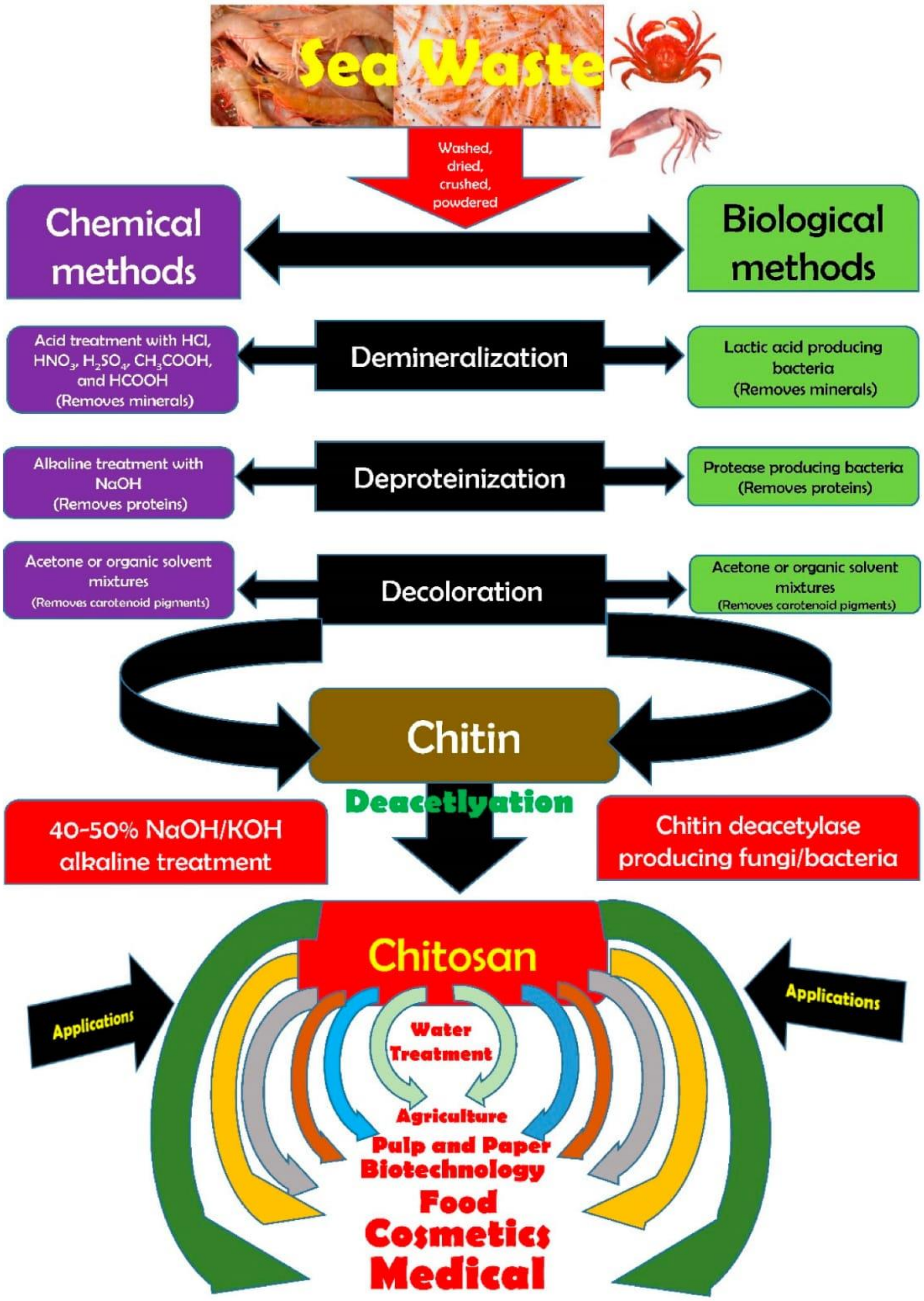

Figure 1: Extraction of Chitin and Chitosan

Mode of Action in Disease Management

Chitosan protects plants through multiple modes:

1. Direct Antimicrobial Activity

- **Electrostatic Interaction:** The positive charge of chitosan interacts with the negatively charged pathogen membranes, causing pore formation and cell lysis.
- **DNA/RNA Interaction:** Low molecular weight chitosan can penetrate microbial cells, bind with nucleic acids, and inhibit replication.
- **Metal Chelation:** Chitosan binds essential nutrients and metal ions required for microbial growth.
- **Deposition on Cell Surface:** Forms a physical barrier that disrupts nutrient transport and metabolic exchange.

Example: Chitosan significantly inhibited *Botrytis cinerea* growth in tomato and strawberry crops (Kim *et al.*, 2023).

2. Elicitation of Plant Defense Responses

Chitosan acts as an **elicitor** by stimulating the plant's innate immune system:

- Induces **pathogenesis-related (PR) proteins like** chitinase and β-glucanase.
- Enhances activity of defense enzymes like **peroxidase (PO), phenylalanine ammonia-lyase (PAL), polyphenol oxidase (PPO),** and **catalase.**
- Promotes the accumulation of **lignin, phytoalexins, and callose** that strengthen plant cell walls (Hadwiger, 2013).

A 2025 study by Liu et al. showed that chitosan-treated rice exhibited increased expression of PR1 and PR5 genes, enhancing resistance against Magnaporthe oryzae.

Chitosan Against Plant Pathogen

1. **Fungal Pathogens:** Chitosan is effective against many fungal pathogens. Chitosan has strong in vitro antifungal activities against plant pathogenic fungi such as *Pyricularia grisea, Rhizoctonia solani, Phytophthora infestans, Sclerotium rolfsii* and so on.
2. **Bacterial Pathogens:** Chitosan have bactericidal (kill bacteria directly) and bacteriostatic (stop bacteria from growing) ability. Recently, some researchers revealed that chitosan has strong in vitro antibacterial activities against plant pathogenic bacteria such as *Streptomyces scabies, Xanthomonas, Pseudomonas syringae, Pseudomonas fluorescens, Agrobacterium tumefaciens, Erwinia, Burkholderia seminalis, Acidovorax citrulli and Acidovorax avenae.*
3. **Viral Pathogens:** Chitosan can inhibit viral infection by inducing hypersensitive response and blocking the virus replication. Suppression of viral infection was reported with the tobacco mosaic and necrosis viruses, potato virus X, peanut stunt virus, cucumber mosaic virus and alfalfa mosaic virus.
4. **Post-Harvest Pathogens:** Chitosan have Film forming property. Control decay of fruits and extend the shelf life. Chitosan provides a coating to the fruits and vegetables which prevents from post harvest pathogens like *Penicillium expansion, Botrytis cinera* and so on.

Mode of Application

- **Applied as seed coating agents:** Seed coating enhances germination index, reduce the mean germination time, and increases shoot height, root length, shoot and root dry weights.
- **Applied as Foliar Treatment agents:** Chitosan has also been extensively utilized as a foliar treatment to control the growth, spread and development of many diseases involving viruses, bacteria, fungi and pests. It has also been used to increase yield and tuber quality of micropropagated greenhouse-grown potatoes. Chitosan applied as a foliar spray on barley reduced locally and systemically the infection by powdery mildew pathogen *Blumeria graminis f. sp. hordei*.
- **Applied as soil amendment:** Chitosan utilized as a soil amendment was shown to control Fusarium wilts in many plant species. Applied at an optimal concentration, this biomaterial is able to induce a delay in disease development, leading to a reduced plant wilting.
- **Post-Harvest Treatments:** Chitosan coatings prevent microbial spoilage during storage and transit.

Table 1: Chitosan against Plant Pathogen

FUNGAL PATHOGEN			
Sr. No.	**Crop**	**Pathogen**	**Reference**
1.	Rice	*Pyricularia grisea*	Badawy *et al*., 2005
		Rhizoctonia solani	Liu *et al*., 2012
2.	Potato	*Phytophthora infestans*	Kowalski *et al*., 2006
3.	Tomato	*Fusarium oxysporum f.Sp lycopersici*	Khiareddine *et al*., 2015
		Alternaria alternata	Algam and Elwagia, 2015
		Sclerotium rolfsii	Abd El Kareem *et al*., 2016
4.	Rubber	*Phytophthora palmivora*	Sunpapao and porsuriya, 2014
5.	Carrot	*Sclerotinia sclerotiorum*	Quing *et al*., 2015
BACTERIAL PATHOGEN			
1.	Tomato	*Ralstonia solanacearum*	Liu *et al*., 2008 Algam *et al*., 2010
		Xanthomonas vesicatoria	Cavalcanti *et al*., 2007
		Pseudomonas syringae	El Rahman *et al*., 2006
2.	Potato	*Erwinia carotovora*	Rabae *et al*., 2006
		Streptomyces scabies	Vruggink, 1970
3.	Cucumber	*Pseudomonas lachrymans*	Acar *et al*., 2008
4.	Poinsettia	*Xanthomonas axonopodis*	Liu *et al*., 2015
VIRAL PATHOGEN			
1.	Tomato	*Tobacco Mosaic Virus*	Zhao *et al*., 2008
		Tomato yellow leaf curl virus	Chirikov *et al*., 2007
		Tomato leaf curl virus	El Rahman *et al*., 2006
2.	Tobacco	*Tobacco Mosaic Virus*	Misra *et al*., 2006
		Tobacco Necrosis Virus	Chirikov *et al*., 2007
3.	Cucumber	*Cucumber Mosaic virus*	Pospieszny *et al*., 2008
4.	Groundnut	*Peanut stunt virus*	Struszcyket *et al*., 2015
POST HARVEST PATHOGEN			
1.	Strawberry	*Botrytis cinera*	Joseph *et al*., 2000
2.	Apple	*Penicillium expansum*	Bautister *et al*., 2011
3.	Tomato	*Botrytis cinera*	Zhang *et al*., 2011
		Penicillium expansum	Liu *et al*., 2007
4.	Grapes	*Botrytis cinera*	Xu *et al*., 2007

Chitosan-Based Nanoparticles (CNPs)

Recent advancements include chitosan-based nanoparticles for:

- Enhanced pathogen inhibition
- Targeted delivery of biocontrol agents or RNAi
- Improved stability and bioavailability

"Nano-chitosan formulations show 3–5 times greater antifungal activity compared to conventional chitosan" (Zhao et al., 2024).

Advantages of Chitosan in Plant Protection

- **Eco-friendly:** Biodegradable and safe for non-target organisms
- **Multi-functional:** Antimicrobial + Elicitor + Film-forming
- **Resistance management:** Reduces dependence on synthetic pesticides
- **Post-harvest use:** Delays spoilage, enhances shelf life

Limitations and Challenges

Limitation	Description
Cost and Availability	Commercial production from crustacean shells is limited
Variable Efficacy	Depends on crop, formulation, and pathogen
Regulatory Hurdles	Not yet widely approved in all countries
Storage Stability	Sensitive to pH, temperature, and UV exposure

Recent Developments

- **RNAi-chitosan complexes** for targeted gene silencing in pathogens **(Phytophthora infestans)** (Santos et al., 2025).
- **CRISPR-delivery via chitosan nanoparticles** to engineer pathogen-resistant crops (Wang et al., 2024).
- **Commercial products:** Several chitosan-based biofungicides now approved in the EU and US markets.

Future Prospects

- **Integration in IPM programs** with biologicals and botanicals.
- **Formulation improvements** using nanotechnology and biopolymer blends.
- **Regulatory support and farmer training** for widespread adoption.
- **Climate-resilient agriculture** through eco-friendly plant protection.

Conclusion

Chitosan represents a paradigm shift in sustainable agriculture, offering a promising, multi-functional, and eco-friendly approach to managing plant diseases. Its diverse roles as an antimicrobial agent, growth promoter, and elicitor of plant defenses align seamlessly with the principles of climate-smart and chemical-free farming. By harnessing its broad-spectrum antimicrobial and immunomodulatory properties, chitosan can significantly reduce reliance on synthetic pesticides. Continued research, improved formulation technologies, and supportive regulatory policies will be crucial in overcoming current limitations and ensuring the widespread adoption of chitosan as a core component of future integrated farming systems.

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Scientific Rearing of Indigenous Fish Species for Small-Scale Farmers

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Abstract

India is home to a rich diversity of indigenous fish species that hold immense potential for sustainable aquaculture, especially for small-scale and rural farmers. With increasing demand for local, eco-friendly, and low-input fish farming methods, the scientific rearing of native species such as **Rohu (Labeo rohita), Catla (Catla catla), Mrigal (Cirrhinus mrigala)**, and **Magur (Clarias batrachus)** offers both economic and ecological benefits. This article explores low-cost, scientifically validated practices for breeding, feeding, pond management, and disease control tailored for smallholder farmers. It highlights the importance of water quality monitoring, integrated fish farming, and the use of locally available feed and bio-remedial inputs. The promotion of indigenous species not only supports biodiversity conservation but also strengthens the resilience of rural livelihoods. The article also features successful farmer case studies and government-supported training programs, demonstrating how applied science can transform fish farming into a profitable and sustainable venture for India's small-scale farmers.

Keywords: Sustainable aquaculture, Native species, Low-cost practices, Bio-remedial inputs, integrated fish farming, Rural livelihoods, Traditional knowledge

1. Introduction

India, with its vast and diverse geographical features, boasts an extensive network of rivers, ponds, lakes, wetlands, and floodplains. These freshwater ecosystems are not only vital for maintaining ecological balance but also serve as a lifeline for millions of people in rural areas. Over the centuries, they have supported a rich and unique variety of **indigenous (native) fish species**, many of which are well-integrated into local diets, culture, and traditional farming practices.

Indigenous fish species such as **Rohu (Labeo rohita)**, **Catla (Catla catla)**, **Mrigal (Cirrhinus mrigala)**, **Magur (Clarias batrachus)**, and **Singhi (Heteropneustes fossilis)** are naturally adapted to local climatic conditions, seasonal variations, and water quality parameters. Unlike exotic species, these fishes require minimal ecological intervention and are more resilient to regional diseases and environmental stresses. Their hardy nature makes them particularly suitable for **low-input and small-scale aquaculture systems**, which are common in rural and semi-urban India.

In recent years, there has been a significant shift toward **sustainable, eco-friendly, and diversified farming practices** in agriculture and allied sectors. This change is driven by growing awareness about environmental conservation, rising input costs, and the need to enhance farmer income. Within this context, the **scientific rearing of indigenous fish species** has gained renewed interest. It not only aligns with the goals of **climate-smart and sustainable agriculture** but also offers farmers a dependable source of **supplementary income**, especially when integrated with traditional farming systems like paddy cultivation or livestock management.

Moreover, indigenous fish rearing plays an important role in **biodiversity conservation**, as many native fish species are under threat due to habitat degradation, pollution, and overexploitation. Promoting their culture through scientific methods ensures their survival while providing economic benefits to farming communities.

This chapter/article explores the **practical approaches, scientific techniques, and success strategies** involved in the rearing of indigenous fishes. It is specifically designed for small and marginal farmers, agri-entrepreneurs, and fisheries extension workers aiming to promote sustainable aquaculture in India. Through real-life examples, best practices, and accessible knowledge, this piece aims to empower readers with the tools to turn **fish farming into a profitable, eco-friendly, and community-oriented venture**.

2. Why Indigenous Fish Species?

Indigenous fish species such as **Rohu (Labeo rohita)**, **Catla (Catla catla)**, **Mrigal (Cirrhinus mrigala)**, **Magur (Clarias batrachus)**, and **Singhi (Heteropneustes fossilis)** are particularly suitable for small-scale aquaculture due to several key advantages:

- **Adaptation to Local Climate:** These native species are well-suited to the temperature, rainfall patterns, and water chemistry of their regional environments. Their ability to survive and grow in natural conditions reduces the need for artificial inputs or extensive water quality management.
- **Disease Resistance:** Indigenous fishes have evolved alongside local ecosystems, making them more resistant to regional pathogens, parasites, and waterborne diseases. This lowers the risk of mass mortality and reduces dependence on antibiotics or chemical treatments.
- **Market Preference:** These species are widely accepted in local markets, often preferred for their taste, texture, and nutritional value. Consumers recognize them as part of traditional cuisine, ensuring better and quicker marketability for small-scale farmers.
- **Environmental Balance:** Farming native species supports ecological harmony. Unlike exotic species, indigenous fishes do not disrupt local biodiversity or aquatic food chains. Their cultivation also helps conserve declining wild populations by reducing pressure on natural stocks.

3. Site Selection and Pond Preparation

A well-managed pond is the cornerstone of successful fish farming. Proper site selection and scientific pond preparation not only enhance fish growth but also help in maintaining water quality and reducing disease risks.

- **Site Selection:** Select a **low-lying area** where water naturally collects. The soil should be **clayey or loamy**, as it retains water efficiently and minimizes seepage. The site should have **easy access to a dependable water source**—such as a borewell, canal, or rain-fed reservoir—for filling and maintaining water levels throughout the culture period.
- **Pond Size:** For small-scale farmers, a pond size ranging between **0.1 to 1 acre** is manageable and cost-effective. This size allows easier monitoring, feeding, and harvesting while keeping input requirements moderate.
- **Pond Preparation:**
  - **De-silting and Cleaning:** Remove accumulated silt, unwanted vegetation, and predatory or wild fish from the pond bottom.
  - **Liming:** Apply **agricultural lime ($CaCO_3$)** to regulate soil pH (ideally 6.5–8.5), neutralize acidity, and improve the pond's fertility.
  - **Fertilization:** Add **organic manure** such as cow dung or compost to encourage the natural growth of **plankton**, which serves as the primary food source for fingerlings in the early stages.

Well-prepared ponds support better fish health, faster growth rates, and higher survival, ultimately leading to improved productivity and profits.

4. Selection of Fish Species and Stocking

Choosing the right species and following proper stocking practices are key to achieving high yield and healthy fish growth, especially in small-scale aquaculture systems.

Popular Indigenous Species

- **Rohu (Labeo rohita):** A fast-growing surface feeder that primarily consumes plankton and plant material. It thrives in well-managed ponds and is one of the most commercially important species in Indian aquaculture.
- **Catla (Catla catla):** This species feeds in the water column and grows rapidly under proper conditions. It is commonly cultured along with Rohu and Mrigal in polyculture systems for better resource utilization.
- **Mrigal (Cirrhinus mrigala):** A bottom feeder that feeds on detritus and decaying plant matter. It complements Rohu and Catla well, making it ideal for composite fish culture.
- **Magur (Clarias batrachus):** An air-breathing fish that can survive in shallow, muddy, and low-oxygen ponds. It is suitable for high-density stocking and can be raised even in small tanks or backyard ponds.

- **Singhi (Heteropneustes fossilis):** Another hardy, air-breathing species that grows well in challenging environments, including stagnant or seasonal water bodies. It is valued for its high protein content and medicinal benefits.

Stocking Density

- **Polyculture:** For mixed-species farming (e.g., Rohu, Catla, Mrigal), stocking **4,000 to 6,000 fingerlings per acre** is recommended. A common stocking ratio is **Rohu:Catla:Mrigal = 3:3:4**, ensuring balanced feeding at different pond levels (surface, column, and bottom).
- **Monoculture:** When cultivating a single species like Magur or Singhi, stocking density varies from **1,000 to 2,000 fingerlings per acre**, depending on pond size, water quality, and management intensity.

Scientific selection and balanced stocking help in efficient use of pond resources, minimizing competition and maximizing growth.

5. Feeding and Nutrition

Feeding is one of the most important factors influencing the health, growth, and overall yield of fish. Proper and timely feeding ensures better weight gain, improved immunity, and efficient conversion of feed into body mass.

Natural Feed

In the initial stages of pond preparation, **natural fish food** such as **phytoplankton (microscopic plants)** and **zooplankton (microscopic animals)** is developed through **organic fertilization**. Application of cow dung or compost promotes the growth of these microscopic organisms, which serve as the **primary food source** for young fingerlings. These natural feeds are rich in essential nutrients and support early-stage development without additional cost.

Supplementary Feed

As fish grow, natural food becomes insufficient, and **supplementary feeding** is essential to meet their nutritional needs. A commonly used and cost-effective supplementary feed is a **mixture of rice bran and mustard oil cake in a 1:1 ratio**.

- **Rice bran** provides energy in the form of carbohydrates.
- **Mustard oil cake** is rich in proteins and essential amino acids.

This combination is easily available, affordable for small-scale farmers, and supports optimal growth when provided in the right quantity and quality.

Farmers may also use **pelleted feed** if available, especially for species like Magur and Singhi, which benefit from high-protein diets.

Feeding Schedule

- Fish should be fed **twice daily**—once in the morning and once in the evening.
- The quantity of feed should be calculated based on the **total biomass** of fish in the pond.
- A general guideline is to feed **3–5% of the total body weight of fish per day**.

For example, if the estimated fish biomass in the pond is 100 kg, daily feeding should be around 3–5 kg, divided into two portions.

Regular observation during feeding helps monitor fish health and feeding behavior. Overfeeding should be avoided, as it leads to water pollution and wastage.

6. Water Quality Management

Maintaining good water quality is essential for the healthy growth and survival of fish. Water acts as the medium through which fish breathe, feed, excrete, and grow. Even minor fluctuations in water parameters can significantly affect fish metabolism, immunity, and overall yield. Therefore, regular monitoring and timely corrective actions are crucial.

Temperature

- The **optimal water temperature** range for most indigenous fish species lies between **25°C to 32°C**.
- In this range, fish feed actively, digest efficiently, and grow at a healthy rate.
- Sudden drops or rises in temperature, especially during extreme seasons, may reduce feeding activity and increase stress, making fish more susceptible to diseases.

pH Level

- The ideal pH range for freshwater fish culture is **6.5 to 8.5**.

- If the pH falls below 6.5 (acidic) or goes above 8.5 (alkaline), it can affect fish respiration and enzyme activity.
- **Lime (agricultural lime or dolomite)** is commonly used to correct low pH levels and improve pond alkalinity.

Dissolved Oxygen (DO)

- Dissolved oxygen is critical for fish respiration. It should be maintained **above 5 mg/L**.
- Low oxygen levels (especially below 3 mg/L) can cause fish stress, reduce feeding, and may even lead to mass mortality.
- To increase oxygen:
    - Avoid overstocking and overfeeding.
    - Use aerators or splash water manually during early mornings.
    - Incorporate aquatic plants in small quantities to improve oxygen levels during the day.

Regular Monitoring

- Farmers are encouraged to **monitor water quality regularly**, at least once a week.
- **Simple water testing kits** are available in the market to check pH, temperature, ammonia levels, and dissolved oxygen.
- Observing fish behavior (like gasping at the surface or reduced feeding) also provides clues about poor water conditions.

7. Disease Management

Fish health is directly linked to water quality, stocking density, feeding practices, and hygiene. While indigenous species are generally hardy and more resistant to local diseases, improper management can still lead to health issues. Timely prevention is always better than treatment in aquaculture.

Common Issues

1. **Fungal Infections:** Appear as cotton-like growths on fish skin or fins, often due to injuries or poor water hygiene.
2. **Bacterial Diseases:** Symptoms may include ulcers, fin rot, or swollen abdomen. These usually result from dirty water or decaying feed.
3. **Parasitic Infestations:** Caused by protozoa or worms, leading to irritation, color changes, or erratic swimming behavior.

Preventive Measures

- **Maintain Hygiene:** Regular cleaning of ponds, removal of uneaten feed, and sludge control at the bottom reduce the risk of disease.
- **Avoid Overstocking:** Crowding increases stress and makes fish vulnerable to infections. Always follow recommended stocking densities.
- **Disinfection:**
    - Use **potassium permanganate ($KMnO_4$)** in small doses (2–3 ppm) as a pond disinfectant and to treat fungal or external infections.
    - **Lime (agricultural lime)** not only balances pH but also acts as a disinfectant and reduces harmful microbes.

Natural Remedies

Traditional remedies, still widely practiced in rural India, are eco-friendly and low-cost:

- **Neem Leaves:** Known for their anti-bacterial and anti-parasitic properties. A bundle of neem leaves can be dipped in the pond or neem leaf extract can be sprayed on the water surface.
- **Turmeric Powder:** Acts as a natural antiseptic and anti-inflammatory. It can be mixed with feed or applied externally in case of wounds.
- **Garlic Paste:** Contains allicin, a natural compound with antibacterial properties. Adding a small amount of crushed garlic to fish feed boosts immunity and helps control internal parasites.

8. Harvesting and Marketing

The final stage of fish farming—**harvesting and marketing**—plays a critical role in determining the farmer's income. Proper planning during this phase helps maximize returns and reduce post-harvest losses.

Harvesting Time

- Most indigenous fish species like **Rohu, Catla, and Mrigal** are ready for harvest **after 6 to 8 months** of culture, depending on feeding, stocking density, and water quality.
- Species like **Magur and Singhi**, known for fast growth and high market value, can also be harvested within a similar timeframe or even earlier if grown under intensive conditions.

Partial Harvesting

- Instead of harvesting all fish at once, **partial harvesting** allows farmers to remove market-sized fish periodically (every 2–4 weeks), while allowing the smaller ones to grow further.
- This method ensures:
    - **Regular income**, especially useful for household needs or loan repayments.
    - **Better space utilization**, as the removal of bigger fish gives smaller fish more room to grow.

Market Linkage

- Strong market linkage is essential for **fair price realization**. Farmers can explore the following options:
    - **Local fish vendors or wholesale traders** who visit farms directly to purchase harvest in bulk.
    - **Fisheries cooperatives** that help in collective selling and often offer better bargaining power.
    - **Cold chain centers and storage units**, where fish can be stored temporarily, reducing spoilage and allowing farmers to sell when prices are favorable.
    - **Weekly markets, farm gates, and retail outlets**, especially for live fish (Magur, Singhi), which fetch a premium rate.
- In recent times, farmers are also using **digital platforms** and WhatsApp groups to connect with buyers, restaurants, and urban markets directly.

Effective harvesting strategies and market connectivity empower farmers to get **maximum returns** from their efforts and reduce dependency on middlemen.

9. Integrated Fish Farming (Optional for Higher Returns)

Integrated Fish Farming is a sustainable approach that combines aquaculture with other farming systems such as agriculture, poultry, or livestock. This method allows farmers to **maximize resource use**, reduce input costs, and earn **multiple streams of income** from the same piece of land.

These systems are especially beneficial for **small and marginal farmers** who aim to optimize their land, water, and labor for higher profitability.

Fish + Duck Farming

- Ducks are allowed to swim freely in the fish pond during the day. Their droppings act as **natural manure**, promoting plankton growth which serves as fish feed.
- Ducks help **control aquatic weeds and insects**, reducing the need for pond cleaning.
- Farmers earn income from **duck eggs and meat**, in addition to fish.
- Typically, **300–400 ducks per hectare** are recommended in this model.

Fish + Paddy Farming

- In this model, paddy fields are modified with shallow canals or trenches to hold fish during the crop season.
- Fish help **control pests** in paddy fields by feeding on insects and larvae.
- The nutrients from fish waste act as **natural fertilizers**, improving paddy yield.
- After paddy harvesting, the trenches can be deepened and used for standalone fish culture.
- Suitable fish: **Rohu, Catla, Mrigal, Common carp, Tilapia**.

Fish + Poultry / Fish + Vegetable Farming

- **Fish + Poultry:** Poultry sheds are constructed over or beside the pond. Droppings fall directly into the pond or are collected and added manually, enriching the water and stimulating plankton growth.
    - Commonly reared birds: **Broiler chicken or desi hens**.
    - Around **500 birds per hectare** can be maintained.
- **Fish + Vegetable Farming:** Pond embankments are used to cultivate seasonal vegetables like okra, tomato, bitter gourd, or leafy greens.
    - Pond water rich in nutrients is used for irrigation, reducing fertilizer use.

- Fish waste supports plant growth, while leftover vegetables can be fed to fish or poultry.

Benefits of Integrated Fish Farming

- Efficient recycling of nutrients and waste.
- Reduced input cost (e.g., on feed and fertilizers).
- Improved soil fertility and water utilization.
- Year-round income through multiple products (fish, eggs, crops, vegetables).
- Environmentally friendly and sustainable.

Integrated models are ideal for farmers with limited landholding, offering **greater returns per unit area** while promoting **eco-friendly and low-cost farming practices**.

10. Government Schemes and Training Opportunities

To promote sustainable and profitable fish farming, various government schemes and institutions offer **financial support, training, and technical guidance** to farmers across India.

- **PM Matsya Sampada Yojana (PMMSY):**
A flagship scheme by the Government of India aimed at **boosting fish production and farmer income**. It provides **subsidies for pond construction, hatcheries, feed units**, and encourages **entrepreneurship in aquaculture**. The scheme also supports training programs and insurance coverage for fish farmers.
- **National Fisheries Development Board (NFDB):**
NFDB works to strengthen fishery infrastructure and **promotes scientific and modern fish farming**. It offers funding for seed production units, biofloc systems, cage culture, and provides support for research and innovation in the fisheries sector.
- **Krishi Vigyan Kendras (KVKs):**
Located in almost every district, KVKs provide **hands-on training, demonstrations, and technical advisory** to farmers on fish breeding, pond management, and integrated farming models. Many KVKs also help in connecting farmers to government schemes.
- **State Fisheries Departments:**
These departments offer **technical support, subsidies on fish seed, feed, equipment**, and guidance on water testing, disease management, and marketing. They also assist farmers in availing central and state-sponsored schemes.

These support systems are designed to **empower small and marginal farmers**, making fish farming more accessible, scientific, and profitable.

11. Case Study: A Small Farmer's Success

Ramesh Sharma, a small farmer from **Morena District, Madhya Pradesh**, adopted scientific fish farming on a **0.5-acre pond** using a combination of **Rohu, Catla, and Mrigal**. He followed proper practices like **balanced stocking, regular feeding**, and use of **lime and organic manure** to maintain water quality and boost plankton growth.

With support from the **PM Matsya Sampada Yojana** and hands-on **training from KVK Morena**, he achieved an impressive **yield of 1.2 tonnes** in the first year and earned a **net profit of ₹1.5 lakhs**, proving that small-scale fish farming can be both **sustainable and profitable**.

12. Conclusion

Scientific rearing of indigenous fish species is a low-risk, high-potential opportunity for small-scale farmers. It combines the strength of traditional knowledge with modern aquaculture practices. By adopting scientific pond management, balanced feeding, and sustainable rearing methods, farmers can enhance productivity, earn steady income, and contribute to the conservation of India's aquatic biodiversity.

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Revolutionizing Vegetable Production: Innovative Technologies for Quality Improvement under Controlled Conditions

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ABSTRACT

Demand for premium veggies is rising quickly worldwide due to increasing consumer knowledge of nutrition and health. However, Traditional vegetable cultivation techniques frequently encounter difficulties such as soil erosion, climate change, and water scarcity, which can lower crop output and quality. The cutting-edge technologies that are transforming the regulated production of vegetables are examined in this research. The potential of the most recent developments in precision agriculture, vertical farming, LED lighting, and hydroponics to enhance crop quality, lessen their negative effects on the environment, and boost output is examined. Our review identifies areas for further research and development while highlighting the advantages and difficulties of these technologies. By implementing this cutting-edge technology, vegetable farmers may meet changing customer demands and contribute to a more sustainable and high-quality harvest.

Keywords; Internet of Things (IoT), Controlled Environment Agriculture (CEA), Robotics, Artificial Intelligence (AI), Precision Irrigation.

INTRODUCTION

At least 400 g, or five pieces, of Fruits and Vegetables should be consumed daily per person, according to WHO recommendations. To provide consumers of all ages with fresh, wholesome food, vegetables (Veg) are an essential component of many cuisines (Wallace *et al*., 2020). One of the most significant worldwide issues of the twenty-first century is the need for sustainable diets. With the world's population forecast to grow to 10 billion people by 2050, there will likely be a major increase in demand for food. These techniques reduce the genetic gain of crops and take a lot of time when creating new crop cultivars. Thus, we may be able to plan and implement strategies to expand sustainable agriculture and speed up global food production with the use of an improved and advanced technique. According to this field, using NPs in agriculture improves plant productivity and growth, which in turn increases food security and reduces environmental effects.

(A) Historical overview

1. Before the 1800s, the pre-industrial era

Conventional agricultural methods: To grow and harvest crops, farmers employed basic implements like rakes, hoes, and Plows pulled by oxen.

Crop rotation: To preserve soil fertility and structure, farmers planted legumes, cereals, and root vegetables in that order.

Composting: By incorporating organic materials like animal dung and vegetable waste into the soil, farmers utilize compost to increase soil fertility.

Irrigation: To water their crops, farmers used basic irrigation techniques, including ditches, canals, and rainfall.

2. The Industrial Era (1800s-1940s) Mechanization: The invention of tractors, plows, and other equipment lowered labour costs and improved efficiency.

Irrigation systems: More complex irrigation systems, involving sprinklers, pumps, and pipes, became utilized by farmers.

Pesticides and fertilizers: The wide availability of synthetic pesticides and fertilizers allowed farmers to better manage illnesses and pests.

Greenhouses: With the construction of the first greenhouse, farmers were able to cultivate crops all year round.

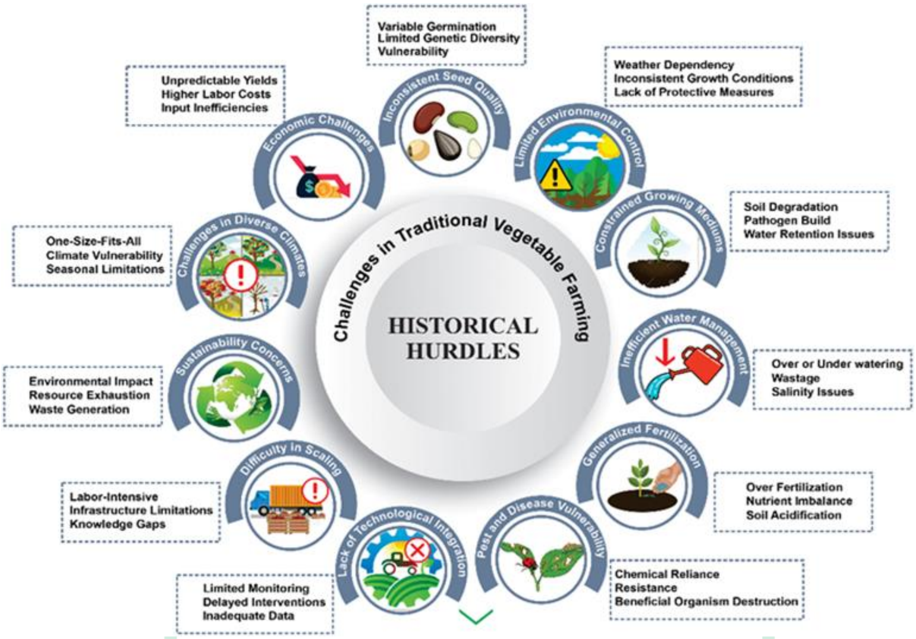
3. Post-War Period (1940s–1980s)

Production in greenhouses: As greenhouses multiplied, farmers began using them to grow a variety of crops, such as fruits, vegetables, and flowers.

Hydroponics: With the development of hydroponic systems, farmers may now grow crops in nutrient-rich solutions as opposed to dirt.

Precision agriculture: To maximize yields and minimize waste, farmers began using precision farming techniques including soil testing and crop monitoring.

Integrated Pest Management (IPM): IPM methods, which employ a combination of chemical, biological, cultural, and physical measures to control pests, have become more popular.



Traditional farming for vegetables endures a variety of challenges, from challenges to seed quality to sustainability.

4. Modernism Era (1990s–Present)

Vertical farming: Vertical farming techniques have grown in popularity. They allow farmers to cultivate food in urban areas while saving money on transportation.

LED illumination: As LED grow lights proliferated, growers were able to lower energy costs and provide specialized lighting for particular crops.

Drones and satellite imagery: To keep an eye on crops, forecast harvests, and maximize fertilizer and irrigation inputs, farmers started utilizing drones and satellite imagery.

Artificial intelligence (AI) and machine learning (ML): These technologies are being used to analyze data, forecast yields, and improve farming methods, which helps farmers make better decisions. AI and ML integration in controlled environment agriculture makes automated decision-making, predictive analytics, and real-time monitoring possible.

Internet of Things (IoT): More accurate management over irrigation, fertilizer supply, and environmental conditions is made possible by the growing use of IoT sensors and devices.

5. Future Developments Autonomous farming: AI and robotics are being used to create autonomous farming systems that will allow farmers to automate a variety of chores, such as planting, watering, and harvesting. The sector is changing as a result of the development of autonomous farming systems, such as automated harvesting and robotic farming.

Gene editing: CRISPR and other gene editing technologies are being investigated for agricultural enhancement, allowing farmers to create crops with desired characteristics like pest and drought resistance.

Urban agriculture: In an effort to boost food production and lower transportation costs, cities are investing in rooftop gardens, community gardens, and vertical farms. Urban agriculture is growing in popularity.

Traditional methods for vegetable cultivation practice:

Traditional vegetable cultivation methods are rooted basis in tried-and-true agricultural practices and have been meticulously influenced by regional environmental oddities and strong cultural norms. The focus on selecting seeds from the greatest plants underscores the little we understand concerning genetics.

(B) Techniques used in the cultivation of vegetables have evolved over the years.

Over the years, the evolution of Vegetable growing techniques changed, giving a fascinating glimpse into a wider path of agricultural progress characterized by technological developments in science and technology, growing theoretical understanding, and an advanced understanding of plant biology.

The latest farming techniques and their many advancements are revolutionizing agriculture and securing sustainable food production all over the world.

(C) Conventional Techniques for Vegetable Production

1. Soil Preparation

- Crop rotation This practice keeps soil fertility and structure intact by rotating crops.
- Adding organic matter to the soil through composting enhances its structure and fertility.
- Manuring is the process of adding nutrients to the soil by applying animal manure.

2. Planting and spreading

- Choose premium seeds that are appropriate for the soil and climate in your area.
- Sowing Depth and Spacing to guarantee that seeds grow properly, sow them at the right depth and spacing.
- Transferring seedlings to bigger pots or straight to the field is known as transplanting.

3. Managing Water and Irrigation

- Harvesting rainwater for irrigation involves gathering and storing it.
- The second strategy is drip irrigation, which lowers evaporation and conserves water.
- Mulching: Using mulch helps keep moisture in and inhibits weed growth.

4. Management of Pests and Diseases

- Crop Monitoring: Consistently keeping an eye out for pest and disease symptoms in crops.
- Physical Barriers: Using physical barriers to keep pests away from crops, like row coverings.
- Organic Pesticides: Use natural pesticides to manage pests, such as neem oil.

5. Harvesting and Taking Care of After Harvest

- Harvesting crops on time: To guarantee the best quality, harvest crops at the right maturity stage.
- Correct Handling: To avoid bruising and damage, handle crops gently.
- Storage and Transportation: Proper storage and transportation of crops is essential to preserving their quality.

6. The benefits of using traditional methods

- Low Cost: Small-scale farmers may typically afford and use traditional methods.
- Environmental Sustainability: Because traditional methods depend on organic materials and natural processes, they are typically more environmentally sustainable.
- Cultural Significance: Conventional practices are frequently ingrained in regional customs and culture.

7. Limitations of Conventional Approaches

- Low Productivity: When compared to contemporary approaches, traditional methods may produce lower yields and productivity.
- Labor-Intensive: Conventional approaches may involve more manual labor and time, making them labour-intensive.
- Limited Adaptability: Conventional approaches could not be flexible enough to meet shifting market demands or environmental constraints.

CONCLUSION

Since the introduction of new technologies, the vegetable-producing sector has changed dramatically. Precision farming, vertical farming, LED lighting, hydroponics, and artificial intelligence are all being combined to transform the production, distribution, and harvesting of vegetables. Increased yields, less environmental impact, and better crop quality are all possible with these technologies. The benefits of these innovative technologies are various such as improved crop quality, increased yields, reduced environmental impact, and enhanced food safety as well there were various challenges including high initial investment costs, limited accessibility, data management, and analysis.

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Hi-Tech Nursery Management in Vegetable Crops: A Gateway Towards Sustainable Production

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Introduction:

The production of vegetable nurseries has grown in popularity in the current environment, with the majority of farmers buying their plugs from professional growers. Young vegetable seedlings are raised or handled in a vegetable nursery until they are prepared for more permanent planting. First, certain vegetable seeds are sown in nursery beds and the seedlings from these beds are then moved to the main field. Some vegetables require nursery-raised seedlings before being transplanted in the main field, including tomatoes, brinjal, chillies, capsicum, cauliflower, cabbage, knol-khol, Chinese cabbage, Brussels sprouts, broccoli, kale collard, celery, parsley, etc. Vegetable farmers spend a lot of money on seedling production, so every attempt should be made to provide high-quality seedlings at a fair price. In order to lower the overall costs of producing vegetables, growers must employ effective nursery growing practices. There is a lot of room for seedling transplants in the future, particularly for crops with high economic value and possibly expensive seed.

Why to raise the vegetable nursery?

Nowadays, hybrid seeds, which are more expensive but give higher yields and quality produce, are planted in a large percentage of India's vegetable farming land. Because seeds can be expensive, some vegetable crops, such as tomatoes, brinjal, capsicum and cucurbits, are being transplanted after growing in nurseries in order to maximize germination and create robust plant life. Some vegetables cannot be cultivated directly in the field due to the small size of their seeds and require specific attention during their early growing stage. The high expense, particularly for hybrid seeds, is the other factor. For each vegetable crop to reach its maximum yield potential, healthy seeds and seedlings are the first and most important prerequisite.

The following is a list of additional benefits of growing seedlings in a nursery:

- ✓ A large number of plants can be grown and maintained in a given area
- ✓ It is possible to cultivate valuable and tiny seeds successfully without any wastage
- ✓ The seedlings can be shielded from both biotic and abiotic stresses
- ✓ It's convenient to care for the fragile and young seedlings in the nursery
- ✓ Compared to directly sowing a crop with little care because the nursery area is small, seedling management can be accomplished more effectively by making efficient use of land, labour and capital
- ✓ It is possible to maintain a 100% crop stand in the main field
- ✓ It is convenient to provide favourable growing circumstances for the successful raising of seedlings
- ✓ It is possible to harvest an early crop or standing crop in the field, which could result in a higher price
- ✓ Because the nursery is cultivated independently, more time is available for the main field's preparation
- ✓ It is feasible to provide favourable growing conditions for both growth and germination
- ✓ The issue of challenging soils is resolved
- ✓ Easier weed management
- ✓ A more precise forecast of the consistent harvest date
- ✓ Entrepreneurship growth in rural regions
- ✓ Creation of jobs, particularly for women in rural areas

Factors influencing vegetable nursery management:

Vegetable nursery management is influenced by several factors, including nursery site selection, soil preparation, soil and seed treatments, nursery bed preparation, seed sowing, removal of seed and nursery bed covering, watering, aftercare, disease and insect pest protection and hardening. When any one of these elements is neglected, seedling germination, growth and development are hampered.

Selection of Site:

The following elements should be taken into account when deciding on a site for nursery management and production:

- ✓ The land should be fertile, well-drained and rich in organic matter
- ✓ Water logging should not exist at the location and there should be adequate drainage
- ✓ It should be kept out of the shade at all times to receive the appropriate amount of sunshine
- ✓ A water source ought to be close to the nursery
- ✓ It is best to keep pets and wild animals out of the area

Growing seedlings in the nursery:

Seedlings are raised in trays of different sizes and cell counts in vegetable nurseries. Greater height and strength are exhibited by seedlings cultivated in larger cells as opposed to smaller ones. It is necessary to use sterile growth media, which may or may not be inert, with a sufficient cation exchange capacity (CEC), ideal pH and the ability to absorb nutrients. The most crucial component of nursery growing media is coco peat which is made from coconut husk and is entirely natural and biodegradable. It has a high C:N ratio and antibacterial qualities. To give the developing seedlings additional advantages, biological agents like bio-fertilizers and bio-control agents (*Trichoderma viride* and *Pseudomonas fluorescens*) are frequently added to the media.

Temperature affects seed germination and varies depending on the crop. The media should have consistent moisture levels. Utilizing customized germination chambers improves germination. To enable warmer temperatures to encourage germination, the protrays are covered with a black plastic sheet after sowing. A certain root zone temperature is necessary for the germination of some vegetable seeds, such as the ideal temperature range for chilli and capsicum (28°C to 32°C) and tomatoes and brinjal (21°C to 24°C). The growth of the seedlings is directly and significantly influenced by a number of elements, including light, irrigation and nutrients. Enough light must be provided for the nursery's structure to support the growth of seedlings. Regular irrigation is necessary for seedlings to grow and develop to their full potential. Rose cane, drip or sprinkler irrigation systems can be used to irrigate seedlings. Nutrients can be provided by foliar application for better growth of the seedlings. Phosphorus, along with a small amount of nitrogen, is essential for greater root growth.

Protected structures used for hi-tech nursery raising:

Because they are delicate and vulnerable, young seedlings need special attention from sucking pests like aphids and white flies, which can also serve as carriers of numerous deadly viral illnesses that may manifest later in the plant's life cycle. These adversaries arise when seedlings are raised in an open field or away from a covered structure. The protective structure also shields young seedlings from harsh weather elements like wind, rain, heat and a range of diseases.

(a) Greenhouses:

With a transparent or translucent covering, a greenhouse is a semi-permanent building that can be anything from basic homemade designs to intricate prefabricated constructions with adjustable conditions for plant growth or propagation. Steel, aluminum, bamboo or wood can all be utilized to build a greenhouse frame. Glass or different types of rigid or flexible plastic can be used as coverings.

- **Glasshouse**: A glasshouse is a greenhouse that has glass as its covering material
- **Polyhouse:** A polyhouse is a greenhouse that is covered in plastic

(b) Plastic Low Tunnels/ Row Covers:

The translucent plastic film is stretched over steel hoops that are appropriately spaced along the plant rows, which are roughly 50 cm high, to cover the rows of plants in the open fields. In order to prevent UV deterioration, a 30–40 micron thick polyethylene sheet that is perforated *in-situ* as the season heats up is utilized. The uses of row coverings in temperate and tropical climates for vegetable growing varied. They are employed in cold climates to preserve warmth, promote early development and germination, shield plants from frost damage and enhance crop quality. There may be further positive outcomes, such preserving the soil's structure and shielding crops from pest and attacks of birds.

(c) Shade Houses: Perforated plastic sheets called shade nets are used to reduce solar radiation and stop plants from being scorched or wilting due to significant temperature increases in the leaf tissue brought on by intense sunshine. These nets come in a range of shade intensities, from 25% to 75%. It is advised to cultivate leafy vegetables under shade nets since, under strong sunshine, their growth rates are noticeably higher than those of unshaded plants.

(d) Net Houses: Although the terms shade house and net house are frequently used interchangeably, a net house is actually enclosed by a perforated screen that serves primarily as a barrier to keep insects and other pests out. Nets made of insect-proof nylon come in a variety of perforation intensities, from 25 mesh to 60 mesh. The majority of flying insects may be effectively kept out of crops and protected from illness by using nets with a mesh size of 40 or higher. Because of these structures, tomatoes and capsicums can be planted earlier without worrying about vectors. However, a larger mesh size limits the structure's ability to exchange air. There are now longer-lasting UV-stabilized nets available.

(e) Naturally Ventilated Greenhouse: The most typical and well-liked greenhouse among Indian farmers is one that has natural ventilation. This greenhouse model uses no energy and has natural ventilation on the top and sides. The saw tooth greenhouse design is the most efficient and appropriate for growing crops since it offers the most ventilation. Depending on the location and climate, this kind of greenhouse can be used for crop production for nine to twelve months.

- **Polybags for Cucurbits:** For most cucurbits, in situ sowing and seed propagation are used. In certain situations where an early yield is required, seeds can be placed in polybags and allowed to germinate under cover from low temperatures. The seedlings are moved when they reach the 2-true-leaf stage. Due to tap root damage, cucurbits typically do not survive transplantation beyond this point. There is a notable decrease in seed quantity, saving roughly 50% to 60% when compared to in situ sowing.
- **Plug Tray Techniques:** Plastic trays, also called protrays, with different cell sizes are frequently used to produce vegetable seedlings. Two kinds of plastic protrays are widely used to nurture seedlings in Israel and several European countries. While lettuce, cabbage, cauliflower and capsicum require 345 cells of 2.5 cm (1.0") size plastic trays, cucumber, muskmelon, tomato and brinjal require 187 cells of 3.75 cm (1.5") size plastic trays. These trays facilitate proper germination, provide a distinct space for each seed to sprout, lower mortality, encourage consistent and healthful growth of seedlings and are simple to handle and store. They are also reasonably priced and dependable to transport.

High-tech methods for growing vegetables in nurseries:

1. The growing medium (coco peat, perlite and vermiculite) is put into the seedling tray (pro-tray).
2. To plant the vegetable seeds in the pro tray or plug tray, a little indentation is made (0.5 cm) in the middle of the cell with the fingertip.

3. Either by hand or with the aid of automatic seeding devices, one seed is planted in each cell and covered with media.
4. Because coco peat with 300–400% moisture content is utilized, no irrigation is needed right away till germination.
5. To guarantee moisture conservation until germination, a polyethylene sheet is placed over the entire stack. Once germination starts, the stacked trays are spread to prevent etiolation.
6. When the seedlings germinate, the trays are moved to the net house and placed on the beds or plate form.
7. A fine-sprinkling rose can or a hose pipe with a rose attached are used to lightly irrigate the trays each day, contingent on the weather. As a preventative strategy against seedling mortality, fungicides are also sprayed on the trays.
8. To promote the growth of the seedlings, 0.3% (3 g/litre) water-soluble fertilizer is sprayed twice (12 and 20 days after sowing) using poly feed (NPK-19:19:19 with trace elements).
9. When it rains, polyethylene sheets are placed over the trays to create a low tunnel, protecting them from the elements.
10. Before being moved or sold to growers, the seedlings at the proper planting stage are toughened by lowering the shade and stopping irrigation.
11. To control the insect vectors, systemic insecticides are treated seven to ten days after germination and prior to transplanting.
12. Depending on the crop, the seedlings would be prepared for transplantation to the main field in 21–42 days.
13. Since there is less root damage when transplanting traditional nursery-raised seedlings in the afternoon, transplanting can be done at any time of day.

Conclusion:

Regardless of the vegetable crop, the development of diverse nursery growing methods has created new opportunities for producing vegetables throughout the year. Thanks to novel ways in high-tech nursery production, growers can now produce crops sustainably, produce vegetables in any season, and protect their crops from a variety of challenges. Their products can also command high prices.

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Quantification of pine needles and their utilization for reducing forest fires

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Abstract

The study conducted in the University Campus from March to June in 2025 has provided valuable insights into the patterns and potential applications of pine needle shedding. The data, collected from eight plots, shows a consistent increase in the accumulation of pine needles over time, with the maximum thickness recorded at 7.0 cm in Plot 7 till 6th June 2025. The variation in accumulation across plots reflects differences in site-specific environmental conditions. A temporary decrease in shedding during early May was attributed to heavy rainfall, which physically removed needles from the surface. Quantitative analysis reveals an average pine needle biomass of approximately 0.497 kg/m^2, translating to an estimated 4,970 kg/ha. The study presented the use of pine needles in bio-oil production, composting, biochar production, paper manufacturing, and briquette formation. These findings highlight the dual role of pine needles as a hazard if unmanaged, and as a resource when utilized wisely. With proper collection and processing, pine needle biomass can significantly contribute to environmental conservation, energy sustainability, and rural economic development.

Introduction

Pinus roxburghii, commonly known as Chir pine or longleaf Indian pine, is a species of pine tree native to the Himalayas. It was named after William Roxburgh. The plant belongs to the family Pinaceae. It comprises the world's largest coniferous genera. The native range of pine forest extends from Tibet in China and Afghanistan through Pakistan, across northern India, Nepal and Bhutan to Myanmar. It generally occurs at lower altitudes than other pines in the Himalayas, from 500-2000m, occasionally up to 2300m. In India, Chir pine forests are primarily found in the subtropical and temperate regions of the Indian Himalayas, covering the states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh.

In Himachal Pradesh, Chir pine is one of the most dominant and economically significant forest types, covering vast areas in the lower and middle Himalayan ranges. They mainly occur in 10 out of the total of 12 districts in HP. The pine needles are composed of cellulose, hemicellulose, and lignin and have antibacterial properties, anti-proliferative properties, anti-inflammatory, antimicrobial properties, immunomodulatory potential, calorific properties, etc, due to the presence of aromatic oils and resinous compounds. Pine needle extract is said to be acidic with a pH range of up to 4-5 (Kwak, 2006).

Pine needles cover soil, retain soil moisture in heat, prevent weeds, check erosion and release nutrients into soil by decomposition, albeit slowly. The spread of forest fire is attributed to pine because of inflammable dry leaves, which it sheds heavily during and before the summer season. This flammable material creates a thick "litter layer" that can ignite and fuel fires readily. Pine needles suppress the growth of other vegetation, creating a drier, more fire-prone environment. Forest fires typically occur between March and June, with May being the most fire-prone month. Forest fires in H.P. are predominantly caused by human activities (Grazing, resin extraction, and negligence) and climatic factors (High temperature, low humidity, lightning, etc.).

Forest fires in pine forests can have devastating impacts and contribute to air pollution, carbon emissions, and economic losses. Fires reduce soil fertility by altering nitrogen and microbial content, increasing soil pH, electrical conductivity, and availability of nutrients like nitrogen, phosphorus, and potassium. Ground vegetation and understory species are destroyed, leading to reduced species diversity. Wild animals can be directly killed by the fire itself, including burns and smoke inhalation. Forest fires release greenhouse gases, contributing to global warming and climate change. Prolonged exposure to wildfire smoke is linked to respiratory illnesses, heart disease, and increased mortality, especially among vulnerable populations (Sharma *et al*., 2023)

There are some effective management practices to prevent and control fires. Collecting and utilizing pine needles for preparing bio-fuel and handicrafts reduces forest floor fuel. Pine needles can be collected and utilized to make briquettes. Briquettes, a renewable source of energy, provide an eco-friendly alternative to traditional fuels such as firewood and charcoal. Briquettes are compacted blocks made from organic waste such as sawdust, agricultural residues, leaves, etc. The production process includes drying, compressing, and binding these materials into uniform shapes, enhancing their combustion efficiency. The resulting product has higher energy density and lower moisture content compared to traditional wood and coal. Switching to briquettes can significantly lower carbon emissions and deforestation rates (Vivek, 2019).

Methodology

Nauni is situated in the district Solan, Himachal Pradesh, with plotted position N 30˚ 51' 44.7444'', E 77° 10' 9.1488'' on the map. The study was conducted mainly in the pine forests of Dr. YS Parmar University of Horticulture and Forestry, Nauni, which covers an area of 5.5 square kilometres. The pine forest area under the University is 41.681 hectares. The weather conditions in Nauni are characterized by a mild and moderate climate. The average annual temperature is 17.5 °C and the annual rainfall is 1262 mm.

The study was conducted during the 4 months (March-June) in 2025. These particular months were decided for the study purposes as these are major months of the Forest Fire Season (FFS). Eight plots, each of 1 m^2, were created at different locations in the pine forest to represent the whole of the pine forest area. Each plot was marked properly with the plot number and the boundaries of the plots were created with stones.

Pine needles start falling from March, so 1st reading was taken on 9th March, 2025. After this, each plot was monitored weekly. The sudden decrease in the shedding of the pine needles was due to heavy rainfall. The pine needles were collected from each plot and weighed using a digital balance. The weight of pine needles from each plot was recorded separately to estimate the pine needles per hectare. The average weight was multiplied by the total pine forest area to estimate the total weight of pine needles in the Nauni region.

Result and Discussion

Table 1 shows the rise in thickness of shedding pine needle layers throughout the four months from March 9 to June 6 in 2025.

Table 1: Shedding of pine needles (cm) from March to June

	Pine needle shedding							
Date	**Plot 1**	**Plot 2**	**Plot 3**	**Plot 4**	**Plot 5**	**Plot 6**	**Plot 7**	**Plot 8**
29-03-2025	0.5	1.5	0.5	1.0	2.0	2.0	1.1	1.0
01-04-2025	0.5	1.5	0.7	1.3	2.0	2.0	1.1	1.3
08-04-2025	2.5	2.0	1.0	2.0	2.5	2.2	1.5	1.7
16-04-2025	3.0	4.0	2.5	3.0	3.5	2.7	4.6	2.3
30-04-2025	5.0	5.5	4.0	3.6	4.1	4.3	6.0	4.8
08-05-2025	4.8	5.0	3.0	2.8	3.6	4.1	5.5	4.1
16-05-2025	5.2	5.6	3.8	3.4	4.2	4.8	6.1	5.0
23-05-2025	6.0	6.2	4.2	4.0	5.0	5.4	6.6	5.6
01-06-2025	6.5	6.6	4.8	4.6	5.5	5.9	6.8	6.0
06-06-2025	6.7	6.9	5.0	4.9	5.8	6.2	7.0	6.3

The data shows a general increasing trend in pine needle shedding across all plots over time. The amount of shedding varied across plots, with some plots showing more shedding than others on certain dates. The data suggests that pine needle shedding is a continuous process, with some plots showing significant shedding on certain dates. The sudden decrease in the readings during the 1st week of May was due to heavy rainfall, which washed off some needles. The maximum shedding (7.0 cm) was observed in Plot 7 and the minimum (0.5 cm) occurred in Plot 1 and Plot 3. The weight of pine needles in each plot is presented in Table 2.

Table 2: Plot-wise weight of pine needles (kg)

Plots	**Weight**
1	0.561
2	0.574
3	0.390
4	0.386
5	0.480
6	0.498
7	0.580
8	0.508
Average	497.125
Total	**3.977**

The average weight of 8 plots was found to be 0.497 kg/m^2. The weight of pine needles in 1 hectare is calculated to be 4,970 kg.

Application and uses of pine needles

Asamoah *et al.* (2016) reported that briquetting utilizes agricultural and organic waste to produce fuel briquettes. The quality of briquettes depends on raw material properties like moisture content and carbon content. Chauhan *et. al* (2017) studied that pine contains over 50% cellulose, making it suitable for developing biodegradable packaging materials, blending them with cardboard pulp and plasticizer, to provide a potential alternative to plastic and help manage forest fires caused by un-decomposed needles.

Sajid *et al.* (2018) evaluated the anti-cancerous properties of *Pinus roxburghii* essential oil and its chemical composition. The oil demonstrated cytotoxic effects against various cancer cell lines, including leukemia, multiple myeloma, pancreatic, head and neck, and lung cancers. The findings suggest potential therapeutic applications, warranting further investigation into its bioactive compounds. Mandal *et al.* (2019) found that needles of a particular size, less than 2mm, pressure of 9MPa and temperature of 150°C were optimum for the production of briquettes. The calorific value of briquettes was found to be 17.56 MJ/Kg, density (1228 Kg/m^3) and compressive strength (7.05 MPa). Rana *et al.* (2022) concluded that pine needles hold significant potential for producing biochar, bioethanol, and activated carbon, their large-scale accumulation in forested regions increases the risk of wildfires, and their effective conversion could serve both economic and environmental purposes.

Sharma *et al.* (2022) examined the potential of pine needle fibre as reinforcement material in biodegradable composites. The study reported that treated pine needle fibres, when combined with polylactic acid (PLA), significantly enhanced the tensile and flexural strength of the resulting composites. The findings suggest that pine needles can serve as a sustainable alternative to synthetic fibres in eco-friendly material development. Jangra *et al.* (2023) studied the chemical composition and antioxidant activity of essential oils extracted from Chir pine needles. The extracted oils were rich in bioactive compounds like α-pinene and limonene, known for their antimicrobial and therapeutic potential. Roy *et al.* (2023) studied that the systematic use of pine needles of Chir pine for energy application can fulfil the growing energy demand, along with preventing forest fires. The transformation of pine needles into biochar and subsequently into briquettes is reported.

Arya *et al.* (2024) studied pine needles with reduced size and ground pine needles for methane production were conducted at a mesophilic temperature of 35°C. The substrates for the study included untreated and urea-treated reduced-size pine needles with or without cow dung and untreated and urea-treated ground pine needles with or without cow dung. Sharma *et al.* (2024) reported that renewable energy currently supplies 42.1% of India's energy needs and pine needle biomass and biochar have the potential to contribute to this growing share. Pine needles are high in lignin and carbon content, which are the primary components of wood biomass and other plant materials that are commonly used for biochar production. Pine needle biomass and biochar have low moisture content (8% and 4.3%) and high calorific value (18 and 29MJ/kg), respectively. These pine needles can be used for making good-quality biochar, which in turn can be utilised for making briquettes and pellets for energy use. Biochar production can generate carbon credits, which can be sold on the global carbon market.

Conclusion

The study was conducted in the pine forest area of Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan. This study provides a comprehensive estimate of pine needle biomass in the Nauni forest area. The whole pine forest area under the University was represented through eight plots of 1 m^2. The findings indicate a significant amount of pine needle accumulation, with an average weight of 0.497 kg/m^2 and an estimated weight of 4970 kg/ha. The study's results have important implications for forest management and fire prevention strategies. The proposed mitigating measures can help reduce the risk of forest fires, promote sustainable forest management, and potentially generate income through the utilization of pine needles. The partnership with stakeholders and policy support is essential for promoting briquette businesses and reducing production costs.

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SMART FARMING, STRONGER FUTURE: INTEGRATED FARMING SYSTEM FOR SMALL & MARGINAL FARMERS

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In countries like India, per capita land holding has been reducing day by day due to fragmentation of land and farmers concentrate mainly on cropping systems approach rather than farming system approach. Integrated farming system (IFS) is considered as one of the best options towards farming system approach through intensification of small holder farm income to ensure livelihood security. In view of the decline in per capita availability of land, it is imperative to develop strategies and agricultural technologies that enable adequate employment and income generation, especially for small-holders (farmers with <2.0 ha of land) who constitute the vast majority of the farming community in the developing world. No single farm enterprise, such as a typical mono-cropping system, is likely to be able to sustain the small-holder farmer. Integrated Farming Systems (IFS) are less risky if managed efficiently, as they benefit from synergisms among enterprises, diversity in produce, and environmental soundness. On this basis, IFS have been suggested for the development of small and marginal farms across Asia, and researchers have developed strategies which have benefited small-holder farmers by providing additional income and employment and minimizing risk.

Keywords: Integrated Farming System, Small and Marginal farmers, Income generation, Employment

INTRODUCTION

Integrated farming is defined as a biologically integrated system, which integrates natural resources in a regulated mechanism into farming activities to achieve maximum replacement of off-farm inputs and sustain farm income. The productivity of a diversified cropping system always tends to increase when it is integrated with crop, dairy, poultry, apiculture or fishery components.

An integrated farming system (IFS) helps farmers, especially small and marginal, to achieve maximum returns and income from different integrated components, thereby improving their standard of living.

The IFS also acts as a means for providing nutritional security to a farmer's family as the farmer is able to provide various IFS components such as vegetables, fruits, egg, milk, fish, etc. to the farmer's family and get the income from the surplus amount of these components.

The higher returns with the farming system were not only due to higher productivity of the system but also due to lower cost of production and recycling of by-products of crop components.

There is an increase in the value for labour absorption in IFS farms due to additional components brought into integration within the farm. The IFS is feasible with respect to socio-economic imperatives, but actual adoption rates of integrated farming are limited and unevenly spread among farmers.

Thus, in order to develop a nation, farmers should be properly made aware of the use and management of IFS.

CHARACTERISTICS OF SMALL AND MARGINAL FARMERS

1) Limited Landholdings:

Marginal farmers typically own less than 1 hectare, while small farmers have holdings between 1 and 2 hectares. These holdings are often fragmented and scattered, making efficient land use and mechanization difficult.

2) Low Investment Capacity:

Most of the farmers depend on local moneylenders, small loans, or government subsidies. As a result, they are unable to invest in quality seeds, fertilizers, or modern farm equipment, which directly affects their productivity and profitability.

3) Dependence on Monocropping:

A large proportion of smallholders rely on monocropping - growing a single crop such as paddy, wheat, or maize during a particular season. This exposes them to high risks, especially in the face of erratic rainfall, droughts, pests, or market price crashes.

4) Limited Access to Irrigation and Infrastructure:

Farmers often rely solely on rainwater. Additionally, basic infrastructure such as storage facilities, transportation, and market access is either inadequate or completely absent in many rural areas.

5) High Input Costs and Low Returns:

The cost of agricultural inputs such as seeds, fertilizers, pesticides, and labour - has risen significantly. Smallholders often pay higher prices due to lack of bulk purchasing power. However, the returns from farming remain low due to small-scale production, yield limitations, and unstable market prices.

IFS MODELS SUITABLE FOR SMALL AND MARGINAL FARMERS

Model 1: Crop + Poultry + Vermicompost (For < 1 ha)

The components include cereal / pulse + vegetables as main crop, backyard poultry and a vermicomposting unit.

- Poultry droppings are used in vermicomposting to produce high-quality manure for crops.
- Crop residues (vegetable peels, weeds, stalks) serve as bedding or feed in the compost unit.
- Compost improves soil fertility, reducing dependence on chemical fertilizers.

This is suitable for homestead or peri-urban areas and ideal for land-scarce families looking for daily income and food security.

Model 2: Crop + Dairy + Fodder + Biogas + Vermicompost (1 - 2 ha)

The components may be Paddy/Wheat + Pulse (crop rotation), 2 dairy cows or buffaloes, Fodder crops (Napier, Lucerne), Biogas unit and Vermicompost pit.

- Dung from dairy is used in the biogas unit (provides cooking fuel), and the slurry is fed into the vermicompost pit.
- Compost from vermiculture enriches the crop fields.
- Fodder crops ensure self-sufficiency in feed, reducing dairy input costs.
- Crop residues feed cattle; dairy waste enriches fields.

This is suitable for irrigated or semi-irrigated small farms with family labour availability and market access for milk.

Model 3: Crop + Fishery + Duck + Horticulture (1.5 - 2 ha, irrigated)

The components include paddy or vegetables as main crop, fish pond with composite fish culture, duck rearing (20 - 30 birds) and fruit trees on bunds (banana, papaya, guava)

- Duck droppings directly fertilize the pond and feed the fish (natural manure/feed).
- Pond water, enriched with nutrients, can be used for irrigating crops and trees.
- Fruits and vegetables supply feed or waste material for ducks.
- Multiple harvests from crops, fish, and fruits ensure regular income.
- This is suitable for wetland or lowland areas with permanent water bodies and labour availability.

Model 4: Crop + Goat Rearing + Agroforestry (Rainfed, 1 - 1.5 ha)

The components are Millets + Pulses (e.g., finger millet + pigeon pea), 5 - 10 goats (meat production) and trees like Moringa, Neem, Subabul on bunds (fodder, fuelwood).

- Goats feed on crop by-products and tree fodder.
- Goat manure is applied to fields, enhancing soil fertility in rainfed systems.
- Agroforestry trees prevent soil erosion and provide long-term income.
- Millets and pulses are drought-tolerant and suitable for dry zones.

This is the suitable for rainfed/dryland regions with grazing space or fallow land.

Model 5: Kitchen Garden + Poultry + Mushroom + Composting (Urban or <0.5 ha land)

The components include seasonal vegetables in backyard/terrace garden, 5 - 10 backyard poultry birds, mushroom cultivation (paddy straw mushroom, oyster) and compost pit using kitchen waste.

- Poultry droppings and kitchen waste feed the compost pit.
- Mushrooms grow on agricultural waste like straw and vegetable stalks.
- Compost enriches vegetable beds, reducing input cost.
- Poultry feathers, droppings, and leftover feed go back into the soil as nutrients.

This model is suitable for urban or peri-urban areas, especially for women-led SHGs and nutrition-focused farming.

SELECTION OF ENTERPRISES

- ✓ Based on landholding size
- ✓ Suitability to agro - climatic conditions
- ✓ Availability of water resources
- ✓ Availability of family labour
- ✓ Complementarity between components
- ✓ Market demand and accessibility
- ✓ Low initial investment requirement
- ✓ Quick and regular income generation
- ✓ Nutritional security for the family
- ✓ Farmer's skill and experience
- ✓ Potential for waste recycling
- ✓ Government support and subsidies

ADVANTAGES

- Efficient resource utilization
- Enhanced income through enterprise diversification
- Year-round employment for farm families
- Risk minimization due to multiple income sources
- Nutritional security through diverse food products
- Low external input requirement
- Waste recycling within the system
- Improved soil fertility and health
- Better use of family labour
- Climate resilience and sustainability

CONCLUSION

Small and marginal farmers, despite their limited land and resources, hold immense potential to achieve sustainable livelihoods through Integrated Farming Systems (IFS). By understanding their unique characteristics and tailoring farming models to their specific needs, IFS enables optimal utilization of every inch of land, labour, and input. Careful selection of complementary enterprises not only boosts productivity and income but also ensures nutritional security, employment, and ecological balance. With proper training, market access, and policy support, IFS can transform small and marginal farms into resilient, self-sustaining units—proving that small land can indeed yield big potential.

Government policies and extension services play a crucial role in promoting awareness, providing training, and facilitating the adoption of integrated practices. Moreover, community-based approaches and farmer cooperatives can enhance the dissemination of successful models and innovations, fostering a collaborative environment for sustainable development.

Overall, the adoption of integrated farming systems holds significant potential to improve the socio-economic status of small and marginal farmers, ensure food security, and promote environmental sustainability. A concerted effort from policymakers, researchers, extension agencies, and farmers themselves is essential to realize the full benefits of this holistic approach and to foster resilient rural communities in the face of ongoing challenges.

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Banana Fibre Extraction

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Abstract

Banana fibre is a natural, biodegradable fibre extracted from the pseudo-stem of the banana plant, typically discarded after fruit harvesting. Its extraction helps reduce agricultural waste while providing additional income for farmers. Rich in cellulose, banana fibre offers excellent strength, moisture absorption and sustainability. The fibre is extracted through manual, mechanical or chemical methods, involving steps such as harvesting, decortication, retting and spinning. Its eco-friendly properties and versatility make it suitable for textiles, paper, ropes, handicrafts and composite materials. With growing global interest in sustainable alternatives, banana fibre presents a promising solution for environmentally responsible industrial and commercial applications.

1. Introduction

Banana fibre is a natural textile fibre that is extracted from the pseudo stems of the banana plant. Banana is primarily cultivated for its fruit, but its pseudo-stem is usually discarded after harvesting, contains valuable fibre that can be extracted and used in various industries. This process not only reduces agricultural waste but also provides an additional source of income for farmers and contributes to environmental conservation. Banana fibre has excellent moisture absorption properties, making it suitable for applications in textiles, handicrafts, paper and composite materials. Banana fibres are biodegradable, sustainable and environmentally friendly, making them an attractive alternative to synthetic fibres, particularly in today's growing focus on sustainability.

2. Extraction of banana fibre

The extraction of banana fibre involves several methods, including manual, mechanical and chemical processes. Traditionally, manual extraction was the primary method, where fibres were stripped from the pseudo stem using knives or blades. However, this method is labor-intensive and time-consuming. Mechanical extraction, using decorticators and specialized machines, has significantly improved efficiency and fibre quality. In some cases, enzymatic and chemical treatments are used to enhance the fibre's softness and durability. The choice of extraction method depends on the intended use of the fibre, cost considerations and environmental impact.

2.1. Method of Banana Fibre Extraction

Banana fibre extraction involves several stages that take the raw plant material from the banana pseudo stem to the finished product.

1. **Harvesting**: The first step in banana fibre extraction is harvesting the banana pseudo stem. The pseudo stem is the main stem of the banana plant, which is composed of several layers of soft, fibrous tissue. Once the banana fruits are harvested, the pseudo stem is cut and processed for fibre extraction. The pseudo stem is typically around 2-3 meters long and contains a substantial amount of fibre.
2. **Decortication**: The harvested pseudo stem is then decorticated to remove the outer layers. Decortication is the process of stripping away the bark and separating the fibres from the stem. This can be done by manual methods or using mechanical decorticators. The outer layer is removed to reveal the long, strong fibres that lie beneath.
3. **Soaking**: After decortication, the fibres are often soaked in water to soften them and make the separation of the long strands easier. This step is particularly important for extracting the best quality fibres, as soaking helps in removing the non-fibrous materials and dirt. Soaking for 2-3 days is typically done in fresh water, depending on the specific method used.
4. **Rettling**: Rettling is the next step in the process, where the softened fibres are further separated. This involves either manual or mechanical scraping to remove the remaining pulp and unwanted materials from the fibre. The rettling process ensures that only pure, clean fibres are left for the next steps.

5. **Drying and Spinning**: Once the fibres are clean, they are spread out in the sun or placed in a dryer to remove excess moisture. After drying, the fibres are ready to be spun into yarn. Spinning involves twisting the fibres together to form a continuous thread, which can then be woven or knitted into fabric.
6. **Finishing**: After the fibres are spun into yarn, they may undergo additional processes such as bleaching, dyeing, or other finishing treatments to improve the appearance and texture of the final product. Banana fibre is known for its strength and durability, but additional treatments may be used to enhance its softness or to impart specific colours for textile production.

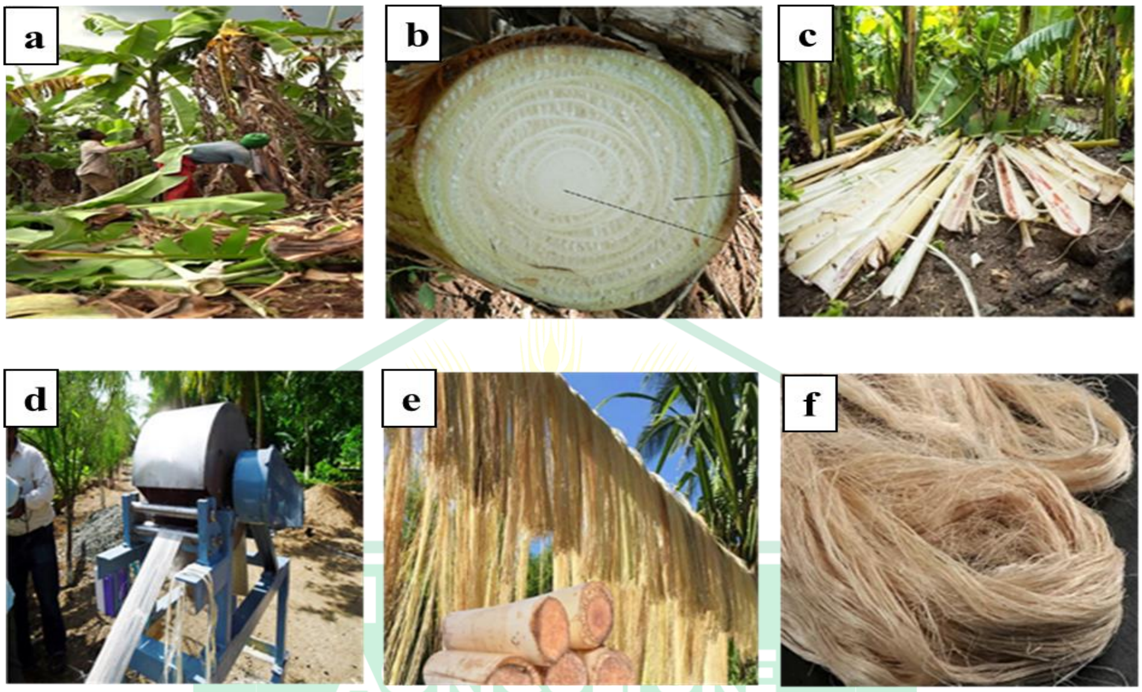

Figure 1: Extraction of banana fiber (a) Harvesting of banana pseudostem (b) Harvested pseudostem, (c) Peeled pseudostem, (d) Retting process (e) Sun-dried fibers and (f) Extracted raw banana fibers

3. Characteristics of Banana Fibre

The key characteristics of banana fibre are:

1. Physical Properties

- **Appearance**: Banana fibre has a natural golden sheen, similar to silk, which enhances its aesthetic appeal, especially in textiles and crafts.
- **Texture**: It is soft yet coarse, making it suitable for blending with other fibres like cotton, jute or wool to improve comfort and durability.
- **Lightweight**: Banana fibre is lightweight, making it ideal for clothing and accessories without adding bulk.
- **Length and Fineness**: The length and fineness of the fibre vary depending on the extraction method and the part of the pseudostem used. The outer layers yield coarse fibres, while the inner layers provide finer fibres.

2. Mechanical Properties

- **High Tensile Strength**: Banana fibre has excellent tensile strength, making it durable and resistant to breakage. This property makes it ideal for ropes, mats and industrial applications.
- **Good Elasticity**: Banana fibre has moderate elasticity, providing flexibility in weaving and crafting.
- **Moisture Absorption**: It has high moisture-absorbing capacity, which makes it breathable and comfortable when used in textiles. However, this also means it requires proper drying and treatment to prevent microbial growth.

3. Chemical Properties

- **Cellulose Content**: Banana fibre is rich in cellulose (around 60-65%), contributing to its strength and biodegradability.

- **Lignin Content**: It has moderate lignin content (around 5-10%), making it slightly stiff but also more durable.
- **Pectin and Hemicellulose**: These components give the fibre some flexibility and help in the natural binding of fibres.
- **Biodegradability**: Banana fibre is completely biodegradable, making it an eco-friendly alternative to synthetic fibres.

4. Thermal and Environmental Properties

- **Heat Resistance**: Banana fibre has good heat resistance, making it suitable for certain industrial applications. However, prolonged exposure to high temperatures can weaken its structure.
- **Eco-Friendliness**: Since it is a byproduct of banana cultivation, banana fibre extraction reduces agricultural waste and promotes sustainable practices.
- **Pest and Fungal Resistance**: While banana fibre is naturally resistant to some pests and fungi, improper storage in humid conditions can lead to microbial degradation.

4. Properties of banana fibre

Tenacity	29.98g/denier
Fineness	17.15
Moisture regain	13.00%
Elongation	6.54
Alco-ben extractives	1.70%
Total cellulose	81.80%
Alpha cellulose	61.50%
Residual gum	41.90%
Lignin	15.00%

5. Applications of Banana Fibre

The versatility of banana fibre has made it an important material in a range of industries, particularly those focused on sustainable and eco-friendly alternatives to synthetic materials.

1. **Textiles and Garments**: Banana fibre is often used in the production of textiles, particularly in countries like India, Nepal, and the Philippines, where the banana plant is abundant. The fibre can be woven into fabrics for making clothing, scarves and other accessories. It has a texture similar to linen and can be used for both high-end and everyday clothing.
2. **Paper Production**: Banana fibre is also used in the production of paper, especially for premium-quality handmade papers. The strong, fibrous structure of the banana plant is ideal for creating high-quality paper that is both durable and eco-friendly. The pulp extracted from banana fibres is often combined with other natural fibres to produce specialized paper products.
3. **Ropes and Twine**: Due to its strength and durability, banana fibre is commonly used to make ropes and twine. The fibres are naturally strong and can withstand significant wear and tear, making them ideal for agricultural and industrial applications.
4. **Handicrafts and Decorative Items**: Banana fibre is widely used for creating handicrafts such as baskets, mats and bags. These items are handmade using traditional techniques and are often sold as eco-friendly and sustainable alternatives to plastic or synthetic products.
5. **Composite Materials**: Banana fibres have been found to be effective in making composite materials, which are used in construction and automotive industries. The strength of the banana fibre makes it a viable option for reinforcing plastics, creating biodegradable materials for various uses.

6. Benefits of Banana Fibre

1. **Eco-Friendly and Sustainable**: Banana fibre is a natural, biodegradable material that reduces the dependence on synthetic fibres such as polyester or nylon. As an agricultural by-product, the extraction of banana fibre provides an additional source of income for farmers, particularly in banana-growing regions.
2. **Durability**: Banana fibres are known for their strength and resistance to wear. This makes them an excellent choice for producing textiles, ropes and paper that require long-lasting durability.
3. **Low Environmental Impact**: The production of banana fibre requires relatively low energy and minimal use of chemicals, making it a more environmentally friendly option compared to synthetic fibres. The process is

also relatively water-efficient, with soaking and retting stages using less water than many other fibre extraction methods.

4. **Economic Value**: The extraction of banana fibre provides economic opportunities in rural areas where banana plants are abundant. By using the pseudostem, which is often considered a waste product, farmers can increase their income by selling the fibres for various commercial applications.

7. Conclusion

Banana fibre extraction is a sustainable and eco-friendly process that offers many benefits, including the production of biodegradable textiles, ropes, paper and handicrafts. While the process faces some challenges, the growing demand for sustainable materials makes banana fibre a promising alternative to synthetic fibres. The continued development of mechanization and improved extraction methods will further enhance the potential of banana fibre in various industries, contributing to environmental sustainability and economic growth in banana-producing regions.

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Foliar Nutrition: An Effective Way to Alleviate Abiotic Stress in Pulses

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Introduction:

- Pulses are leguminous crop that constitute an essential part of Indian diet because pulses are important protein source.
- India is the largest producer (25%), consumer (27%) & importer (14%) of pulses in the world.
- Enrich the soil through BNF & improve soil physical conditions.
- They are called "Unique Jewels" of Indian crop husbandry.

Stress: Stress in plants refers to external conditions that adversely affect growth, development or productivity

Stresses trigger a wide range of plant responses.

- ✓ Altered gene expression
- ✓ Cellular metabolism
- ✓ Changes in growth rates and crop yields.

Biotic Stress:

- Weeds
- Insects
- Fungi
- Bacteria
- Virus
- Herbivores

Abiotic Stress:

- ➢ Heat stress
- ➢ Chilling stress
- ➢ Drought stress
- ➢ Salinity stress
- ➢ Radiation stress
- ➢ Waterlogged stress

Heat stress:

- Rise in temperature beyond threshold level for a period of time sufficient to cause irreversible damage to plant growth and development.
- Heat stress is serious threat to crop production world wide.
- Different greenhouse gases will gradually increase worlds average ambient temperature.

Chilling stress:

- Chilling stress - when plants are exposed to a low temperature above 0 °C.
- Freezing stress - when plants are exposed to a low temperature below 0 °C.
- Plant chilling injury refers to an injury that is caused by a temperature drop to below to 10 to 15°C but above the freezing point.
- The most common site implicated for chilling injury is plasma membrane.

Drought stress:

- Drought stress occurs when the available water for plants in the soil is decreased due to low soil moisture at a certain time.
- Physiologically water stress (deficiency) in plant occurs when the transpiration rate from leaf surfaces is higher than the water uptake by roots.

Waterlogged stress:

- The soil which is saturated with water is called waterlogged soil.
- Inhibition of aerobic respiration during waterlogging limits energy metabolism and restricts growth and a wide range of developmental processes, from seed germination to vegetative growth and further reproductive growth

Salinity stress:

- Soil salinity is the amount of dissolved salts in the soil solution (the aqueous phase in the soil).
- The process of accumulating soluble salts in the soil is known as salinization.
- Salinity is caused due to high accumulation of Calcium, Magnesium as well as sodium and then anions such as SO_2, NO_3, CO and HCO_3, Cr, etc.

Radiation stress:

Radiation stresses, including ultraviolet (UV-B) irradiance, trigger a wide array of plant responses, ranging from altered gene expression and cellular metabolism (e.g., membrane injuries, photosynthetic disorders) to changes in growth rates and crop yields.

Factors determining severity of abiotic stresses

1. Soil type
2. Temperature
3. Relative humidity
4. Organic matter in the soil
5. Local vegetation
6. Precipitation etc.

Plant response to stress:

1. Effects on growth

- Reduced growth
- Reduced productivity
- Premature senescence

2. Effects on plant physiology

- Reduced water uptake
- Reduced photosynthesis
- Altered transpiration
- Decreased nitrogen assimilation
- Metabolic toxicity

3. Other effects

- Altered gene expression
- Disorganisation of membrane system
- Altered protein synthesis
- Breakdown of macromolecules

Stress Resistance Mechanism

Escape: Complete their life cycle before the occurrence of a stress.

Avoidance: Achieved through morphological changes in the plant, such as reduced stomatal conductance, decreased leaf area and increased root/shoot ratios

Tolerance: Sustain the effect of stress without dying or suffering injury.Achieved by specific physiological, biochemical and molecular mechanisms at cell level which include specific gene expression and accumulation of specific proteins.

Foliar Nutrition:

Foliar nutrition is a technique of feeding plants by applying liquid fertilizer directly to their leaves

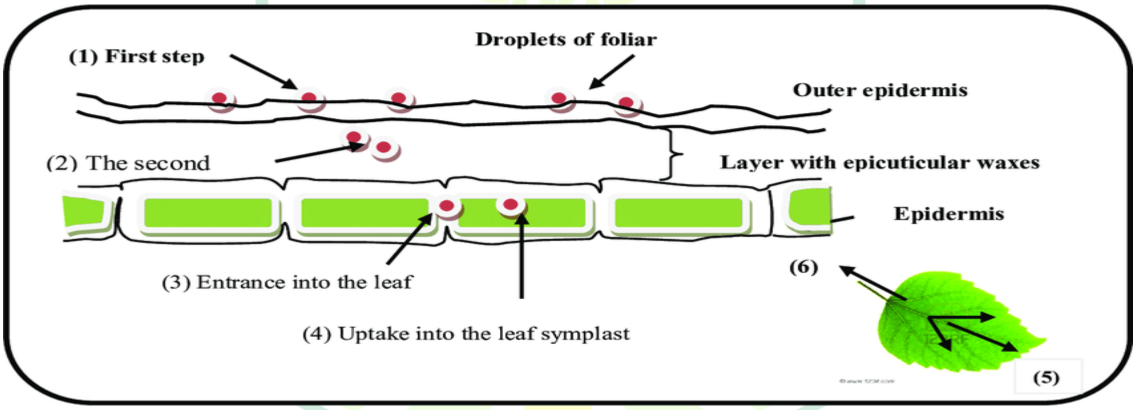
Need of foliar application

- Unfavorable soil conditions
- Unfavourable weather conditions
- Rapid response
- Restricted root growth condition
- To improve NUE

Advantages of foliar nutrients:

- Quick nutrient absorption
- Enhanced movement
- Quality of crops
- Effectively used under topographical conditions
- Poor and marginal lands
- Removing leaching and fixation losses
- Supply nutrients in peak periods

Mechanism Of Foliar Feeding:



Response of plants to foliar nutrition:

- Activation of stress-related genes
- Biosynthesis of antioxidant enzymes osmoprotectants
- Heat shock proteins (HSPs)
- Detoxification of ROS
- Functional or structural protection of proteins
- DNA repair
- Membrane stability

Conclusion:

Foliar nutrition serves as an efficient and targeted strategy to mitigate the adverse effects of abiotic stresses such as drought, heat, and nutrient deficiencies in pulse crops. By delivering essential nutrients directly to the leaf surface, it ensures rapid nutrient absorption, bypassing root-related uptake limitations commonly encountered under stress conditions. This method enhances photosynthetic activity, improves metabolic functions, and strengthens plant resilience, thereby sustaining growth and yield even under unfavorable environments. As a cost-effective and timely intervention, foliar feeding complements soil fertilization and plays a vital role in improving productivity and stress tolerance in pulse cultivation.

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Influence of Monsoon Variability in Agriculture and Other Ecosystems

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Introduction:

What is Climate Change?

Climate change refers to long-term shifts in temperatures and weather patterns, primarily caused by human activities-especially the burning of fossil fuels like coal, oil, and gas. These activities release greenhouse gases (such as carbon dioxide and methane) into the atmosphere, trapping heat and leading to global warming.

Impact of Climate Change on agriculture:

- As 60% of agriculture in India is rain-fed, monsoon variability has a large impact on agricultural production.
- These uneven distribution rains along with increasing temperatures and humidity give rise to pest attacks and diseases.
- Heat stress and weak monsoon affect plant physiological processes, leading to spikelet sterility, non-viable pollen and reduced grain quality.
- Drought, on the other hand, reduces plant transpiration rates and may result in leaf rolling and drying, reduction in leaf expansion rates and plant biomass, immobilization of solutes and increased heat stress of leaves.

Natural causes of climate change:

- Greenhouse gases
- Solar output
- Axil tilt
- Ocean current
- Volcanic
- Forest fires

Anthropogenic causes of climate change:

- Deforestation
- Chemical fertilizers
- Livestock production
- Transport Vehicles
- Fluorinated and Industrial Gases

Global Warming and Monsoon:

- A drastic change in the monsoon rainfall intensity, duration, frequency and spatial distribution can be attributed to the climate change.
- All this is in response to global warming then it can be permanent and might accelerate.
- More data is needed to get a clear picture on the complete separation of the global warming impact from natural climate variability (such as El Niño).

Impact of Climate Change is Affecting the Indian Monsoon:

Monsoon variability: Impact of Climate Change, increasing water vapour transport from the ocean into land increases because warmer air holds more water vapour. This triggers changes in large-scale circulations, which influence the strength and extent of the overall monsoon circulation.

Impact of Climate Change Delayed Monsoon Withdrawals: Intense warming of Indian peninsula and oceans resulting in the formation of local-low pressure systems are attributed to delayed monsoon withdrawals.
Atmospheric Teleconnections: Impact of Climate Change rising temperatures, there has been an increase in the occurrence of atmospheric teleconnections such as ENSO, Indian Ocean Dipole (IOD) and Madden-Julian Oscillation (MJO), which are directly impacting the monsoonal circulations.
El Niño–Southern Oscillation (ENSO): Is an irregular periodic variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting the climate of much of the tropics and subtropics. El Nino leads to a weaker monsoon whereas La Nina favours Indian monsoon.
The Indian Ocean Dipole (IOD): Also known as the Indian Niño, During the period of positive IOD, the Indian summer monsoon rainfall is considerably good as compared to the negative IOD period.
Madden-Julian Oscillation (MJO): Is an eastward moving disturbance of clouds, rainfall, winds, and pressure that traverses the planet in the tropics and returns to its initial starting point in 30 to 60 days, on average. Shorter the cycle of MJO, better the Indian Monsoon. If it is nearly 30 days then it brings good rainfall during the monsoon season.
If it is above 40 days then MJO doesn't give good showers and could even lead to a dry monsoon.
Monsoon variability:
Indian monsoon exhibits variability in all time scales:

- Diurnal
- Daily
- Intra-seasonal
- Inter-annual
- Decadal

Temporal scales of monsoon variability:

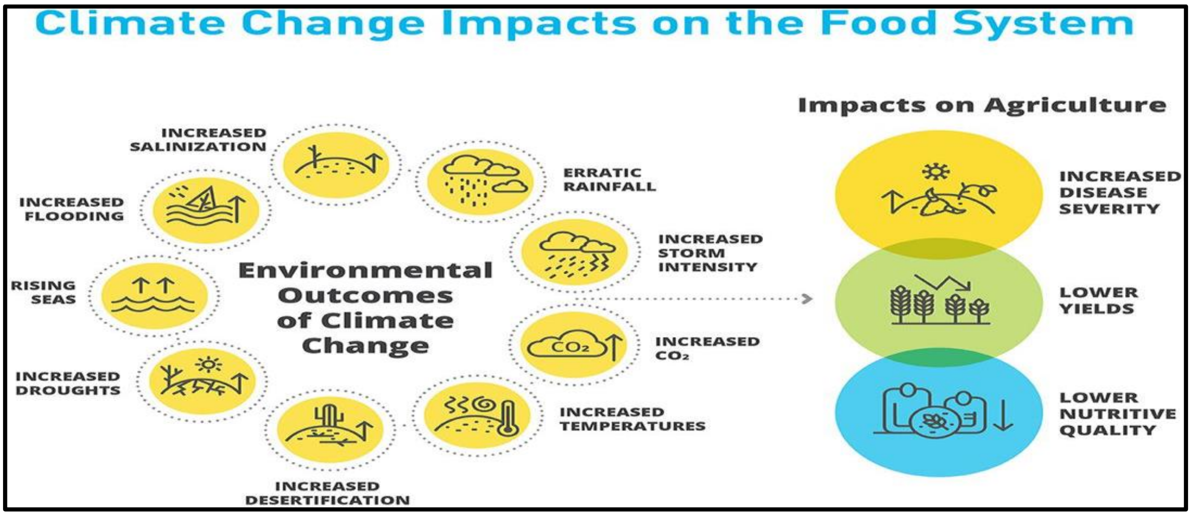
Scale	Intra-seasonal	Inter-annual	Decadal & centurial	Millenial & longer
Features	Active & break monsoon phase day oscillations	Droughts & floods	Changes in the frequency of droughts and floods	Changes in the areal extents of monsoon
Factors	Atmospheric variability; tropical-mid-latitude interactions; soil moisture; sea surface temperature	Atmosphere interactions; el nino, southern oscillation; top layers of tropical oceans; snow cover; land surface characteristics	Monsoon circulation variations; deep ocean involvement; greenhouse gases increase; human activities; biospheric changes; volcanic dust	Global climate excursions; ice ages; warm epochs; sun-earth geometry.

Effect of monsoon/precipitation on agriculture:

- Rainfall patterns determines cropping systems.
- Decisions on preparatory tillage, time of sowing, scheduling of irrigation, plant protection, time of harvesting etc depends on rainfall.
- Rain analysis is necessary for designing farm ponds, tanks and irrigation projects.
- Amount, distribution and intensity of rainfall dictate crop productivity.
- High intensity rains leads to floods and soil erosion.
- Deficit and untimely rain leads to drought.
- Food grain production and fodder needs of a country (adequacy, surplus or deficit) depend on untimely rainfall during crop growing season.

Impact of Climate Change on Insect Pests:

- Agricultural crops and their corresponding pests are directly and indirectly affected by climate change.
- Direct impacts are on pests reproduction, development, survival and dispersal.
- Indirectly the climate change affects the relationships between pests, their environment and other insect species such as natural enemies, competitors, vectors and mutualists.



Impact of Monsoon variability on the Indian Economy:

- Impact on Indian Agriculture
- Impact on GDP
- Impact on Balance of Trade
- Impact on the food supply
- Impact on the hydro-power sector and irrigation facilities
- Impact on rural economy

Conclusion:

- The inter annual variation of monsoon revealed that El Niño play a significant role in altering the monsoon onset.
- In India, an alteration in the spatial and temporal variability of rainfall induced by El Niño and its intensity, sensitivity of crops to El Niño.
- A drought in summer in generally leads to large reduction food grain production and has large intra seasonal variability of rainfall.
- Day to day variation of rainfall can have significant impact on *kharif* food grain yield.

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Role of Silicon in Drought Management

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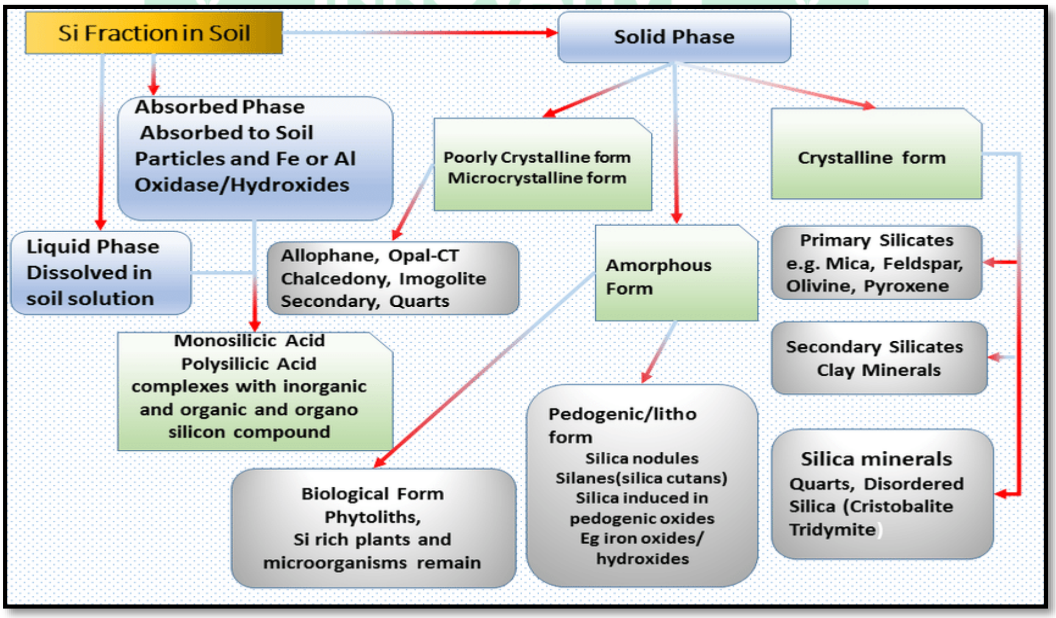
Introduction:

The water stress may be recorded as one of the major adverse variables affecting plant performance. It causes loss in crop productivity and quality both. The mineral nutrients conferred a crucial role in maintaining desirable growth and also stress tolerance. **Si** is considered as a bioactive beneficial element in providing benefits for plant development during **stress** and **Si** get accumulated in the walls of the epidermal and vascular tissues of monocots to enhance water uptake transport along with antioxidant enzymes and photosynthetic capacity. The concentration of **Si** in plants on the basis of dry weight varies from 0.1 -10%. Concentration of **Si** in a plant varies from organ to organ and accumulate higher in mature leaves.

Criteria of siliocon:

- The element is part of a molecule which is an intrinsic component of the structure or metabolism of the plant.
- The plant can with severely deficient in silicon element that exhibits abnormalities in growth, development or reproduction, i.e. 'performance', compared to plants with lower deficiency.

Sources of Silicon:



Silicon as beneficial element:

- Provide strength and rigidity to cell wall, improved growth, health and productivity.
- Developed potency to improved drought, frost and salt stress.
- Decreased lodging.
- Developed potential and boosting the plant's against natural insects, pests and disease causing pathogens.

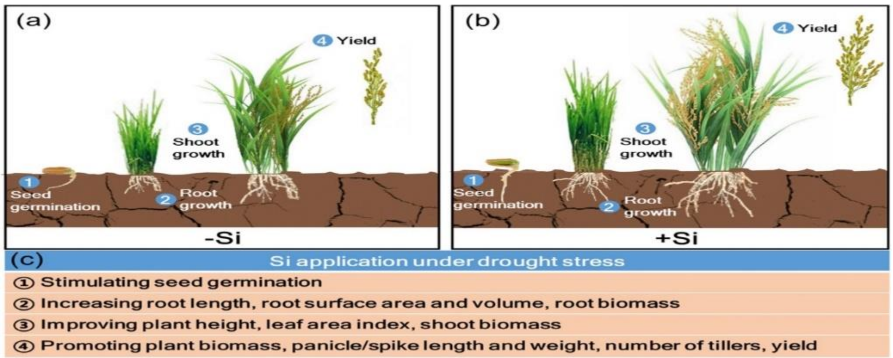
Role of Silicon in plants:

- It act as physical barrier and enhance plant resistance to toxic elements.
- Reduce oxidative stress and it help in alleviating the salt damage.

- ❖ Alleviate drought stress (rice) by improving plant water status, photosynthesis and mineral nutrient absorption.
- ❖ It improves the yield and quality of some crops.
- ❖ It help in decreasing the susceptibility to disease and insect damage.
- ❖ Si application enhances endogenous growth factors, resulting in the development of denser roots (root diameter, area, volume, and length) and the shoot biomass of stressed plants.
- ❖ Si also stimulated an increase in cell wall extensibility in the growth region along with root/shoot ratio and water uptake ability.
- ❖ Si played an essential role in balancing the uptake, transport, and distribution of minerals to the aerial parts of plants during stress as it expanded the accretion of nutrients.

Effects of silicon in plants:

- ✓ Si Alleviates the Effects of Water Stress on Photosynthetic Responses.
- ✓ Si Mitigates the Effects of Water Stress on Chlorophyll a Fluorescence, Chlorophyll Content, and Chlorophyll Index.



Beneficial effects of silicon (Si) on the growth and development of plants under drought stress condition

Silicon mediated drought tolerance mechanisms:

1. Modification of gene expression:

- ➢ Secondary messengers such as Ca^{2+}, ROS, and phospholipids send initial signals to drought-responsive genes via kinases.
- ➢ These genes encode functional proteins that protect cellular proteins, maintain membrane integrity besides water absorption and transport.

2. Osmotic adjustment and osmolytes:

- Si application increases water content of many plant species under drought stress.
- Si application increases water potential as well as osmotic potential in plants under drought stress while maintaining higher turgor pressure.

3. Regulation of phytohormone biosynthesis

- Phytohormones such as abscisic acid, salicylic acid, jasmonic acid, etc. are known to play an essential role in improving tolerance to multiple stresses by mediating different aspects of growth and physiological responses in plants.
- These phytohormones act as chemical messengers, which help plants in sensing and responding to the drought stress and other stress.
- For example, exogenous application of salicylic acid (SA) and H_2O_2 enhances relative water content (RWC) and maintain optimum water status in plants under drought.

4. Reduction in oxidative stress

- ❖ **Si** application has been documented to decrease oxidative damage in plants by improving the activities of essential plant antioxidant enzymes such as SOD, CAT, POD, GR and APX, as well as the concentration of GSH which helps to scavenge ROS.

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5. Increase in absorption and assimilation of mineral nutrients

- The use of **Si** can play a key role in stabilizing the absorption, transportation and distribution of different mineral nutrients in plants under drought stress thereby helping plants in stress elevation on and assimilation of mineral nutrient.

6. Modification of gas exchange attributes

- **Si** addition significantly increases photosynthetic rate, stomatal conductance and transpiration rate in drought stressed plants in contrast to plants not supplied with Si.

Conclusion:

- we conclude that **Si** supplementation can successfully improve plant growth, biomass, photosynthesis, nutrient uptake and antioxidant enzymes during drought stress conditions, which may be triggered by various biochemical mechanisms, physiological and molecular mechanisms.
- **Si** addition can be useful in boosting crop growth, quality and yield under drought stress.

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Precision Water Management in Drylands

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Introduction:

Dryland farming is cultivation of crops in regions with annual rainfall around 750 mm. These are semi arid tracts with a growing period between 75 to 120 days. Moisture conservation practices are necessary for crop production. Precision water management (PWM) is related to the judicious use of water so as to achieve sustainable water management. It refers to the precise application of quality water.

Characteristics of dryland:

- Uncertain and limited annual rainfall
- Occurrence of extensive climatic hazards like drought, flood.
- Undulating soil surface
- Relatively large size of fields
- Very low crop yield
- Poor economy of the farmers
- Poor health of cattle as well as farmers

Contribution of dry farming in Indian agriculture:

- 70 % of rural population
- 60 % livestock population
- 84-87 % coarse cereals and pulses
- 80 % horticulture
- 77 % oilseeds
- 60 % cotton
- 50 % fine cereals

Constraints of dry land agriculture:

- ✓ Climatic constraints
- ✓ Soil moisture
- ✓ Traditional cultivation practices
- ✓ Lack of suitable varieties
- ✓ Socio economic constraints.
- ✓ Soil related constraints

How to address this challenge in drylands (4R):

- Right time
- Right place
- Right method
- Right stage

Objectives PWM:

- Water Saving
- Reducing costs
- Environmental impact
- Optimizing the economic value
- Optimizing crop production

- Resource use

Why Precision in is required:

- ✓ Precision eliminates manual operations
- ✓ Increased WUE and increase yield
- ✓ Smooth and efficient operating system
- ✓ Optimizing energy requirements
- ✓ Possibility to change frequency of irrigation
- ✓ Optimization of fertigation process

Components of PWM:

1. Drip irrigation:

a) Surface drip irrigation: where water is applied directly to the soil surface

b) Sub-surface drip irrigation: where water is applied below the soil surface through narrow tubes.

2. Sensor based automation:

Sensor: Sensor is a device, module, machine whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor.

- Soil moisture sensors measure the water content in the soil.
- The World's soil moisture sensor market has been estimated to grow at a rate of 16.2% between 2015 and 2022 reaching sales of 206.2 million U.S. dollars.

a) Neutron probe:

- Soil moisture can be estimated continuously without disturbing the soil.
- This meter scans the soil about 15 cm diameters around the neutron probe in wet soil and 50 cm in dry soil. consists of a probe and a scalar or rate meter.
- This contains a fast neutron source which may be a mixture of radium and beryllium or americium and beryllium.

b) Time Domain Reflectometry (TDR):

- This contains two parallel rods. The rods are connected to an instrument that sends an electromagnetic pulse (or wave) of energy along the rods.
- The rate at which the wave of energy is conducted into the soil and reflected back to the soil surface is directly related to the average water content of the soil.

c) Tensiometers:

- ✓ A tensiometer measures soil water suction (negative pressure), which is usually expresses as tension.
- ✓ This suction is equivalent to the force or energy that a plant must exert to extract water from the soil.

3. Crop sensors:

a) Sap flow sensor: Sap flow is the movement of fluid (water and nutrients) through a plant. Sap flow will reduce as a plant goes from an irrigation cycle to a stress cycle.

b) Dendrometer: Dendrometers measure microvariations in stem diameter caused by cycles of shrinking and swelling, which indicate changes in plant water content.

c)Infrared thermometer: It provides crop canopy temperature, a relative measure of transpiration and an indication of crop water stress.

Automation Based irrigation:

Conditional:

- Sensors placed in the irrigated area.
- Opening and closing of the values –data of sensors passed on the Programme installed in the irrigation computer.
- Very efficient but it require smooth operation.
- Precise irrigation as and when required by the plant to meet out crop water requirement.

Non-conditional:

- Numerical data fitted manually in the irrigation computer – programme.
- Require skilled irrigation personnel.

Advantages of automation irrigation system:

- ✓ The manual operation of valves is not necessary.

- ✓ Alteration in the frequency of irrigation and fertigation to optimize the application is possible.
- ✓ Precision water management in drylands It uses advanced technologies for complex cropping systems which are difficult to operate.

Disadvantages of Automation:

- The systems can be very expensive.
- Self-help compatibility is very low with big-scale systems, which are very complex.
- Most automated irrigation systems need electricity.

Variable rate of irrigation:

- ✓ Variable rate systems allow growers to adjust the application rates based on soil conditions and other factors to prevent over-watering some areas of the field and under-watering others.
- ✓ It optimizes the spatial and temporal distribution of water so as to promote crop growth and yield.

Low – Elevation Spray Application (LESA):

- Operating pressures - 6 to 15 psi.
- Application efficiencies between 88 and 97%.
- LESA has been shown to use about 18% less water than MESA.
- On an average 21% more irrigation-water reached the ground with LESA than with MESA systems.

Low energy Precision Application (LEPA):

- Operating pressures - 15 psi.
- Application efficiencies around 95%.
- LEPA systems applicability is limited to fields with relatively low slope (less than 1% slope).

Mid Elevation Spray Application (MESA):

- Operate at pressures of 25 to 40 psi
- 78 to 85% Application efficiency

A I Irrigation:

a) Irrigation control system

CropX:

- The CropX software system for advanced irrigation.
- Sensor stations placed strategically in the fields according to a GPS-enabled smartphone app synch to the phone to transmit data updates on soil conditions.
- CropX informs farmers about the amount of water, fertilizer and pesticide needed by each patch at specific times, and also control the irrigation system accordingly, automatically handling daily decisions for farmers.

B) Tevatronic:

- ✓ This irrigation technology, based on research at the Ministry of Agriculture's Volcani Institute.
- ✓ Fully automates irrigation and fertilization customized to achieve desired root system depth, as well as the decision-making behind them.
- ✓ The system increases productivity from 15-31% and saves up to 27-75% on water.

Challenges to precision irrigation water management system in India:

- Small land holdings.
- Lack of investment capacity of small and marginal farmers.
- Insufficient supporting infrastructure like computers/ controllers.
- Cropping system-mismatch.
- Low lands / shallow waterlogged areas/challenge ecosystems.
- Maintenance services and supporting schemes.
- Technical services.
- Non-uniform development of micro irrigation in Indian states.

Government initiatives towards water management:

- National Mission on Micro Irrigation (NMMI)
- National Horticulture Mission (NHM)
- Pradhan Manthri Krishi Sinchayee Yojana (PMKSY)
- Horticulture Mission for North East and Himalayan States (HMNH)

- Rastriya Krishi Vikas Yojana (RKVY)

Conclusion:

- Precision water management is a critical tool for sustainable development in drylands. By using technology to collect and analyze data about water use, we can identify areas where water is being wasted or used inefficiently.
- This information can then be used to develop targeted interventions that can improve water productivity and reduce water stress.
- Precision water management is not a silver bullet, but it is a promising tool that can help us to better manage our water resources in drylands. As climate change continues to put pressure on water supplies, precision water management will become increasingly important.

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Effect of Different Organic Residues on Carbon Sequestration and Nutrient Availability in Soil

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Introduction:

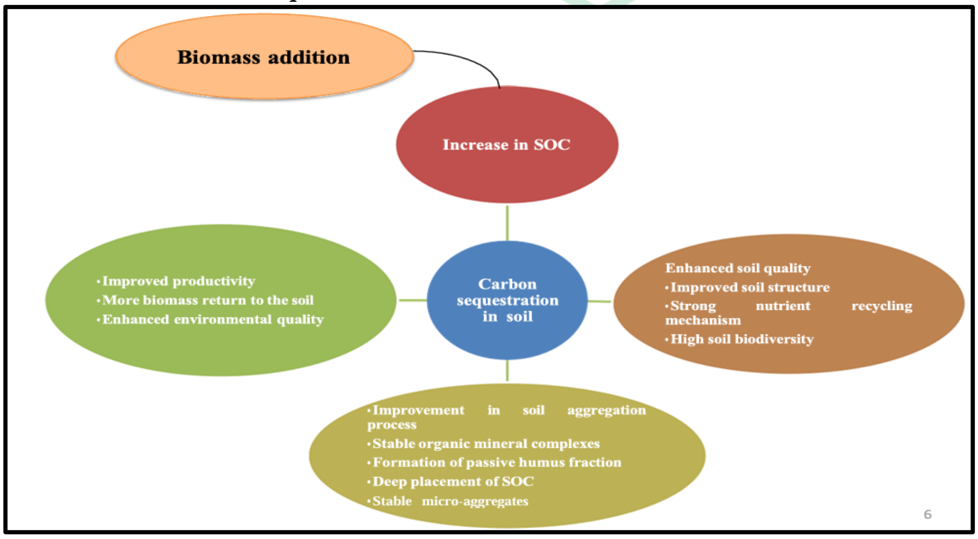
Carbon is an essential element found in various forms on Earth. It is the building block of life and play a critical role in the carbon cycle. The carbon cycle is a natural process that involves the continuous exchange of carbon dioxide (CO_2) between the atmosphere, plants, animals, and soil. Through photosynthesis, plants absorb CO_2, converting it into organic carbon compounds. When plants and animals respire or decompose, carbon is released back into the atmosphere as CO_2.

CO_2 is one of the main greenhouse gases that is causing global warming and forcing climate change. The continued increase in CO_2 concentration in the atmosphere is believed to be accelerated by human activities such as burning of fossil fuels and deforestation. One of the approaches to reduce CO_2 concentration in the atmosphere is carbon sequestration. Carbon Sequestration is the placement of CO_2 into a depository in such way that it remains safely and not released back to the atmosphere. Sequestration means something that is locked away for safe keeping. The trapping of a chemical in the atmosphere or environment and its isolation in a natural or artificial storage area. Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change.

Mechanism of carbon sequestration:

Organic matter decomposition plays a major role in the cycling of carbon (C) and nutrients in terrestrial ecosystems across the globe. Climate change accelerates the decomposition rate to potentially increase the release of greenhouse gases and further enhance global warming in the future. However, fractions of organic matter vary in turnover times and parts are stabilized in soils for longer time periods (C sequestration). Overall, a better understanding of the mechanisms underlying C sequestration is needed for the development of effective mitigation policies to reduce land-based production of greenhouse gases. Known mechanisms of C sequestration include the recalcitrance of C input, interactions with soil minerals, aggregate formation, as well as its regulation via abiotic factors.

Mechanism of Carbon sequestration in soil:



Classification of carbon sequestration:

a. Geological carbon sequestration

Geological sequestration refers to the storage of CO_2 underground in depleted oil and gas reservoirs, saline formations, or deep, un-minable coal beds. Once CO_2 is captured from a point source, such as a cement factory, it would be compressed to ≈100 bar so that it would be a supercritical fluid. In this form, the CO_2 would be easy to transport via pipeline to the place of storage. The CO_2 would then be injected deep underground, typically around 1 km, where it would be stable for hundreds to millions of years. At these storage conditions, the density of supercritical CO_2 is 600 to 800 kg / m3.

b. Oceanic geological sequestration

If CO_2 were to be injected to the ocean bottom, the pressures would be great enough for CO_2 to be in its liquid phase. The idea behind ocean injection would be to have stable, stationary pools of CO_2 at the ocean floor. The ocean could potentially hold over a thousand billion tons of CO_2. However, this avenue of sequestration isn't being as actively pursued because of concerns about the impact on ocean life, and concerns about its stability. A biological solution can be growing seaweed that can naturally be exported to the deep ocean, sequestering significant amounts of biomass in marine sediments. River mouths bring large quantities of nutrients and dead material from upriver into the ocean as part of the process that eventually produces fossil fuels. Transporting material such as crop waste out to sea and allowing it to sink exploits this idea to increase carbon storage. International regulations on marine dumping may restrict or prevent use of this technique.

c. Terrestrial carbon sequestration.

Terrestrial sequestration is a process that captures and stores carbon dioxide (CO_2) in vegetation and soil within a few feet of the Earth's surface, providing them with the components they need to live and grow and reducing CO_2 in the atmosphere. During photosynthesis, carbon from atmospheric carbon dioxide is transformed into components necessary for plants to live and grow. As part of this process, the carbon present in the atmosphere as carbon dioxide becomes part of the plant in a leaf, stem, or roots, and the carbon is sequestered for a long period of time. Once the plant dies, or as limbs, leaves, seeds, or blossoms drop from the plant, the plant material decomposes and the carbon is released. Trees are valuable as greater amounts of carbon are tied up for longer time periods.

Strategies to improve carbon sequestration

a. Reclamation of degraded soils: Degraded soils usually have poor soil structure, so when we reclaim the soil then soil structure improves soil structure, leads to the formation of macro and micro aggregates, which in turn help in carbon sequestration.

b. New cultivars and new species: Herbicide resistant crops can reduce the use of herbicide and weeding, it promotes no-till, which in turn reduces CO2 emissions. GM crops can increase C sequestration by increasing the productivity and the amount of residue carbon that can be sequestered.

c. Crop residues and biomass management: Crop residues are materials left in an agricultural field after the crop has been harvested. Crop residues can be incorporated back into the soil, so it will increase carbon content and return back nutrients to the soil.

d. Conservation tillage: Tillage loosens the soil increasing the exposure of soil organic matter and hence speeding oxidization. This results in a reduced soil organic matter content and consequent release of CO2 into the atmosphere. On the other hand, conservation tillage can reduce carbon dioxide emission from the soil and effectively retain carbon in the soil.

Effects:

1) High amount of biomass returned to the soil
2) Deep and massive root system development
3) High soil biodiversity and biomass C in soil

Organic residues Organic residues:

It refers to the large pool of organic based compounds found within the natural and engineered, terrestrial and aquatic environments. It is matter composed of organic compound that have come from the remains of organisms such as plants and animals and their waste products in the environment. Organic waste that has been transformed into a new product after being subject to aerobic or anaerobic biological treatment, is also referred as Organic residues, E.g., biogas residues, compost and sewage sludge.

Classification of Organic residues:

a. Crop residues / waste: Crop residues are materials left on cultivated land after the crop has been harvested. Retention of crop residues after harvesting is considered to be an effective anti-erosion measure. Crop residues can improve soil structure, increase organic matter content in the soil, reduce evaporation, and help fix CO2 in the soil. Good residue management practices on agricultural lands have many positive impacts on soil quality.

b. Animal wastes / by products: Animal wastes predominantly include manures from cows, pigs, and chickens.

c. Forest residues / by products: Forest residues are a byproduct from forest harvesting, which is a major source of biomass for energy. This includes thinning, cutting stands for timber or pulp, clearing lands for construction or other use that also yields tops and branches usable for bioenergy.

d. Fish wastes and aquatic biomass: Fish waste may include, but is not limited to, particles of flesh, skin, bones, entrails, shells or liquid stick water. Just like manure, this waste is full of biological activity and well-balanced, essential plant nutrients and many other micronutrients. **e. Human habitation wastes:** city garbage, sewage and sludge.

Use of organic residue in Agriculture:

- Increases the humus content: humus acts as buffering agent in soil pH.
- Enhances the water holding capacity: hence reduces leaching of nutrients.
- Improves soil structure:Organic matter causes soil to clump and form soil aggregates, which improves soil structure.
- Improves microbial activity:Microbial biomass is the living component of soil organic matter, and microorganisms are the catalysts for most nutrient-releasing processes.
- Improves nutrient availability: as organic matter decomposes, it releases plant available nutrients.

Organic residues on Nutrient availability:

a. Nutrient supply from organic matter
b. Improves pH and CEC
c. Improves solubility of nutrient elements
d. Enhances nutrient transformations in soil by improving microbial activity
e. Improves saline-sodic soils

Conclusion:

The soil fertility, foliar nutrient concentrations and soil carbon sequestration were significantly influenced by the application of organic and inorganic fertilizer amendments in mango orchard soil of low fertility status. Soil nutrient status was highest in the treatments where vermicompost and microbial inoculants were used as a component. Lowest fertility status was observed where only FYM and inorganic fertilizer were applied without consideration of other organics sources. In general, the soil and leaf nutrients were improved over the years. Vermicompost emerged as more important organic input than FYM in soil nutrient management strategy as a function of crop residues management. Thus, to sustain the long-term fertility of orchard soil and soil and leaf nutrient dynamics, application of vermicompost along with N2 fixers and P solubilizing microorganisms and organic mulching should be integrated with NPK fertilizers.

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INTEGRATED FARMING SYSTEMS: A PATHWAY TO ECONOMIC VIABILITY AND ENVIRONMENTAL SUSTAINABILITY

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Integrated Farming Systems (IFS) represent a holistic approach to agricultural production that combines various agricultural enterprises such as crop cultivation, livestock rearing, aquaculture and agroforestry within a unified framework. This system aims to optimize resource utilization, enhance productivity and promote sustainability. The economic viability of IFS is primarily determined by its ability to generate consistent income streams, reduce input costs and improve resource efficiency. By diversifying income sources, farmers can mitigate risks associated with market fluctuations and climatic uncertainties, thereby ensuring financial stability. Additionally, IFS can lead to cost savings through resource recycling, such as using crop residues for livestock feed or manure for crop fertilization, which further enhances profitability. Environmental sustainability is a core component of IFS, emphasizing the conservation of natural resources, reduction of environmental pollution, and enhancement of biodiversity. The integrated approach minimizes the reliance on chemical inputs by promoting organic practices and natural pest control methods. It also encourages soil health improvement through crop rotation, cover cropping, and organic manure application, which increases soil fertility and reduces erosion.

Keywords: Integrated Farming System, Economic benefits, Environmental sustainability

INTRODUCTION

In India, Agriculture and allied sector provides livelihood support to about two third of the population and still continues to be the main stay employing and feeding most of the rural mass. IFS seeks to increase productivity & profits and minimize risks through the proper utilization of organic waste and crop residues. FAO stated that "There is no waste," and "Waste is only a misplaced resource which can become a valuable material for another product" in an integrated farming system.

An integrated farming system consists of a range of resource-saving practices that aim to achieve acceptable profits and sustained production levels, while minimizing the negative effects of intensive farming and preserving the environment. Based on the principle of enhancing natural biological processes above and below the ground, the integrated system represents a winning combination that reduces erosion, increases crop yields, soil biological activity and nutrient recycling, intensifies land use, improving profit therefore help reduce poverty and malnutrition and strengthen environmental sustainability.

INTEGRATED FARMING SYSTEM

Integrated Farming System (IFS) is an innovative agricultural approach that aims to optimize the use of resources by combining various agricultural activities into a single, sustainable system. This method promotes diversification, resource efficiency, and environmental sustainability, ultimately enhancing the productivity and profitability of farming operations.

The concept of IFS originated as a response to the challenges faced by traditional farming practices, such as resource depletion, environmental degradation, and economic instability among farmers. It integrates different agricultural enterprises - such as crop cultivation, livestock rearing, aquaculture, agroforestry and horticulture - into a cohesive system that benefits from synergistic interactions. The main objectives of IFS include

- Maximize resource utilization by recycling farm waste and by-products
- Reduce dependency on external inputs like chemical fertilizers and pesticides
- Enhance farm productivity and income diversification
- Improve soil health and conserve natural resources
- Promote sustainable agricultural practices that are environmentally friendly

Integrated Farming is a whole farm policy and whole systems approach to farm management. The farmer seeks to provide efficient and profitable production, which is economically viable and environmentally responsible and delivers safe, wholesome, and high-quality food to consumers through the efficient management of livestock, forage, fresh produce, and arable crops. He also provides conservation and enhancement of the environment to society. At the core of IF is the need for profitability. To be sustainable, the system must be profitable. Profits generate support for all the activities outlined in the IF Framework.

Financial support for environmental and biodiversity activities varies throughout the European Community but in all cases requires the farmer to commit labour and planning to such activities.

ECONOMIC BENEFITS

1) Multiple sources of income:

IFS offer farmers multiple sources of income by combining various agricultural activities like crops, livestock, aquaculture and agroforestry. This diversification helps reduce risks associated with relying on a single income stream and can increase overall farm profitability.

This may vary according to the farming system model, for example, if the farmer has the wetland IFS, the income may be from the crop, egg, meat, fish, etc. For garden land IFS, the income can be obtained from crop, honey & its byproducts, milk & its byproducts, etc. For dryland, the income is generated from crop, goat (meat), timber, etc.

The main point is that, if a component fails to attain the yield, the other one will let the farmer carry on his work without facing any losses.

2) Efficient use of resources:

IFS promotes interdependency between components. Crop residues can be used as fodder for cattle. Animal waste is used to produce compost or biogas, reducing dependence on chemical fertilizers and LPG. Pond water enriched with fish excreta can be used for irrigation, thus reducing fertilizer costs.

Simply, the waste of one component is efficiently as the input of another component. Thus, the resources are utilized efficiently.

3) Risk reduction and Income security:

Farming is a risky business due to weather and market fluctuations. IFS acts as a natural insurance. If one enterprise fails to give the output, (e.g., crop failure), other enterprises may (e.g., dairy or poultry) compensate for the loss. This risk diversification protects farmers from total income loss. According to ICAR, IFS farms show 30 - 40% more income stability than mono- crop farms.

4) Better Employment Opportunities:

IFS creates continuous employment within the farm because of the daily tasks. It includes feeding animals, irrigating crop, collecting eggs, preparing compost, milking of livestock etc. It reduces migration by engaging family labour throughout the year. It helps generate rural employment for women and youth. The impact of this provides more working days, and it generates more wages thus improving the standard of living of the farmer.

5) Scope for Value Addition and Marketing:

There is a wide scope for value addition from the components of IFS.

- Millets - Millet biscuits
- Vegetables - Pickle
- Milk - Curd, Ghee, Buttermilk
- Manures - Packaged organic compost

ENVIRONMENTAL BENEFITS

1) Improved Soil Health:

Crop residues, animal dung, and compost are returned to the soil, increasing organic matter content.Organic inputs help form soil aggregates that improve aeration and water retention thus enhanced soil structure. Legume crops and green manures fix nitrogen, reducing the need for synthetic fertilizers. Compost and organic matter foster beneficial soil microbes, which help break down organic material and make nutrients available to plants. This will result in long-term fertility, better root development and increased yields without soil degradation.

2) Efficient Water Use and Conservation:

IFS ensures smart and efficient water management through multi-use water systems. For example, wastewater from fish ponds can be used for irrigating crops. By adopting agroforestry and mulching, water evaporation & runoff can be reduced and moisture retention is improved. This will enable the farmers to year-round cultivation even in drought-prone areas.

3) Reduced Chemical inputs:

In IFS, reliance on synthetic inputs is significantly reduced. Natural fertilizers like Compost, Vermicompost, Green manure & Green leaf manure etc., replace chemical ones. Integrated Pest Management (IPM) combines biological control, mechanical traps, and resistant varieties. Manure and urine from animals act as natural inputs for crop nutrition and pest deterrence. Fish - duck systems can reduce algae growth without using chemical treatments. Thus, a cleaner environment, reduced pollution, and safer food production is guaranteed.

4) Waste Utilization and Pollution Reduction

IFS transforms farm waste into resources. Livestock dung is used for biogas production or composting. Crop residues serve as mulch, fodder, or feedstock for mushroom cultivation. Pond sludge from fish farming is nutrient-rich and used to fertilize crops. In many IFS models, nearly all waste is reused within the system thus promoting cleaner surroundings, improved sanitation, and reduced environmental pollution.

5) Lower Greenhouse Gas Emissions:

IFS helps mitigate climate change by reduced synthetic fertilizer usage that leads to lower nitrous oxide emissions, a potent greenhouse gas. Carbon sequestration by agroforestry trees and deep-rooted crops captures CO_2 from the atmosphere. Biogas production from animal waste replaces fossil fuels for cooking or lighting. Shorter supply chains from on-farm integration reduce transportation-related emissions.

CONCLUSION

Integrated Farming System (IFS) offers a comprehensive approach to agriculture that combines various agricultural activities such as crop cultivation, livestock rearing, fishery, agroforestry, and allied activities within a unified framework.

This system aims to optimize resource utilization, enhance productivity, and promote sustainability, thereby delivering significant economic and environmental benefits.

In conclusion, the integrated farming system presents a sustainable approach that benefits both the economy and the environment. It enhances farmer's livelihoods by increasing productivity and income while promoting ecological balance and resource conservation.

Adoption of IFS can lead to resilient agricultural practices capable of addressing the challenges posed by climate change, resource depletion, and market uncertainties, ultimately contributing to sustainable rural development and environmental preservation.

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What's in Your Fabric? Understanding Textile Labels

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Introduction:

More Than Just a Tag

Ever pulled a brand-new shirt from your closet only to find it shrunken and shapeless after a wash even when you thought you followed all the rules? That little label inside your clothing holds more power than we often realize. From fibre content and washing instructions to brand identity and sustainability claims, garment labels are silent storytellers stitched into every outfit. Let's take a closer look at why these tags matter, who regulates them, and how they impact both consumers and brands.

Labels are more than just small pieces of fabric or stickers they're essential tools for communication. Whether it's stitched onto your shirt or printed on a product box, a label shares important details about the item it represents. In the world of fashion, garment labels play a vital role. They help customers understand what they're buying offering information about size, fabric content, care instructions, and even brand identity.

There are various types of labels used in clothing, each serving a different purpose. Some are descriptive, others are instructional, and many are designed to reflect a brand's image. Major fashion brands typically use pre-designed, machine-attached labels as part of their large-scale production process. However, small businesses, boutique designers, and online sellers often get creative designing and printing their own labels using simple tools like Microsoft Word.

Labels aren't limited to clothing, either. From barcodes and mailing tags to nutrition facts on food packages, labels are everywhere, helping consumers make informed choices. So, the next time you spot a tag inside your T-shirt or scan a barcode at checkout, remember it's not just a label, it's a silent guide telling the story of the product.

Types of Labels You'll Find in Your Clothes

1. **Brand/Identification Label** – This usually features the company name or logo, helping customers connect with the brand.
2. **Size Label** – Indicates the fit (S, M, L, XL, or numeric sizing).
3. **Fibre Content Label** – Lists the materials used (e.g., 100% cotton, 60% polyester, 40% rayon).
4. **Care Label** – Offers laundering instructions using both text and symbols.
5. **Country of Origin** – Shows where the garment was manufactured (e.g., Made in India).
6. **Price Label or MRP** – Includes the maximum retail price and tax details.
7. **Eco-Label or Certification Tag** – Indicates organic or sustainable practices (e.g., GOTS-certified, Fair Trade).

Who Makes the Rules? Global Regulatory Bodies

Each country has its own authority for ensuring clothing labels are honest and informative. Here's a quick overview:

India – The Bureau of Indian Standards (BIS) and Legal Metrology Rules, 2011 require key details like fibre content, size, MRP, and manufacturer/importer information.

USA – The Federal Trade Commission (FTC) oversees care labelling, while U.S. Customs and Border Protection (CBP) checks imports for compliance.

UK – The Department for Business, Energy & Industrial Strategy enforces labelling, sometimes through local agencies.

European Union – The European Commission sets textile labelling standards, but individual countries may have extra rules.

Australia – The Product Safety Australia (PSA) under the ACCC regulates clothing labels.

New Zealand – The Commerce Commission ensures garment labels meet national trade laws.

Consumer Guide: How to Read a Clothing Label

Understanding what's written (or symbolized) on a label can save time, money, and disappointment. Here's what to look for:

Fibre content – Important for comfort, allergies, and durability.

Care symbols – Washing and drying instructions can extend a garment's life.

Certifications – Tags like GOTS or OEKO-TEX assure you of ethical or non-toxic production.

Country of origin – May help you identify quality or support local businesses.

Why It Matters for Brands and Businesses

For entrepreneurs, startups, and growing fashion labels, proper labelling is not just a legal requirement it's a trust-building tool. A well-labelled product:

Enhances brand credibility

Meets international trade standards

Prevents legal penalties and recalls

Improves customer satisfaction and reduces product returns

Especially in export-driven businesses, understanding regional labelling laws can open doors to global markets.

Eco-Labels: The New Frontier of Conscious Fashion

With consumers becoming more eco-conscious, labels have evolved. Today, you may spot:

QR Codes linking to a product's supply chain

"Organic Cotton" or "Made with Recycled Polyester" claims

Fair Trade, GOTS, or PETA-approved vegan labels

These aren't just marketing buzzwords they signal responsibility toward the planet and the people involved in production.

Top Labelling Mistakes to Avoid

For brands, a label slip-up can cost more than a refund. Common errors include:

Inaccurate fibre percentages

Missing or unclear care symbols

Incorrect country of origin

Using only non-local language

Ignoring labelling laws of export countries

A small mistake can lead to heavy fines, reputation damage, or import rejections.

Did You Know? Fun Label Facts

The first care labels were introduced in the 1970s.

Some countries legally mandate bilingual labelling.

Labels made of recycled polyester are trending among eco-friendly brands.

A single misprint on a label has led to product recalls in Japan.

Conclusion: Tiny Tags with Big Responsibility

A clothing label may be small, but its role is anything but minor. It bridges the gap between the producer and the consumer, offering clarity, transparency, and guidance. Whether you're a shopper checking for cotton content or a designer preparing a global launch, labels are your silent allies in the fashion world.

Call to Action

Next time you shop, take a moment to read the label. You might be surprised by how much it tells you not just about the garment, but about the values of the brand behind it. And if you're a business owner, remember: the label is your product's first handshake with the customer. Make it count.

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Mushrooms: A Rising Hope for Himalayan Livelihood and Ecosystems

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Mushrooms: more than a culinary delight

Often called "white vegetables," mushrooms are not plants but fungi; organisms with unique abilities to recycle waste, form forest symbioses, and offer high nutritional value. They contain essential proteins, fiber, vitamins, and medicinal compounds, all while requiring minimal land and water. For the Himalayan region, where farming is constrained by terrain and weather, mushrooms present a scalable, sustainable alternative.

The Himalayan states currently contribute about 19% of India's total mushroom output (nearly 60,000 tonnes). Yet, there is still scope for increasing the production in the region. With adequate infrastructure and policy support, the region could become a national mushroom hub, boosting livelihoods and protecting the fragile ecology.

Nature's bounty: a rich mushroom habitat

From the high-altitude alpine pastures of Uttarakhand to the subtropical forests of the Northeast, the Himalayas harbor incredible fungal biodiversity. Species like Cordyceps militaris, Pleurotus ostreatus (oyster), Lentinula edodes (shiitake), and Morchella esculenta (morel) thrive here. Several of these wild mushrooms are not only edible but also highly valued in global nutraceutical markets.

This diversity is enabled by the region's vast agro-climatic range and forest residues. Crop residues from rice, maize, and horticulture serve as ideal substrates for mushroom cultivation. Moreover, specific mushrooms like shiitake prefer sawdust from native broadleaf trees, a plentiful resource in Himalayan forests.

From Lab to Land: scientific innovations

The ICAR-Directorate of Mushroom Research (DMR), Solan has led pioneering work in mushroom science. Over the past decade, it has released multiple high-yielding varieties of button, oyster, shiitake, and milky mushrooms. Technologies like ready-to-fruit (RTF) bags, zero-energy poly-tunnels (ZEPT) for composting, and chemical sterilization techniques have made small-scale cultivation more affordable and efficient. Additionally, DMR has developed high yielding and disease resistant varieties, and more than 25 value-added mushroom products—from mushroom noodles and snack bars to medicinal extracts and fortified biscuits. These innovations open new revenue streams while reducing post-harvest losses.

Challenges

- Despite its potential, the Himalayan mushroom sector is thwarted by systemic barriers: infrastructure gaps: limited spawn labs, cold chains, processing units, and market linkages.
- Technical know-how: Farmers often lack training in disease management, post-harvest practices, or climate control.
- Ecological vulnerability: Climate change, deforestation, and biodiversity loss threaten both wild and cultivated species.
- High input costs: Cultivation units, substrates, and energy for controlled environments can be costly for marginal growers.
- Moreover, community landholding patterns and migration-induced 'ghost villages' have made farming unviable in many areas. A coordinated response is needed.

Strategies for a Mushroom-Led Revival

To unlock the potential of mushrooms in the Himalayas, we propose a multi-pronged approach:

1. Spawn security: Establish certified spawn labs at the district level, train youth in hygienic spawn production, and introduce spawn certification systems.

2. Research & conservation: Prioritize indigenous mushroom species for germplasm conservation, strain improvement, and bioactive compound research.
3. Integrated farming: Promote mushrooms as a pillar of Integrated Farming Systems (IFS), utilizing crop residues and recycling nutrients.
4. Post-Harvest value Chain: Invest in hybrid solar dryers, cold chains, and biodegradable packaging. Promote ready-to-cook products and mushroom-based vegan meat.
5. Capacity building: Design localized training programs in native languages. Encourage entrepreneurship among rural youth and women.
6. Policy support: Provide financial incentives, input subsidies, and linkages to institutional buyers and export markets.
7. Eco-Education and Health Promotion: Launch campaigns on the nutritional and medicinal value of mushrooms to boost domestic consumption.

Looking Ahead: Mushrooms for Mountain Prosperity

Mushroom cultivation requires low space, less water, and gives high returns; an ideal fit for mountainous terrains. In a region grappling with environmental stress and economic stagnation, mushrooms offer hope. They are not just crops, but agents of change- bridging ecology, nutrition, income, and innovation. As India looks to revitalize its Himalayan economies, it's time we give this “third food kingdom” the attention it deserves. Mushrooms, with the right push, could bloom into the next green revolution of the hills.

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Integrated Fish cum Poultry Culture: A Profitable and Sustainable Farming Approach

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Introduction

Integrated farming systems (IFS) have emerged as a sustainable alternative to conventional monoculture practices, especially for resource-constrained farmers in developing countries. Among the various IFS models, Integrated Fish cum Poultry Culture has gained prominence due to its ability to enhance productivity, resource-use efficiency and farm profitability with minimal external inputs. This synergistic system involves rearing poultry (typically broilers or layers) in sheds constructed over or adjacent to fish ponds, allowing poultry droppings to serve as nutrient-rich manure that promotes the growth of natural fish food like plankton, thereby reducing feed costs and improving water productivity (Jena & Das, 2011; Das & Patnaik, 2017). In addition to recycling nutrients within the farm, the model enables farmers to generate dual income from fish and poultry, diversify risks and reduce dependency on chemical inputs, making it both ecologically and economically viable (Pillai *et al*., 2018; Ayyappan *et al*., 2006). As the demand for integrated and climate-resilient farming practices grows, this model offers a promising pathway for smallholder farmers to achieve sustainable livelihood and food security.

What is Integrated Fish Cum Poultry Culture?

Integrated Fish cum Poultry Culture is a synergistic farming approach that combines fish culture with poultry rearing in a single unit to optimize resource utilization and enhance farm productivity. In this system, poultry sheds are constructed above or adjacent to fish ponds, allowing poultry droppings to fall directly into the water or to be collected and applied as organic manure. These droppings serve as a rich source of nutrients, stimulating the growth of phytoplankton and zooplankton natural food for fish thereby reducing the need for artificial fish feed and lowering input costs (Jena & Das, 2011; Das & Patnaik, 2017). This integration not only improves nutrient cycling and water fertilization but also enables farmers to obtain dual outputs meat or eggs from poultry and fish from ponds on the same land area. The system is particularly beneficial for small and marginal farmers as it supports low-input, high-output farming while promoting environmental sustainability (Pillai et al., 2018; Ayyappan *et al*., 2006).

Why Integrate Poultry with Fish Culture?

Integrating poultry with fish culture offers multiple agronomic, ecological and economic advantages, making it an ideal practice for smallholder and marginal farmers. One of the primary benefits is efficient nutrient recycling poultry droppings are rich in nitrogen and phosphorus, which stimulate the growth of natural fish food such as phytoplankton and zooplankton, reducing the dependence on commercial fish feed by 20-30% (Das & Patnaik, 2017). This not only cuts down input costs but also enhances fish growth and productivity. The integrated system enables optimal land utilization, as the same area supports both poultry and aquaculture, thereby increasing total farm output per unit area (Jena & Das, 2011). It also promotes dual income generation, providing farmers with regular returns from poultry (meat or eggs) and periodic income from fish harvests (Pillai *et al*., 2018). Moreover, the use of poultry manure as organic input supports eco-friendly production by minimizing the use of chemical fertilizers and feeds, contributing to sustainable and low-input agriculture (Ayyappan *et al*., 2006). This integration reduces waste, improves farm nutrient cycling and supports livelihood resilience against climate and market uncertainties.

Suitable Fish and Poultry Species

The selection of appropriate fish and poultry species is crucial for the success of Integrated Fish cum Poultry Culture. Among fish, Indian Major Carps such as *Catla* (*Catla catla*), *Rohu* (*Labeo rohita*) and *Mrigal* (*Cirrhinus* *mrigala*) are most commonly used due to their compatibility in composite culture systems and their efficient utilization of natural food resources in the water column. These species exhibit fast growth, high market demand, and tolerance to a wide range of pond conditions. In addition, exotic carps like Silver Carp (*Hypophthalmichthys molitrix*), Grass Carp (*Ctenopharyngodon idella*) and Common Carp (*Cyprinus carpio*) are often integrated to utilize different ecological niches in the pond, improving total biomass production (Jena & Das, 2011; Pillai *et al*., 2018).

For the poultry component, fast-growing broiler chickens are preferred for meat production due to their short rearing cycle and high feed conversion efficiency. Alternatively, layer birds may be used where egg production is also a goal. The choice depends on market preference, input availability and the farmer's objectives. The poultry droppings from both broilers and layers effectively fertilize the pond, promoting plankton growth and thus supporting natural fish food production (Das & Patnaik, 2017; Ayyappan *et al*., 2006).

Pond and Shed Design

An effective pond and shed design is critical for maximizing the efficiency of Integrated Fish cum Poultry Culture. The ideal pond size ranges from 0.1 to 1.0 hectare, with a water depth of 1.5 to 2.0 meters to ensure optimal growth conditions for fish. The pond should be well-sunned, have an inlet and outlet for water exchange and be free from seepage to maintain water levels (Jena & Das, 2011). Poultry sheds are typically constructed on bamboo, wooden, or steel poles raised about 1.5 to 2.0 meters above the pond surface. This elevated design allows poultry droppings to fall directly into the pond or be easily collected for controlled application as organic manure. The shed should be well-ventilated, protected from predators and extreme weather and constructed with a slatted or mesh floor to allow easy droppings fall-through (Pillai *et al*., 2018). The stocking density should be scientifically maintained: approximately 6,000-8,000 fingerlings per hectare for fish, in a suitable species combination; and about 500-1,000 poultry birds per hectare of pond area for optimal manure production and nutrient recycling (Das & Patnaik, 2017). Proper spatial planning of the shed and pond layout helps in disease management, operational convenience and enhanced resource-use efficiency.

Manure Management and Nutrient Recycling

Effective manure management and nutrient recycling are central to the success of Integrated Fish cum Poultry Culture. Poultry droppings serve as a rich organic fertilizer containing essential nutrients like nitrogen, phosphorus and potassium, which stimulate the growth of phytoplankton the primary natural food source for fish. On average, one poultry bird produces about 25-30 kg of manure annually and the recommended manure input is approximately 30-40 kg per hectare per day to maintain balanced pond fertility (Das & Patnaik, 2017). Direct dropping into the pond is common in over-the-pond shed systems; however, excessive accumulation can lead to eutrophication, oxygen depletion and fish stress. Therefore, careful monitoring of water quality parameters, particularly dissolved oxygen and ammonia levels, is essential. In systems where droppings are collected, partial composting before application helps regulate nutrient release and reduce pathogenic risks (Jena & Das, 2011). Nutrient recycling in this integrated model enhances pond productivity and reduces the dependence on costly inorganic fertilizers and supplementary fish feed. It also supports a low-external-input farming system by utilizing on-farm waste to close nutrient loops, contributing to both economic efficiency and ecological sustainability (Pillai et al., 2018; Ayyappan *et al*., 2006).

Feeding and Management

Efficient feeding and proper management practices are essential to optimize the productivity of both components in Integrated Fish cum Poultry Culture. Poultry birds, particularly broilers, should be provided with nutritionally balanced commercial feed containing 18-22% crude protein to ensure rapid weight gain and efficient manure output (Ayyappan *et a*l., 2006). The quality and quantity of poultry feed directly influence the nutrient composition of the droppings, which in turn affect the productivity of the fish pond ecosystem. In the aquaculture component, fish primarily rely on the natural food web sustained by the nutrients derived from poultry manure. However, supplementary feeding using rice bran, groundnut cake, or commercial fish feed may be necessary based on stocking density, fish growth rates, and seasonal plankton availability (Jena & Das, 2011). Routine pond management is crucial for maintaining optimum water quality. Dissolved oxygen levels should be kept above 5 mg/L, while ammonia and hydrogen sulphide concentrations must be monitored and controlled to prevent fish stress and mortality. Regular de-weeding, pond aeration (if needed) and periodic checking of fish health and poultry vaccination schedules should be incorporated into daily farm routines (Das & Patnaik, 2017). Proper synchronization of poultry manure application and fish stocking ensures ecological balance, reduces nutrient waste, and promotes overall system sustainability (Pillai *et al*., 2018).

Economic Benefits

Integrated Fish cum Poultry Culture significantly improves farm economics by increasing productivity and reducing input costs through resource recycling. One of the primary advantages is dual income generation farmers can earn from both fish production and poultry meat or egg sales, thereby enhancing overall profitability and income stability (Jena & Das, 2011). By utilizing poultry droppings as organic manure, the cost of fish feed and chemical fertilizers can be reduced by up to 30%, which contributes substantially to lowering the cost of production (Das & Patnaik, 2017). On average, integrated systems yield a net profit ranging from ₹2.0 to ₹2.5 lakh per hectare annually, depending on the species combination, stocking density and local market prices (Pillai et al., 2018). Furthermore, the system reduces the need for external inputs, thereby improving the benefit-cost (B:C) ratio compared to monoculture systems. It also diversifies income streams, helping smallholder farmers mitigate market and climate risks, and promotes year-round employment opportunities in rural areas (Ayyappan *et al*., 2006). With proper technical support and access to markets, this model can play a transformative role in enhancing farm-level incomes and supporting rural livelihood security.

Advantages of Integrated Fish cum Poultry System

The Integrated Fish cum Poultry System offers multiple agronomic, economic, and environmental benefits, making it a sustainable and profitable model for smallholder farmers. One of the key advantages is resource efficiency the poultry droppings act as a nutrient-rich organic input, enhancing pond productivity by stimulating plankton growth, which serves as natural fish food (Das & Patnaik, 2017). This reduction in external inputs, particularly fish feed and fertilizers, significantly lowers production costs and improves the benefit-cost ratio. The system also allows dual income generation from both fish and poultry, helping farmers stabilize income and reduce dependence on a single commodity (Jena & Das, 2011).

Environmentally, it supports waste recycling and promotes eco-friendly production, reducing pollution and nutrient loss. Furthermore, the integration provides year-round employment, particularly in rural areas, enhancing livelihoods and food security. It also contributes to climate resilience by diversifying farm enterprises, thereby reducing vulnerability to market or weather-related shocks (Pillai *et al*., 2018; Ayyappan *et al*., 2006). Overall, this system is an ideal example of low-input, high-output farming that aligns with sustainable agricultural development goals.

Challenges and Precautions

While Integrated Fish cum Poultry Culture offers several benefits, it also presents certain challenges that require careful management. One of the primary concerns is over-fertilization from excessive poultry droppings, which can lead to water quality deterioration, eutrophication, and fish mortality due to oxygen depletion. Maintaining the correct manure application rate and monitoring water parameters such as dissolved oxygen, ammonia, and pH are essential to avoid stress in fish. Disease transmission is another potential risk, especially if proper hygiene and biosecurity measures are not followed. Poultry should be regularly vaccinated, and sheds must be kept clean and well-ventilated to prevent outbreaks that could affect both birds and fish. Structural safety is also crucial; poorly designed poultry sheds can collapse or allow droppings to fall unevenly, creating nutrient hotspots in the pond. Moreover, farmers may face challenges related to marketing both fish and poultry simultaneously, and lack of technical know-how can limit the efficiency of integration. Therefore, proper training, regular monitoring, and timely interventions are key to overcoming these challenges and ensuring the success of the system.

Conclusion

Integrated Fish cum Poultry Culture is a scientifically sound, economically viable and environmentally sustainable farming model that maximizes the use of on-farm resources. By combining fish and poultry enterprises, farmers can enhance nutrient recycling, reduce input costs, and generate dual income from the same land unit. The system promotes organic production, minimizes waste, and supports year-round employment, making it especially beneficial for small and marginal farmers. With proper pond and shed design, efficient manure management, and regular monitoring of water and animal health, the integrated approach can significantly boost farm productivity and profitability. As the demand for sustainable and climate-resilient agricultural practices continues to rise, this model offers a promising pathway for improving rural livelihoods and achieving long-term food and nutritional security.

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Jamun (*Syzygium cumini*): Nature's Purple Powerhouse for Health

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Jamun (*Syzygium cumini*), also known as Indian blackberry or java plum, is a fruit that not only tantalizes the taste buds but also offers numerous health benefits. With its vibrant purple color and unique flavor profile, jamun stands out as a jewel among summer fruits. In an age where lifestyle diseases like diabetes and gut disorders are increasingly prevalent, nature offers potent remedies in the form of medicinal fruits, one of the most remarkable being Jamun. Revered in traditional systems like Ayurveda and Unani medicine, Jamun is now gaining attention in contemporary nutritional science for its role in regulating blood glucose levels and enhancing gastrointestinal health.

The Origin and History of Jamun

The Java plum is believed to have originated in the Indian subcontinent, including India, Pakistan, Sri Lanka, and Myanmar. It also naturally occurs in other regions of Southeast Asia, such as Sri Lanka, Myanmar, and the Andaman Islands. The tree and its fruit have been known and used for centuries in traditional medicine systems like Ayurveda and Unani.

It's mentioned in Hindu scriptures, with Lord Rama supposedly subsisting on its fruits during his exile, leading to its association with the divine. The Java plum has been introduced to many tropical and subtropical regions worldwide, including parts of Africa, Australia, and the Americas. Throughout history, jamun has been revered for its ability to cool the body, aid digestion, and alleviate various ailments.

Nutritional Value of Jamun

Jamun is a powerhouse of nutrients, packed with vitamins, minerals, and antioxidants. It is low in calories and rich in dietary fiber, making it an excellent choice for those aiming to maintain a healthy weight. Jamun is a low-glycemic fruit, rich in bioactive phytochemicals such as anthocyanins, ellagic acid, gallic acid, and flavonoids, along with micronutrients like vitamin C, calcium, potassium, and iron. The fruit's deep purple hue is attributed to anthocyanins, which possess powerful antioxidant and anti-inflammatory properties.

The seeds, often discarded, are in fact the therapeutic core of Jamun, containing jamboline and jambosine—alkaloids that modulate carbohydrate metabolism and insulin activity.

The fruit is a good source of vitamin C, which boosts immunity and supports collagen production for healthy skin. It also contains essential minerals like iron and potassium, which play vital roles in maintaining overall health. Additionally, jamun is known for its high antioxidant content, particularly anthocyanins, which give the fruit its distinctive purple hue and help combat free radicals, reducing the risk of chronic diseases.

Health Benefits of Jamun

Jamun offers a wide array of health benefits due to its unique composition. Firstly, it has been used in traditional medicine to manage diabetes. The fruit's natural sugars are absorbed slowly, preventing sudden spikes in blood sugar levels. Research suggests that certain compounds in jamun may also enhance insulin sensitivity, making it beneficial for individuals with diabetes. The fruit is also known for its cooling properties, making it a popular choice during the scorching summer months. It helps in reducing body heat and refreshing the system.

Furthermore, jamun possesses anti-inflammatory properties, which can aid in reducing inflammation in the body. It has been studied for its potential in managing conditions like arthritis and skin disorders.

Jamun's high fiber content aids in digestion and promotes a healthy gut. It acts as a natural laxative, preventing constipation and promoting regular bowel movements.

The antioxidants found in jamun play a crucial role in promoting heart health by protecting against oxidative stress and reducing cholesterol levels. Regular consumption of jamun may help improve cardiovascular health and reduce the risk of heart disease.

That intense jamun hue comes from anthocyanins – potent antioxidants also found in blueberries. But jamun's anthocyanins are unique: Delphinidin-3-glucoside dominates known for blocking inflammatory pathways. Protect cells by neutralizing free radicals linked to aging and metabolic disease.

Compounds present in seeds (ellagitannins) and pulp (myricetin) inhibit α-amylase and α-glucosidase – enzymes that break down carbohydrates into sugar which slower digestion and causing gentler blood glucose spikes.

Jamun seeds contain:

Ellagitannins: Gut microbes convert these to urolithins – anti-inflammatory warriors linked to reduced cancer risk.

- Jambosine: A rare alkaloid (needs human trials) that may block sugar-to-starch conversion.
- Browning: When cut, enzymes oxidize phenolics (like in apples). Add lemon juice to slow this.
- Color Fading: Canned/jam products lose 60-80% anthocyanins. Opt for freeze-dried powders or fresh.

Modes of Consumption and Standardization

Jamun can be incorporated into the diet in various forms:

- Fresh fruit (seasonal)
- Jamun juice (with controlled sugar content)
- Seed powder (standardized extracts, 250–500 mg capsules)
- Jamun vinegar (used as a digestive tonic)

It is crucial that supplements be standardized for active constituents, especially jamboline, to ensure therapeutic efficacy and safety.

Culinary Uses and Delicious Recipes

In addition to its health benefits, jamun is a versatile fruit that can be used in various culinary creations. It is often enjoyed fresh, either on its own or added to fruit salads and desserts. The fruit's tangy and slightly sweet flavor adds a delightful twist to a range of dishes.

Jamun can be incorporated into beverages like refreshing summer coolers, smoothies, and even cocktails. Its deep purple juice adds a vibrant touch and unique flavor to these drinks.

The fruit can also be used to make jams, jellies, and preserves. Its natural pectin content makes it ideal for setting jams without the need for additional additives.

Precautions and Considerations

While generally safe, Jamun should be used with caution in individuals on antidiabetic or antihypertensive medications, as it may potentiate their effects. Overconsumption may also cause gastric irritation due to its tannin content. Pregnant and lactating women are advised to consult a healthcare professional before supplementing with Jamun extracts.

Conclusion:

In conclusion, jamun truly deserves its title as the purple jewel of summer fruits. From its rich history and cultural significance to its impressive nutritional profile and health benefits, jamun stands out as a fruit that offers both taste and wellness. Whether you enjoy it fresh, incorporate it into recipes, or reap its benefits through traditional medicine, jamun has something to offer everyone.

Its role in managing diabetes, promoting heart health, aiding digestion, and providing antioxidant protection highlights its versatility as a superfruit. Moreover, its vibrant color and unique flavor make it a delightful addition to various culinary creations.

As we embrace the wonders of jamun, let us appreciate its natural goodness and incorporate it into our lives for a healthier and more flavorful experience. So, the next time you come across this beautiful purple fruit, savor its taste, celebrate its benefits, and relish in the abundance of nature's bounty that jamun offers.

Jamun represents a unique convergence of traditional wisdom and scientific validation. Its multifaceted role in modulating blood glucose, supporting gut health, and offering systemic antioxidant protection makes it a valuable functional food and nutraceutical candidate.

As research continues to unlock its full potential, Jamun stands as a promising natural intervention in the dietary management of diabetes, metabolic syndrome, and gastrointestinal disorders.

Smart Preservation Practices for Extending Mushroom Shelf Life

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Introduction

Mushroom cultivation has become an increasingly popular enterprise among farmers due to its short production cycle, high market value, and relatively low land requirement. However, mushrooms are highly perishable and prone to rapid spoilage, especially during times of high production and limited market access. In such cases, preservation techniques offer a valuable solution to minimize post-harvest losses, stabilize income, and ensure product availability throughout the year. Various preservation methods ranging from basic cold storage to long-term canning and drying can be adopted depending on the available infrastructure, scale of operation, and market requirements (Table 1). Each technique varies in complexity, cost, and the extent to which it prolongs the shelf life of mushrooms.

Cold storage

Cold storage is the most straight forward and widely used method for preserving mushrooms for short durations. When stored at temperatures between 0 to 2 degrees Celsius with a relative humidity of 85 to 95 per cent, mushrooms retain their freshness for 5 to 7 days. These conditions help slow down the metabolic processes and inhibit the growth of spoilage-causing microorganisms. However, the effectiveness of cold storage depends heavily on careful handling to avoid bruising, which can accelerate deterioration. Mushrooms should be packed in breathable materials such as perforated plastic bags or ventilated crates to maintain the appropriate humidity and airflow. Regular monitoring is necessary to remove any spoiled mushrooms that could otherwise affect nearby healthy ones. Cold storage is most suitable for producers and vendors who require only a brief holding period before transportation or sale in the nearby markets.

Freezing

Freezing is a reliable preservation technique that allows mushrooms to be stored for extended periods while maintaining their nutritional and sensory qualities. The process begins with selection, cleaning, and blanching of the mushrooms. Blanching is necessary to inactivate enzymes that may otherwise affect color and texture during freezing. The mushrooms are then rapidly frozen using equipment such as blast freezers or fluidized bed freezers. Commercial freezing is typically conducted at temperatures ranging from -18 to -35 degrees Celsius to ensure the formation of small ice crystals that do not damage cell structures. Individually Quick Frozen (IQF) mushrooms are preferred in the industry as they do not clump together and can be easily portioned. After freezing, the mushrooms are transferred to cold storage at temperatures between -18 and -20 degrees Celsius, where they can be preserved for up to 6-12 months. This method is ideal for large-scale operations supplying to hotels, processing units, and export markets.

Brining and steeping

Brining or steeping is a cost-effective and relatively simple method that can be used for short-term preservation of mushrooms. It is particularly useful during peak harvest periods when immediate marketing is not feasible. In heavy brining, mushrooms are immersed in a concentrated salt solution containing more than 15 per cent sodium chloride (NaCl). The concentration is maintained at 20 per cent, and the pH of the solution is adjusted to 3.5 using acid to inhibit microbial growth. This allows the mushrooms to be stored for 2- 6 weeks. Another method involves steeping mushrooms in a chemical mixture containing 2 per cent each of NaCl, citric acid, and sodium bicarbonate ($NaHCO_3$), along with 0.15 per cent potassium meta-bisulphite (KMS). This mixture is used to preserve blanched mushrooms for 8-10 days at ambient temperatures ranging from 21-28 degrees Celsius. Though the shelf life achieved through this method is shorter than freezing or canning, steeping serves as a quick and practical alternative for temporary storage and transportation in resource-limited settings.

Canning

Canning is one of the most reliable and long-term methods of preserving mushroom, offering a shelf life of up to 1-3 years. The process begins with thorough washing, usually in multiple cycles using cold water supplemented with 0.1 per cent citric acid to prevent discoloration. This is followed by blanching in a solution containing 0.1 per cent citric acid and 1 per cent salt at a temperature of 95- 100 degrees Celsius for 5-6 minutes. The blanched mushrooms are then filled into sterilized cans along with a hot brine solution composed of 2 per cent salt and either 0.1 per cent citric acid or 100 ppm ascorbic acid. Commonly used cans include A 2½ and A-1 sizes, which contain approximately 440 grams and 220 grams of drained mushrooms, respectively. The filled cans are subjected to exhausting for 10-15 minutes to remove air and achieve an internal temperature of 85 degrees Celsius. Sealing is done using a double seamer, followed by sterilization at 118º Celsius under 10-15 pounds of pressure. After sterilization, the cans are immediately cooled in water tanks to prevent over-cooking. Finally, the cans are labelled, packed in cardboard or wooden boxes, and stored in cool and dry conditions. This method ensures long-term storage and is well-suited for commercial processing and export.

Drying

Drying is an age-old technique that remains relevant due to its simplicity and effectiveness in extending the shelf life of mushrooms. The method involves reducing the moisture content of fresh mushrooms from 85–90 per cent to below 10–12 per cent, which inhibits microbial growth and enzymatic activity. Drying can be achieved through several means including cabinet dryers, solar dryers, and traditional sun drying. In cabinet dryers, mushrooms are dried at 45-50º Celsius over 18- 20 hours to ensure proper dehydration. Solar dryers are more energy-efficient and environment friendly, making them suitable for rural settings. Sun drying is the most economical option but is dependent on weather conditions and requires protection from rain, dust, and insects. Once dried, mushrooms must be packed in airtight containers and stored in a cool and dry place to maintain their quality for six months to one year. Dried mushrooms can be rehydrated by soaking in hot water or boiling, and are commonly used in soups, sauces, noodles, and ready-to-eat products. Additionally, dried mushrooms can be powdered and incorporated into bakery items, snack foods, and seasoning mixes, offering excellent scope for value addition.

Modified atmosphere packaging (MAP)

One of the smart techniques being used these days to keep mushrooms fresh for longer is modified atmosphere packaging, often referred to as MAP. This method works by adjusting the mix of gases inside the packaging; mainly oxygen, carbon dioxide, and nitrogen to create a more favorable environment that helps slow down spoilage. For mushrooms, the right balance typically involves keeping carbon dioxide between 2.5- 5.0% and oxygen between 5.0-10.0%. Since mushrooms breathe quite actively even after harvest, the packaging film needs to allow a certain amount of gas exchange. To handle this, special films with tiny holes called micro- or macro-perforations are often used. The type of packaging film plays a key role in how well this system works. Among various options like films coated with polyvinylidene chloride, oriented nylon, or ones designed to prevent fogging or for vacuum sealing, it was found that using an anti-fogging film helped retain the quality of mushrooms for as long as 24 days. This approach offers a practical way for growers and suppliers to cut down on waste and deliver better quality mushrooms to the market.

Table 1: Mushroom Preservation Methods

Method	Shelf Life	Best Use Case
Cold Storage	5–7 days	Local market sales, short-term delays
Freezing	6–12 months	Institutional buyers, food processors
Brining/Steeping	8–10 days	Bulk handling in peak harvest seasons
Canning	1–3 years	Export, off-season sale, retail packaging
Drying	6–12 months	Online sales, powdered forms, ready mixes
MAP (Modified Atmosphere Packaging)	15–24 days	Retail chains, extended shelf life in packaged fresh mushrooms

Conclusion

The use of suitable mushroom preservation techniques is essential for improving market stability, reducing post-harvest losses, and ensuring a consistent supply of quality produce throughout the year. As shown in Table 1, each preservation method offers a distinct shelf life and is best suited for specific marketing or processing needs. From cold storage for short-term requirements to long-term options like freezing, brining, canning, and drying, each method presents unique advantages depending on scale, infrastructure, and market goals. By adopting appropriate preservation practices, mushroom growers and entrepreneurs can enhance the profitability of their operations, reduce wastage, and meet the growing demand for mushrooms in both domestic and international markets.

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Effect of Weather Parameters on Pearl Millet Pests

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Abstract

Pearl millet (*Pennisetum glaucum*) is a crucial cereal crop in arid and semi-arid regions, particularly in India. The incidence and severity of pests affecting pearl millet are influenced by various weather parameters, including temperature, humidity, and rainfall. This review synthesizes existing literature to elucidate the impact of these climatic factors on pest dynamics in pearl millet cultivation, aiming to inform integrated pest management strategies.

1. Introduction

Pearl millet is susceptible to a range of pests, including insect herbivores and pathogens, whose population dynamics are closely linked to climatic conditions. Understanding how weather parameters influence pest behavior and development is crucial for predicting pest outbreaks and implementing timely control measures. This review examines studies that have investigated the relationship between weather variables and pest incidence in pearl millet.

2. Influence of Temperature on Pest Dynamics

2.1 Downy Mildew (*Sclerospora graminicola*)

- **Temperature Effects**: Studies have indicated that minimum temperatures significantly affect the incidence of downy mildew in pearl millet. A unit increase in minimum temperature can increase disease incidence by 0.41% during the vegetative phase

2.2 Spotted Stem Borer (*Chilo partellus*)

- **Developmental Thresholds**: Research has identified the lower developmental threshold (T_0) for *C. partellus* at approximately 12°C, with upper thresholds (T_1 and T_2) ranging between 27°C and 33°C. Development ceases at temperatures exceeding 37°C to 40°C (Singh, 1991).

3. Impact of Humidity and Rainfall

3.1 Downy Mildew and Blast Disease

- **Humidity Correlations**: Morning relative humidity has a significant positive correlation with downy mildew incidence, while evening relative humidity and wind speed show negative correlations. Rainfall during the vegetative phase also positively correlates with disease incidence.

3.2 Insect Pest Populations

- **Humidity Effects**: High humidity levels have been associated with increased populations of certain insect pests, such as the shoot fly (*Atherigona soccata*). However, the relationship between humidity and pest dynamics is complex and may vary among different pest species .

4. Rainfall Patterns and Pest Incidence

- **Rainfall Influence**: Increased rainfall during the growing season has been linked to higher incidences of both fungal diseases and insect pests in pearl millet. Excessive moisture can create favorable conditions for pathogen development and may also support the proliferation of pest populations.

5. Phenological Impacts of Weather Parameters

- **Growth Stages and Weather**: Weather parameters significantly affect the phenology and yield of pearl millet. For instance, maximum temperatures positively correlate with grain and stover yield at certain growth stages, while minimum temperatures and relative humidity have varying effects depending on the growth phase (Singh et al., 2020).

6. Conclusion

The incidence and severity of pests in pearl millet are influenced by various weather parameters, including temperature, humidity, and rainfall. Understanding these relationships is essential for developing effective pest management strategies and optimizing crop production. Further research is needed to explore the complex interactions between weather conditions and pest dynamics to enhance the sustainability of pearl millet cultivation.

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Soil: A Sustainable Use of Land Source

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I. Introduction

Soil is one of the most essential and dynamic resources on earth, which lies the foundation for the ecosystem and maintains life. Often known as the "skin's skin," it gives the soil significant nutrients, composition, and housing that supports plant growth, agriculture, and biodiversity. At a time when global population growth, climate change and industrialization are quickly threatened by natural resources (Lutz W. 2017), it has become more important than ever to use permanent practice for soil management.

Importance of Sustainable land use

Permanent soil management is not just about the protecting soil for future generations; it is about maintaining soil health, increasing productivity and promoting environmental balance from improving the soil's fertility to lowering erosion and mitigating the desert, consistent land use maintains that the nation is productive, adaptable, and able to meet both ecological and economic needs for coming generations. Sustainable land use involves practices that maintain or improve soil fertility over time, ensuring its ability to support plant growth and ecosystem services while minimizing adverse environmental impacts. This approach encompasses a range of strategies such as conservation tillage, crop rotation, agroforestry, organic farming, and integrated nutrient management.

By prioritizing soil health, we can mitigate erosion, reduce nutrient runoff, enhance water retention, and promote biodiversity. Moreover, sustainable land management practices contribute to climate change mitigation by locking up carbon in soils and reducing greenhouse gas emissions associated with agricultural activities.

In this article, we will explore the importance of soil in the context of sustainability, the challenges it faces, and the innovative practices that can help us preserve this invaluable resource. Understanding the link between soil health and sustainability is key to creating a future where both people and the planet thrive.

II. Understanding Soil Fertility

A primary concept in agriculture is soil fertility, which is the capacity of soil to provide essential nutrients to plants in sufficient quantities and in ways that plants can easily acquire. Fertile soil is vital for a healthy plant boom, sturdy crop production, and sustaining ecosystems. It is a dynamic asset encouraged by different factors, which include natural matter, mineral content, and soil structure. Soil fertility is not naturally a fixed property; in fact, it can be influenced by human activity, climate, and agricultural methods, which can lead to its control, improvement, or depletion.

Components & Factors Influencing to Soil Fertility.

Soil fertility is a vital component in figuring out agricultural productiveness and the general fitness of an ecosystem. It refers to the soil's potential to provide essential nutrients in sufficient amount to the plant for completion of their life cycle. Several elements impact soil fertility, ranging from natural elements to human activities. Understanding those elements can assist in preserving and improving soil fertility for sustainable agricultural practices.

To better apprehend soil fertility, it is essential to discover the components that contribute to these critical belongings. These additives consist of:

1. Soil Organic Matter (SOM)

Organic matter, which includes decomposed plant and animal-based material, performs a key role in enhancing soil fertility. SOM will boost microbial activity, enhance moisture retention, and complement soil structure. It is also an excellent reservoir of nutrients like nitrogen, phosphorus, and sulphur. The decomposition of natural matter releases these nutrients slowly into the soil, making them available to plants over the years.

2. Nutrient Availability and Balance

Soil fertility largely relies upon the availability of crucial nutrients for plant growth. These nutrients are divided into macronutrients and micronutrients:

Macronutrients: These are required by way of plants in large quantities and encompass nitrogen (N), phosphorus (P), and potassium (K), frequently called the "primary nutrients", along with calcium, magnesium, and sulphur known as "secondary nutrients".

Micronutrients: These are required in smaller quantities but are similarly vital for plant growth. Examples include iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu). Deficiency or excess of any nutrient can impact plant growth and productivity. Regular soil testing and balanced fertilization are vital to preserve proper nutrient levels.

3. Soil pH

Soil pH, which measures the acidity or alkalinity of the soil, influences nutrient availability and microbial activity. Most plants life succeeds in a slightly acidic to neutral pH range (6.0 to 7.5). Soils which can be too acidic or too alkaline may also restrict the uptake of certain nutrients, leading to nutrient deficiencies or toxicities. Lime application may be used to correct overly acidic soils, even as sulphur or organic matter can reduce alkalinity.

4. Soil Texture and Structure.

The texture of soil refers to the relative proportions of sand, silt, and clay debris present within the soil. These particles affect the soil's potential to hold water, nutrients, and air. Well-balanced soil textures—loam, as an example—are considered ideal for fertility because they offer proper drainage at the same time as keeping enough moisture and nutrients for plant roots.

Soil Structure refers to the arrangement of soil primary particles into aggregates or clumps. Good soil structure promotes root development, facilitates water movement, and improves aeration. Soils with a loose, crumbly structure are typically more fertile, as they permit plant roots to easily uptake to nutrients and water. Poor soil structure, including compacted or sandy soils, can prevent root boom and nutrient availability.

5. Soil Microorganisms

The fitness of soil is closely tied to its microbial network. Beneficial soil microbes, such as fungi, bacteria, and earthworms, break down natural compounds into available form to plant, and help in cycling nutrients to absorb by the plants. These organisms additionally contribute to soil structure through creating aggregates that improve aeration and water infiltration. Soil that is populating with beneficial microbes shifts to be extra fertile and resilient.

6. Water Availability and Drainage

Adequate moisture is vital for nutrient dissolution and absorption by using plant roots. Fertile soils have the potential to maintain water while additionally permitting excess water to infiltrate into deeper layers. This stability is vital for maintaining plant fitness, particularly in regions with fluctuating rainfall patterns. water can cause waterlogging, which reduces oxygen availability and negatively affects root health, while soil that drains too quickly might not provide enough moisture for plant life to develop optimally.

7. Climate and Weather Conditions

Soil fertility is influenced by temperatures, rainfall, and seasonal variations. High temperatures can accelerate the breakdown of organic matter and have an effect on microbial activity. Excessive rainfall may also cause nutrient leaching, whilst drought conditions can restriction nutrient mobility. Understanding local weather patterns enables in soil conservation and control.

8. Soil Erosion and Conservation Practices

Soil erosion eliminates the fertile topsoil layer, depleting essential Nutrients. Wind and water erosion can significantly degrade soil satisfactory through the years. Conservation strategies inclusive of crop rotation, cover cropping, terracing, and contour ploughing can assist reduce soil erosion and maintain fertility.

9. Human Activities and Land Management

Agricultural practices, deforestation, commercial pollution, and urbanization can affect soil fertility. Overuse of chemical fertilizers and insecticides can cause soil degradation and loss of useful microbes. Sustainable land control practices, along with natural farming, composting, and incorporated nutrient control, are critical for long-term soil health.

III. Why Fertile Soil need in Sustainable Agriculture

Soil fertility plays a crucial role in sustainable agriculture because it provides suitable resources like nutrients for plant growth and reduce dependency on synthetic fertilizers, to ensures high crop yields, food security, and help in maintaining biodiversity. It additionally plays a vital position in carbon cycling, supporting to mitigate climate change. Sustainable practices like organic fertilization, conservation tillage, and crop rotation help maintain soil fitness for future generations.

A. Importance of Soil Fertility in crop production and food security.

Soil fertility plays vital role to make sure proper crop yields, which affects food security. Nutrient-rich soil supports wholesome plant boom, leading to extended agricultural productiveness and stable food substances. Fertile soil reduces production costs, and enhances the resilience of vegetation against environmental stresses. By retaining soil fertility, farmers can sustainably produce sufficient food to satisfy the growing worldwide populace's desires while preserving herbal resources.

B. Impact of soil degradation on agricultural productiveness

Soil degradation negatively impacts agricultural productivity by reducing the soil's ability to preserve essential nutrients for plants, water, and organic matter. Erosion, salinization, compaction, and lack of biodiversity bring about lowering crop yields and accelerated reliance on chemical inputs. Degraded soils combat to increase plant support, also chances to food shortages and economic losses for farmers. Sustainable practices of soil control consisting of crop diversification, organic amendments, and conservation strategies, are critical to mitigate soil degradation and maintain long-term sustainability for coming generations.

IV. Troublesome for Soil Fertility

Several components threaten soil fertility, leading to declining agricultural productivity and environmental imbalance. Some components are here:

1. Soil Erosion – The loss of the top fertile soil layer due to wind and water erosion, depletes essential nutrients, and organic matter, and decreases soil depth, making it difficult for plant life to establish strong root systems.

2. Deforestation – The elimination of flora disrupts nutrient cycling, exposes soil to erosion, and reduces organic matter cycling.

3. Overuse of Chemical Fertilizers and Pesticides – Excessive use of synthetic inputs can degrade soil structure, lessen microbial population, and rise nutrient imbalances.

4. Salinization – The accumulation of soluble salts in the soil, regularly due to saline water irrigation practices, reduces soil fertility and water absorption with the encouragement of plant life.

5. Soil Compaction – Heavy machinery and overgrazing can compact soil, restricting root increase, water infiltration, and air circulation in soil.

6. Climate Change – Increasing temperatures, changing precipitation patterns, and intense climate activities can interrupt soil strategies and increase the risk of soil degradation.

7. Industrial wastage as pollution– pollutants containing heavy metals, plastics, and chemicals from industrial and concrete activities can go to in topsoil and damage plants and microbial activity.

Consequences of Soil Fertility Loss

Reduced Agricultural Productivity – Loss of soil fertility results in lower crop yields and terrible-satisfactory produce.

Food Insecurity – Decreased agricultural output threatens international meals deliver and nutrition.

Environmental Degradation – Soil degradation contributes to deforestation, loss of biodiversity, and water pollution.

Economic Losses – Lower yields increase production cost and reduce farmers' incomes (Benefit-cost ratio), impacting rural livelihoods.

V. Principles of Sustainable Land Management

A. Conservation Tillage Techniques

- Reduces soil erosion and compaction
- Enhances moisture retention
- Improves soil shape and natural depend content

B. Crop Rotation and Cover Cropping

- Prevents soil depletion of vitamins
- Improves soil shape and fertility
- Reduces pests and diseases

C. Integrated Nutrient Management

- Combines natural and inorganic fertilizers
- Maintains soil fertility and productiveness
- Reduces environmental impact of chemical fertilizers

D. Organic Farming Practices
- Enhances soil biodiversity and fitness
- Reduces reliance on synthetic chemical substances
- Improves lengthy-term sustainability of agriculture

VI. Importance of Soil Fertility in Sustainable Land Management

Conservation and improvement of soil organic matter Supports microbial activity and improves soil structure and nutrients as well as water retention. Reduces soil erosion enhances root development minimizes nutrient Loss improves nutrient cycling prevents nutrient depletion encourages efficient use of organic and inorganic inputs.

VII. Case Studies

A. Examples of Successful Sustainable Land Management Practices
- Adaptation of agroforestry practices to restore degraded lands.
- Implementation of conservation tillage at large scale in farming.
- Use of organic amendments (vermicompost, compost) to improve soil fertility.

B. Positive Outcomes in Soil Fertility Restoration
- Increased crop yields and soil natural remember content material
- Enhanced biodiversity and advanced soil structure
- Long-term sustainability in agricultural productivity

VIII. Challenges and Solutions

A. Economic, Technical, and Policy Challenges
- High expenses of enforcing sustainable land control practices
- Limited get entry to advanced agricultural technology
- Inadequate regulations and incentives for soil conservation
- Lack of awareness and schooling on sustainable practices

B. Strategies for Promoting Sustainable Land Management
- Providing financial aid and incentives for farmers adopting sustainable practices
- Enhancing studies and development in soil conservation strategies
- Strengthening rules and policies on land use and soil safety
- Promoting training and cognizance campaigns on soil health and fertility

Conclusion

Summary of Soil Fertility's Significance in Sustainable Land Management Maintaining environmental health, ensuring food safety, and maintaining agricultural output all depend on soil fertility. Sustainable soil management techniques improve nutrient cycling, reduce soil deterioration, and conserve biodiversity. Appeal to Action for Adopting Sustainable Practices to Preserve Soil Fertility Sustainable land management strategies should be adopted and supported by farmers, policymakers, and organizations to ensure soil fertility over the long term. Future generations will benefit from steady agricultural productivity and environmental sustainability if soil health is invested in now.

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Dragon Fruit: A Low-Calorie Superfood

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1. Introduction

Dragon fruit is also known as pitaya or strawberry pear, is an exotic tropical fruit that has gained popularity worldwide due to its unique appearance, rich nutritional value and numerous health benefits. Belonging to the cactus family (Cactaceae), dragon fruit is native to Central and South America but is now cultivated extensively in regions such as Vietnam, Thailand, India and Philippines. The fruit is characterized by its bright pink or yellow skin and white or red flesh speckled with small black seeds. Apart from being visually appealing, dragon fruit is known for its refreshing taste and versatility in culinary applications (Choo *et al*., 2018).

Dragon fruit thrives in warm and humid climates, requiring well-drained soil and adequate sunlight for optimal growth. It is a climbing cactus that produces night-blooming flowers, often referred to as the "Queen of the Night." These flowers are large, fragrant and pollinated by bats and insects. The fruit typically takes 30 to 50 days to mature after flowering, making it a relatively fast-growing crop. Given its adaptability and resilience, dragon fruit cultivation has become an attractive agricultural venture, contributing to the economy in various tropical and subtropical regions (Joshi *et al*., 2020).

Despite its growing popularity, a significant portion of dragon fruit is wasted due to post-harvest losses, market fluctuations, lack of awareness, limited processing industries and lack of proper processing facilities (Choo *et al*., 2018). In many regions, dragon fruit is discarded due to its short shelf life and perishable nature. While dragon fruit has immense potential for value-added products such as juices, powders, jams and cosmetics, many regions have not yet fully explored these opportunities. Establishing efficient processing units, cold storage facilities and market linkages could help reduce waste and improve the fruit economic value.

2. Varieties of Dragon Fruit

Dragon fruit is available in three main varieties, each differing in taste, appearance and nutritional profile:

1. ***Hylocereus undatus*** **(White-fleshed Pitaya):** This variety has bright pink or red skin with white flesh and black seeds. It has a mild, slightly sweet taste and is the most commonly found type in markets worldwide.
2. ***Hylocereus costaricensis*** **(Red-fleshed Pitaya):** This variety features deep red or magenta-coloured flesh with pinkish-red skin. It has a slightly sweeter taste and contains a higher concentration of antioxidants compared to the white-fleshed variety.
3. ***Hylocereus megalanthus*** **(Yellow Pitaya):** Recognized by its yellow skin and white flesh, this variety is the sweetest among all. It has a slightly different texture and is primarily grown in South America.

Each variety has its unique taste and nutritional composition, making them suitable for various culinary and commercial applications. The choice of variety depends on consumer preference, intended use and regional availability.

4. **Nutritional Profile**

Dragon fruit is known for its low-calorie content while being rich in essential nutrients. A 100-gram serving of dragon fruit provides (Joshi *et al*., 2020):

1.	Calories	50-60	6.	Vitamin C	3-5mg (5-8% of Daily Value)
2.	Carbohydrates	13-15g	7.	Iron	1-2mg
3.	Protein	1-2g	8.	Magnesium	10-15mg
4.	Fat	0.1-0.6g	9.	Calcium	8-10mg
5.	Fibre	3-4g	10.	Antioxidants	Betalains, Flavonoids and Carotenoids

This nutritional composition makes dragon fruit an excellent choice for those looking to maintain a healthy diet. The high fibre content aids digestion, while antioxidants protect the body from oxidative stress and inflammation. Additionally, its vitamin and mineral content supports various bodily functions, from immune defence to bone health (Jalgaonkar *et al*., 2018).

5. Health Benefits of Dragon Fruit

1. A Low-Calorie and Weight-Friendly Superfood

One of the primary reason dragon fruit is regarded as a superfood is its low calorie and high fibre content. Fibre helps keep you full for longer, reducing unnecessary snacking and aiding in weight management. Since dragon fruit is naturally sweet but low in sugar compared to other tropical fruits, it serves as a great alternative for those looking to satisfy their sweet cravings without excessive calorie intake (Liaotrakoon *et al*., 2012).

2. Rich in Antioxidants

Dragon fruit is packed with powerful antioxidants such as betalains, flavonoids and vitamin C. These compounds help neutralize harmful free radicals in the body, reducing oxidative stress and lowering the risk of chronic diseases such as heart disease and cancer. The red-fleshed variety contains higher levels of antioxidants, making it an excellent choice for individuals seeking to boost their overall health.

3. Boosts Immunity

The high vitamin C and flavonoid content in dragon fruit strengthens the immune system, helping the body fight off infections and illnesses. Regular consumption of dragon fruit may enhance the body ability to defend against common cold, flu and other bacterial infections.

4. Supports Digestive Health

Dragon fruit is an excellent source of dietary fibre, which plays a crucial role in promoting gut health. Fibre helps in regulating bowel movements, preventing constipation and supporting a healthy digestive system. Additionally, dragon fruit contains prebiotics which help nourish beneficial gut bacteria like lactobacilli and bifidobacteria, enhancing overall gut microbiome health.

5. Improves Heart Health and Regulates Blood Sugar Levels

Dragon fruit helps in lowering the bad cholesterol (LDL**)** while increasing good cholesterol (HDL). The fruit also contains natural compounds that regulate blood sugar levels, making it a good dietary choice for individuals with diabetes or prediabetes. The high fibre content helps slow down the absorption of sugar and preventing blood sugar spikes.

6. Enhances Skin and Hair Health

Dragon fruit rich in vitamin C and antioxidant content contribute to healthy and glowing skin. The antioxidants combat free radicals that cause premature aging, while vitamin C aids in collagen production and keeping the skin firm and youthful.

6. Extraction of Colour from Dragon Fruit

Dragon fruit, particularly the **red-fleshed variety (*Hylocereus costaricensis*)** rich in natural pigments known as **betalains**, which are responsible for its vibrant red-purple colour. Betalains are water-soluble pigments that belong to the same group of compounds found in beetroots. These natural colorants are widely used in **food, cosmetics and pharmaceuticals** due to their **antioxidant properties and non-toxic nature**. Extracting colour from dragon fruit involves various techniques that help retain the pigment stability and maximize its usability in commercial applications (Jalgaonkar *et al*., 2018).

1. Selection of Raw Material

The first step in extracting colour from dragon fruit involves selecting fresh and ripe dragon fruit with deep red or magenta-coloured flesh. The quality of the fruit significantly impacts the yield and intensity of the extracted pigment. Overripe or under ripe fruits may not provide optimal colour extraction.

2. Preparation and Pulping

Once the fruit is selected, it is washed thoroughly to remove dirt and contaminants. The outer peel is separated and the inner flesh is **blended into a fine pulp.** This process helps in breaking down the cell structure, making it easier to extract the pigments.

3. Solvent Extraction Method

Solvent extraction is one of the most commonly used techniques for extracting betalains from dragon fruit. Different solvents such as **ethanol, methanol and water** can be used depending on the desired purity and stability of the pigment.

- **Aqueous extraction:** The dragon fruit pulp is mixed with distilled water and allowed to sit for a few hours. The mixture is then filtered to obtain a liquid extract rich in betalains.
- **Ethanol or methanol extraction:** A mixture of ethanol or methanol with water is used to enhance the solubility of betalains. This method helps in achieving a more concentrated pigment extract.

4. Ultrasound-Assisted Extraction

Ultrasound-assisted extraction is an advanced technique that uses high-frequency **ultrasonic waves** to break open the plant cells and releasing the pigments efficiently. This method reduces processing time and improves pigment yield.

5. Vacuum Filtration and Purification

After the extraction, the pigment solution is filtered using a **vacuum filtration system** to remove solid residues. The filtered extract is then subjected to **purification processes** such as **centrifugation or membrane filtration** to obtain a more refined pigment solution.

6. Spray Drying for Powdered Form

To extend the shelf life and enhance usability, the liquid extract can be converted into a **powdered form using spray drying technology.** The extracted pigment is mixed with a carrier agent like **maltodextrin or gum arabic**, and then subjected to high-temperature spray drying to obtain a fine and stable pigment powder.

7. Stability and Storage

Betalains are sensitive to heat, light and pH variations. To ensure the stability of the extracted pigment, it is recommended to store it in **cool, dark conditions** and use stabilizers such as **ascorbic acid or citric acid**. Encapsulation techniques can also be used to protect the pigment from degradation (Jalgaonkar *et al*., 2018).

7. Applications of Dragon Fruit Pigments

Dragon fruit pigments have a wide range of applications in different industries due to their natural composition and health benefits:

- **Food Industry:** These pigments are used as natural colorants in beverages, dairy products, candies and baked items. They enhance the visual appeal of foods while providing antioxidant benefits.
- **Cosmetic Industry:** Dragon fruit pigments are incorporated into skincare products, lipsticks and blushes due to their vibrant colour and skin-nourishing properties.
- **Pharmaceuticals and Nutraceuticals:** Used in health supplements and functional foods for their anti-inflammatory and antioxidant properties.
- **Biotechnological Applications:** Betalains from dragon fruit are also studied for their potential in medical imaging and bio-sensors due to their fluorescence properties.

8. Value-Added Products and Processing of Dragon Fruit

With the rising demand for dragon fruit, several value-added products have been developed to extend its shelf life and enhance its usability. Some of the most popular value-added products include (Joshi *et al*., 2020)

1. Dragon Fruit Juice and Smoothies

Dragon fruit juice and smoothies provide a refreshing and nutrient-rich beverage option. The fruit natural sweetness and hydrating properties make it an ideal base for healthy drinks.

2. Dragon Fruit Jam and Jelly

With its natural pectin content, dragon fruit is processed into jams and jelly that can be stored for longer period. These products are commonly used as spreads for bread, pancakes and desserts.

3. Dried Dragon Fruit

Dried dragon fruit serves as a convenient and healthy snack. The drying process retains most of the fruit nutrients while enhancing its shelf life.

4. Dragon Fruit Powder

Dragon fruit is dehydrated and ground into a fine powder that can be used in smoothies, baked goods and health supplements. This form extends the usability of dragon fruit and allows for easy incorporation into daily diets.

5. Dragon Fruit Wine and Beverages

Fermented dragon fruit can be used to make wine, flavoured alcoholic drinks and refreshing infused beverages. The fruit vibrant colour and natural sugars make it a desirable ingredient for innovative beverages.

6. Dragon Fruit-Based Skincare and Cosmetics

The high antioxidant and vitamin C content in dragon fruit makes it a valuable ingredient in skincare products, including face masks, creams and serums. These products help in maintaining youthful and hydrated skin.

9. Conclusion

Dragon fruit is a low-calorie superfood that offers a wide range of health benefits, making it an excellent addition to any balanced diet. Its versatility allows it to be consumed fresh, blended into smoothies or processed into various value-added products. With its high antioxidant content, digestive benefits and immune-boosting properties, dragon fruit continues to be a popular choice among health-conscious individuals. Whether enjoyed raw or in processed forms, dragon fruit provides a delicious and nutritious way to enhance overall well-being.

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Role of Krishi Vigyan Kendras in Motivating Rural Youth towards Agricultural Entrepreneurship

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Abstract

Agriculture remains the backbone of the Indian economy, employing a significant portion of the population and contributing substantially to GDP. However, in recent years, rural youth have increasingly moved away from farming, lured by the prospects of urban jobs and the perception of agriculture as labor-intensive and less rewarding. Amid this scenario, Krishi Vigyan Kendras (KVKs) have emerged as vital institutions for rekindling interest in agriculture, particularly by motivating rural youth towards agripreneurship. By fostering innovation, providing hands-on training, and connecting youth to market opportunities, KVKs play a transformative role in shaping the agricultural landscape.

Understanding Krishi Vigyan Kendras

Krishi Vigyan Kendras (KVKs) are agricultural extension centers established by the Indian Council of Agricultural Research (ICAR). There are currently 731 Krishi Vigyan Kendras (KVKs) operating in India. These centers function as knowledge hubs for farmers, offering scientific advice and skill-building opportunities. Spread across the country, KVKs cater to the localized needs of farmers, ensuring that agricultural advancements are accessible to all.

The mandate of KVKs includes:

1. Conducting On-farm testing (OFT) to identify the location-specificity of agricultural technologies.
2. Organizing frontline demonstrations (FLD) to showcase the potential of new technologies.
3. Conducting vocational and hands on training for farmers, rural youth, and extension personnel.
4. Providing advisory services to solve agricultural challenges.
5. Implementation of Central Government Flagship Programmes like, Natural Farming, NMOOP, NFSM, PKVY etc

Challenges Faced by Rural Youth in Agriculture

Rural youth often perceive agriculture as a high-risk, low-reward venture due to multiple challenges:

1. **Lack of Awareness**: The rural youth often lack exposure to modern farming techniques and agribusiness opportunities. This knowledge gap limits their ability to adopt innovative practices or explore agriculture as a viable entrepreneurial venture. Without awareness of advanced methods, tools, or market trends, young farmers might struggle to compete, innovate, or see agriculture as a profitable and sustainable career choice. KVKs aim to bridge this gap by offering training and resources tailored to local agricultural contexts.
2. **Market Access**: Rural youth often lack direct access to markets, forcing them to rely on middlemen who exploit their dependency by offering low prices for their produce. This reduces profitability and discourages investment in agriculture, perpetuating a cycle of low income and disinterest.
3. **Capital Constraints**: A major hurdle for rural youth in agriculture: limited access to financial resources and institutional credit. This restricts their ability to invest in modern farming techniques, infrastructure, and

agribusiness ventures. Without adequate capital, they face significant challenges in scaling their operations or taking calculated risks in entrepreneurship.

4. **Climate Risks**: The susceptibility of agriculture to unpredictable weather events and crop diseases, which create uncertainty and financial risks. For rural youth, this unpredictability discourages investment in agriculture and entrepreneurship. KVKs address this challenge by promoting climate-resilient practices, advanced crop management techniques, and insurance schemes to mitigate risks.
5. **Social Stigma**: The perception that agriculture, especially in rural areas, is considered a low-status occupation compared to urban jobs. This societal view often discourages rural youth from pursuing farming or related entrepreneurship, as they aspire to professions perceived as more prestigious or modern in urban settings, creating a barrier to agricultural development.

KVKs as Catalysts for Agricultural Entrepreneurship

KVKs have strategically positioned themselves to address these challenges and motivate rural youth towards agriculture entrepreneurship. Their interventions span across multiple dimensions:

1. Skill Development and Vocational Training

KVKs conduct regular training programs tailored to the needs of rural youth. These programs cover diverse topics, including:

- Organic farming practices.
- Integrated pest and nutrient management.
- Dairy and poultry farming.
- Food processing and value addition.
- Precision farming and use of technology in agriculture.

For instance, the KVK in Jorhat, Golaghat, Kokrajhar and Karbi Anglong has trained over 2,000 youth in mushroom cultivation, helping them establish small-scale enterprises, FPC that generates steady income.

2. Promoting Agri-Tech Adoption

Technology adoption is critical for enhancing productivity and sustainability. KVKs play a pivotal role in introducing rural youth to technologies such as:

- Drip irrigation and water-saving techniques.
- Mobile apps for market intelligence and weather updates.
- Mechanization of farming practices to reduce labor dependency.

Through demonstration plots and workshops, KVKs showcase the effectiveness of these technologies, instilling confidence in young farmers.

3. Incubation and Mentorship

KVKs often act as incubation centers for agripreneurs. They provide mentorship and support in developing business plans, securing funding, and navigating the regulatory environment. Initiatives like the Agri-Business Incubation (ABI) centers under KVKs have helped numerous startups thrive.

For example, the KVK in Jorhat has facilitated the establishment of agro-tourism ventures with various events like angling and allowing farmers to diversify their income sources while promoting rural culture.

4. Market Linkages and Value Addition

One of the significant barriers to agripreneurship is market access. KVKs bridge this gap by connecting youth with market players, cooperatives, and e-commerce platforms. Additionally, they emphasize value addition—converting raw agricultural produce into market-ready products—to enhance profitability.

For instance, the KVKs in Assam have been instrumental in promoting value-added products, enabling rural youth and farm women to tap into the growing demand for pickles, indigenous foods and health foods.

5. Encouraging Sustainable Practices

KVKs emphasize sustainable agricultural practices to ensure long-term viability. Programs on organic farming, agroforestry, and renewable energy usage attract environmentally conscious youth.

In Assam, the KVK's initiatives on Natural Farming cultivation have not only provided lucrative opportunities but also contributed to ecological conservation.

Success Stories of Youth Empowerment through KVKs

Numerous success stories highlight the effectiveness of KVKs in transforming rural youth into successful agripreneurs:

1. **Madhurima's Mushroom Magic**: A young woman in Jorhat, Assam received training in mushroom cultivation from her local KVK. Today, she employs 10 people and supplies mushrooms to major urban markets of Jorhat and Guwahati.
2. **Digital Farming in Rajasthan**: A group of tech-savvy youth in Rajasthan developed a mobile app for soil health monitoring, supported by their KVK's mentorship. The app now serves thousands of farmers across the state.
3. **Organic Revolution in Assam**: Inspired by KVK's training, a group of youth started an organic tea and king chilli plantation, exporting their product globally and earning accolades.
4. **Assam's Bamboo Entrepreneurship**: In Assam, KVK training programs on bamboo cultivation and processing have empowered local youth to establish businesses that create value-added bamboo products. These products are now sold both domestically to Assam Bio Refinery and internationally, creating a sustainable income source for many families.
5. **Fish Farming Success in Assam**: Another remarkable initiative from Assam involves youth trained in advanced fish farming techniques. Supported by KVKs, they have set up fish hatcheries and breeding units, contributing to the state's economy while creating employment opportunities in rural areas.
6. **Nutrition Garden Initiative in Assam**: In a unique success story, the KVK in Jorhat, Assam, introduced the concept of nutrition gardens to rural households and Schools. By training youth and women in cultivating diverse vegetables and fruits in small spaces, the initiative has enhanced household nutrition in mid day meals of schools and provided additional income. Several families have adopted this model, selling surplus produce in local markets and inspiring others to replicate the idea.

Challenges and Recommendations for KVKs

Despite their significant contributions, KVKs face challenges such as limited infrastructure, inadequate staffing, and financial constraints. To enhance their effectiveness, the following recommendations are proposed:

1. **Motivating the Employees:** Timely salary, Promotion and providing all the required logistic support will increase the efficiency of the KVK employees.
2. **Increased Funding**: Allocating higher budgets for KVKs can help expand their outreach and improve facilities.
3. **Leveraging Technology**: Utilizing digital platforms for training and advisory services can increase their impact.
4. **Public-Private Partnerships**: Collaborating with private companies can bring in resources and market insights.
5. **Youth-Centric Policies**: Tailoring programs specifically for young aspirants, including leadership development and startup grants.
6. **Monitoring and Feedback**: Regular impact assessments to identify gaps and refine strategies.

Conclusion

Krishi Vigyan Kendras are more than just agricultural extension centers; they are enablers of transformation in rural India. By motivating rural youth towards agripreneurship, KVKs not only address the challenges of unemployment but also revitalize the agricultural sector with innovative ideas and sustainable practices. With increased investment and strategic interventions, KVKs can become the cornerstone of a new agricultural revolution, driven by the enthusiasm and enterprise of rural youth.

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Understanding the Early Monsoon Onset in 2025: Weather Anomalies and Global Influences

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INTRODUCTION

The Indian summer monsoon, delivering nearly 70 % of South Asia's annual rainfall, is vital for agriculture, water resources, and ecosystems. Traditionally beginning around June 1st in Kerala, the monsoon's early arrival in 2025-nearly two weeks ahead of schedule marked a significant climatic deviation. From early sowing in Tamil Nadu to heavy downpours in coastal Maharashtra, this shift brought both opportunities and challenges. Far from being a mere anomaly, the early onset was driven by a complex interplay of climatic factors including elevated sea surface temperatures, La Niña conditions, early cyclonic activity, and weakened jet streams. These changes have implications not only for agriculture but also for urban planning, disaster management, and long-term climate resilience. Understanding the causes behind this early monsoon is critical for informing immediate responses and shaping sustainable strategies for the future.

1. Normal Monsoon Timeline and Pattern

India's southwest monsoon is a seasonal climate system driven by land-ocean heat differences, pressure gradients, and global wind patterns. It begins with summer land heating, creating a low-pressure zone that draws in moisture-laden winds from the Arabian Sea and Bay of Bengal. Typically arriving in Kerala by June 1st, it advances northward, covering most of India by mid-July and withdrawing by early October. This monsoon is vital for agriculture and water resources, but increasing climate variability is disrupting its timing and reliability, underscoring the need to understand its historical trends for better future planning.

2. What Happened in 2025?

In 2025, the monsoon arrived in Kerala by May 21st, almost 10 days earlier than the long-term average. This early onset triggered a chain reaction of early rainfall across several states, including Karnataka, Maharashtra, Odisha, and parts of Andhra Pradesh.

Observations:

- Early rainfall events began in mid-May in coastal regions.
- Farmers in many areas commenced sowing by the last week of May.
- Weather models recorded unusually high pre-monsoon humidity and wind activity.

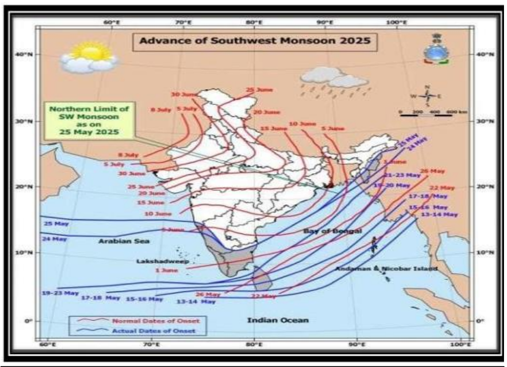

Fig 1: Early onset of the Indian monsoon in 2025

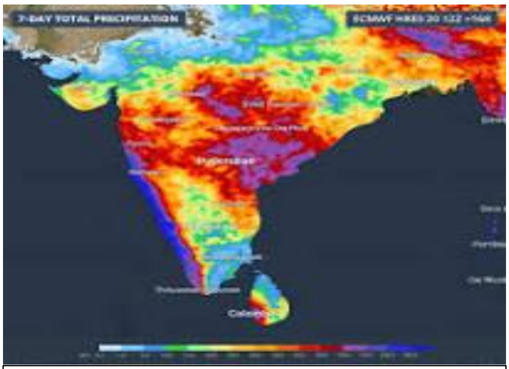

Fig.2: Satellite-derived moisture transport pattern illustrating intense monsoonal airflow across India during early May 2025 (Source: DTN APAC)

From Fig.1 In 2025, the IMD declared the monsoon onset over Kerala on May 21st—about 10 days early marking one of the earliest advances in recent years. Preceded by widespread pre- monsoon showers, coastal states like Karnataka, Goa, and Maharashtra saw early rains, prompting farmers to begin sowing by late May. Cities like Mumbai and Hyderabad faced heavy pre-onset showers and flooding. Favorable atmospheric and oceanic conditions, including high humidity and strong sea breezes, accelerated the monsoon's early spread across much of India.

3. Possible Reasons for Early Monsoon

Warmer Sea Surface Temperatures

During March to May 2025, the Arabian Sea and Bay of Bengal recorded sea surface temperatures 1.5°C to 2°C above normal, leading to increased evaporation, higher atmospheric moisture, and intensified convection. This enhanced cloud formation, strengthened cross-equatorial winds, and accelerated the southwest monsoon's arrival, resulting in widespread early rainfall across peninsular India.

Climate Change Effects

Rising global temperatures are reshaping monsoon patterns, leading to earlier heat waves, quicker formation of low-pressure zones, and increased atmospheric moisture. Since 2010, India has seen more frequent early or delayed monsoon onsets, extreme rainfall events, and prolonged dry spells. Key drivers include record-high global temperatures in 2025 and rising upper tropospheric humidity.

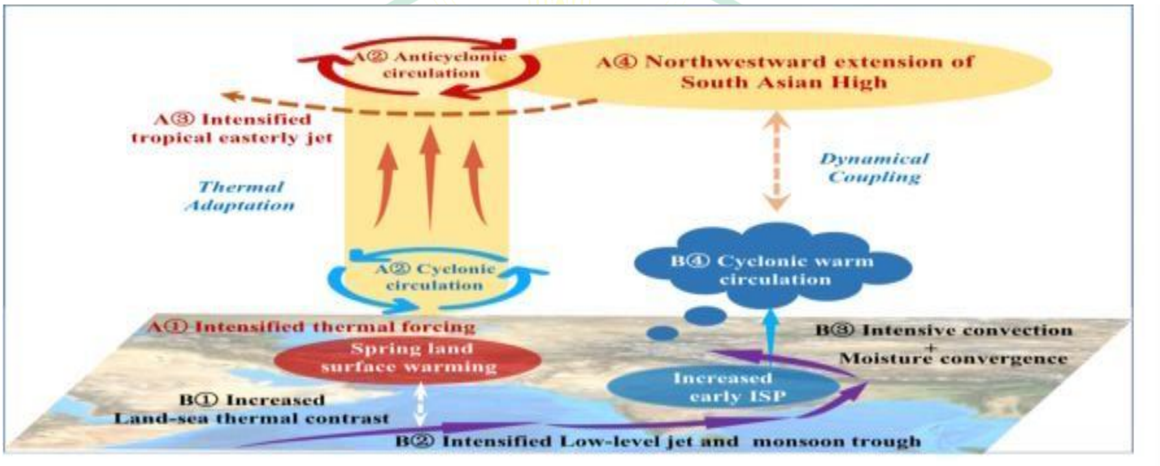

Fig. 3: Flowchart showing land-ocean heating interaction accelerating monsoon process

El Niño and La Niña Phenomena

In 2025, the early and strong monsoon onset was driven by key ocean-atmosphere phenomena. La Niña conditions enhanced monsoon activity by strengthening trade winds and convection. A positive Indian Ocean Dipole (IOD) further intensified monsoon winds, while an active Madden-Julian Oscillation (MJO) in May boosted vertical moisture transport. Together, these factors created ideal conditions for early and widespread rainfall.

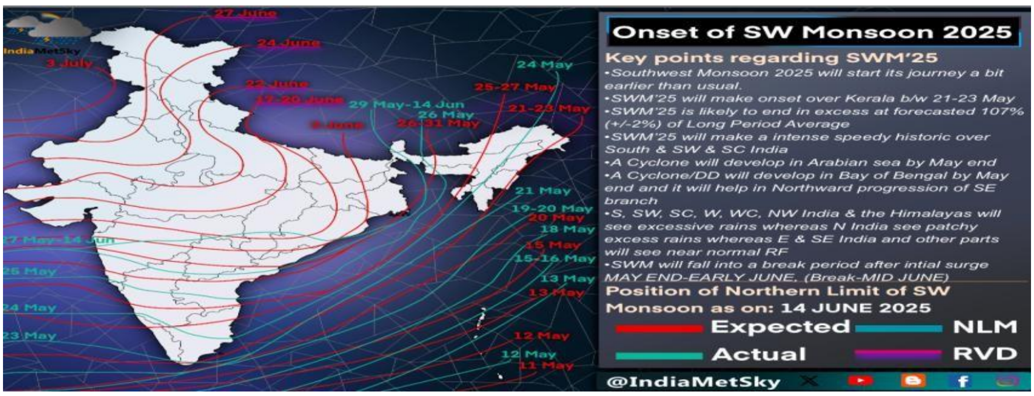

Fig 4: Monsoon driver summary chart outlining ENSO, IOD, SST, and MJO conditions for May 2025 (Source: IndiaMetSky)

In 2025: La Niña conditions prevailed.
IOD (Indian Ocean Dipole) was in positive phase, which strengthens monsoon.
MJO (Madden-Julian Oscillation) active during May, bringing convection closer to Indian shores.

Cyclonic Systems

In May 2025, Cyclone Maha formed over the Arabian Sea and accelerated the monsoon onset by pulling monsoon troughs closer to India, enhancing moisture convergence, and strengthening southwesterly winds. Unlike typical cyclones that may delay monsoon winds, Maha created favorable conditions for early rainfall. Its formation underscores the growing role of early-season cyclones, driven by warming oceans, in shaping monsoon dynamics.

Jet Stream and Wind Pattern Changes

Before the 2025 monsoon, a weakened and northward-shifted subtropical jet stream over India enabled greater vertical air movement, aiding convection and early cloud formation. This reduced dry air intrusions and supported early, steady rainfall—an anomaly increasingly tied to global warming and emphasizing the need for better jet stream monitoring.

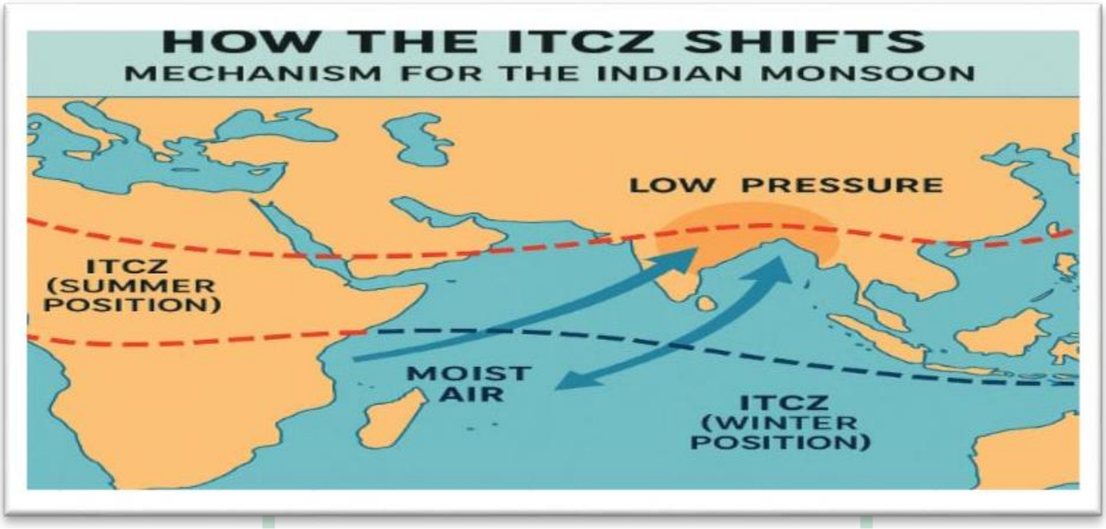

Fig. 5: Depiction of jet stream shifts influencing monsoon onset timing (Source: Medium)

4. Impact of Early Monsoon

The early onset of the 2025 monsoon had broad impacts across sectors. In agriculture, it enabled earlier sowing of crops like rice, pulses, and cotton, potentially boosting yields but straining seed and fertilizer supply chains. Urban areas saw relief from heat and improved air quality, yet faced flooding and disruptions due to inadequate drainage.

Category	**Positive Effects**	**Negative Effects**
Agriculture	Early sowing opportunity for kharif crops	Delay in rabi crop harvesting and damage to matured crops
Water Resources	Early groundwater recharge and reservoir filling	Sudden runoff may lead to poor absorption and soil erosion
Temperature	Relief from extreme summer heat	Unseasonal temperature drop may affect crop physiology
Crop Season Length	Longer kharif season, potentially higher productivity	Improper crop planning due to unexpected rains
Vegetation	Early green cover development and improved air quality	Excess moisture may promote weed growth
Pests and Diseases	-	Increase in pests, fungal infections, and plant diseases due to prolonged humidity
Urban Impact	-	Urban flooding, traffic disruption, and waterlogging in low-lying areas
Infrastructure	-	Delay in construction and maintenance activities

5. Importance of Climate-Responsive Planning

Agriculture:

- Implementation of flexible sowing schedules.
- Adoption of heat-, drought-, and flood-resilient seed varieties.
- Dissemination of real-time agro advisories and rainfall alerts.

Water Management:

- Dynamic reservoir release planning based on evolving rainfall patterns.

6. Role of Technology and Forecasting

- AI-based monsoon prediction tools are being developed.
- Satellite data and ocean monitoring crucial for accuracy.
- Collaboration between global meteorological agencies enhances preparedness.

Conclusion

The early arrival of the Indian monsoon in 2025 was not just a meteorological anomaly but a clear signal of the evolving and increasingly unpredictable nature of climate systems in the 21st century. Driven by a combination of oceanic anomalies, atmospheric shifts, cyclonic activity, and long-term climate change, the early onset brought both benefitssuch as timely sowing and improved water availability—and challenges, including urban flooding and supply chain disruptions. It exposed gaps in preparedness and underscored the urgent need for adaptive planning, resilient infrastructure, robust early-warning systems, and climate literacy. The 2025 monsoon affected millions and highlighted the growing volatility of India's weather patterns, emphasizing that understanding and responding to such events is essential for the nation’s environmental, economic, and social sustainability. As climate change accelerates, the lessons from this event must catalyze improvements in forecasting, policy, and grassroots readiness—making the 2025 monsoon not just a warning, but a call to action India cannot afford to ignore.

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Encapsulation Technologies in Functional Food Development and Waste Valorization: Methods, Materials, and Industrial Applications

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Abstract

Encapsulation has become a transformative technology in the food industry, offering novel ways to stabilize, protect, and deliver bioactive compounds such as flavors, vitamins, essential oils, enzymes, and probiotics. This article comprehensively reviews various encapsulation techniques—spray drying, fluidized bed coating, spray chilling, coacervation, and interfacial polymerization—highlighting their mechanisms, materials used, and industrial relevance. Emphasis is placed on the roles of proteins, polysaccharides, and lipids as wall materials, and their impact on the controlled release and targeted delivery of encapsulated compounds. The article also explores the valorization of fruit and vegetable processing wastes rich in bioactive nutrients, presenting an eco-friendly approach to encapsulate and convert them into value-added products. Challenges such as thermal sensitivity, pH-dependent polymer stability, and microbial viability are discussed alongside future perspectives for green technologies and novel materials. Overall, encapsulation holds promise for advancing functional food innovation, sustainability, and consumer health.

Introduction

Encapsulation is an extensively used technique for designing engineered products in various food industries especially in functional and specialties food manufacturing, food processing and product innovation. It involves entrapping a functionally active core material into a matrix of an inert material. The material which is to be encapsulated is known as core or active material. It is also known as fill, internal phase or payload. On the other hand, the material which is used to encapsulate the active ingredient is called coating material, wall, capsule, membrane, shell, matrix or carrier material (Zuidam *et al.*,2010). Encapsulation technology was industrially applied first time almost after two decades to obtain pressure-sensitive coatings for the manufacture of carbonless copying paper (Madene *et al.*, 2006). Microencapsulation technology received increased interest in industrial application owing to its ability to provide protection to unstable bioactive component, incorporate new functional properties into designed food products and effectively deliver the active material at targeted site at controlled rate. As a consequence, various methods of encapsulation have been explored for a long time. However, the choice of the suitable process varies with the nature of the active ingredient, the properties of the shell material and the desired characteristics of the final product based on the intended use.

In general, food grade proteins and polysaccharides are used to encapsulate sensitive and bioactive food ingredients including highly unsaturated edible oils (e.g. fish oils), vitamins, enzymes or various flavours for enhancing their shelf-life and/or masking the undesirable flavor or taste (Weinbreck *et al.*, 2004); however, recent research works focus on enhancing the functionality and health benefits of processed foods and enhancing the efficacy of probiotics and targeted delivery of various enzymes or coenzymes, bioactive peptides and other therapeutic agents. Controlled and sustained release and targeted delivery have been achieved by encapsulating artificial sweeteners, therapeutic proteins and other bioactive ingredients (Cárdenas *et al.*, 2012). The ultimate objective is to extend product shelf life and improve the overall acceptability of the engineered product (Dziubla *et al.*,2005).

Food processing, a vital agricultural sector, has expanded significantly, reducing wastage of perishable commodities while generating diverse food products, creating employment, and improving livelihoods. However, production, processing, and preparation generate large quantities of waste, causing environmental pollution and health hazards. This waste includes leaves, straw, harvest residues, processing by-products, unused materials, and food preparation leftovers. Poor management of agri-economic practices contributes to excessive wastage, making waste disposal a serious challenge as regulatory bodies demand eco-friendly treatments. Effective utilization of these wastes for value-added products is crucial for sustainable waste management. Fruit and vegetable wastes are rich in essential nutrients like carbohydrates, proteins, fats, minerals, and fibers. For example, mango seed kernels are high in carbohydrates, fats, proteins, and minerals; orange, melon, and pumpkin seeds provide fats and minerals; while apricot kernels contain about 45% oil and are protein-rich. Proper waste utilization can convert potential pollutants into valuable resources, supporting sustainability.

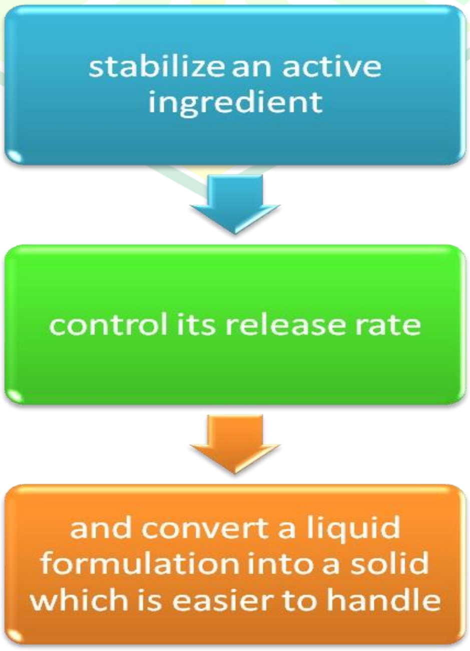
Table 1: Type of waste generated (%) from various horticultural processing industries

Commodity	% waste (weight basis)	Type of waste
Apple	20-30	Pomace
Apricot	8-25	Stones
Banana	-	Peel
Mango	40-60	Peel, pulp, stones
Orange	50	Peel, rag and seed
Grapes	-	Stem, skin and seed
Guava	-	Peel, core and seeds
Sweet potato	15	Peel
Potatoes	10-15	Peel, starch, fibre
Peas	6-79	Shell
Tomato	20-30	Skin, core and seeds
Carrot	18-52	Peel, top portion, pomace
Cabbage	5-25	Outer leaves

Purpose of Encapsulation

In general, food scientist and land development companies are employing encapsulation process for specific purposes and used for volatile flavours, fortified ingredients with masked odour and taste, in ingredients to prevent oxidation and in products such as chewing gums which contains flavours for long-lasting effects.

For instance, ingredients that are encapsulated include vitamins that need protection from the external atmosphere, moisture and flavourings that need to be released during mastication.



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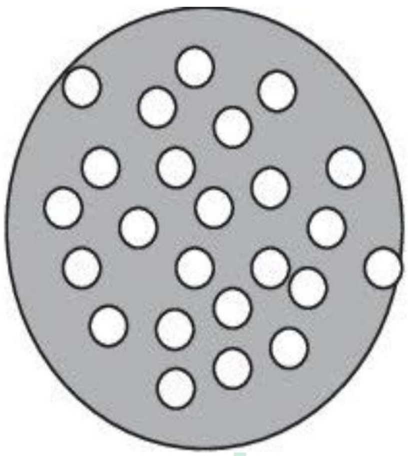
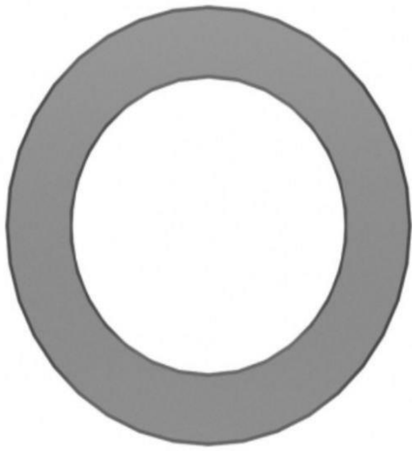
There are two main types of encapsulates

1. The reservoir type has a shell around the active agent. This type is also called capsule, single-core, mono-core or care-shell type.

The latter is a combination of the first two. Only spherical shaped encapsulates are shown but other forms are also possible. Here the active is indicated in white, and the carrier material in gray.

2. The active in the **matrix type** of encapsulates might be in the form of tiny droplets or is dispersed at the molecular level throughout the particle.





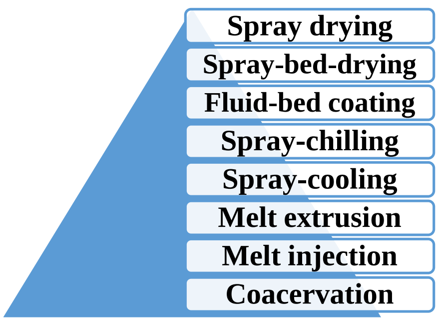
The Matrix Type **The Reservoir Type**

Materials used for Encapsulation

Polysaccharides	Starch and their derivates – amylase, amylopectin, dextrins, maltodextrins
Plant extracts	Gum Arabic, gum karaya, pectin and soluble soybean polysaccharides
Marine extracts	Carrageenans and alginate
Proteins	Milk and whey proteins are casein and gelatine
Lipids	Fatty acids and fatty alcohols, waxes and phospholipids
Microbial and animal polysaccharides	Dextran, chitosan and xanthan

Encapsulation Techniques

Encapsulation techniques are broadly categorized into three groups: (i) physical or mechanical methods, which include spray drying, freeze-drying, extrusion, fluidized-bed coating, and supercritical fluid processing; (ii) physicochemical methods, encompassing spray chilling, ionic gelation, solvent evaporation, liposomal entrapment, and coacervation; and (iii) chemical methods, such as interfacial polymerization and molecular inclusion through cross-linking.



In the food industry, spray drying and freeze drying are the most widely employed techniques for controlled release of functional ingredients and for recovering valuable by-products from agro-industrial operations.

Spray Drying

Spray drying is a widely adopted and highly efficient encapsulation method in the food and pharmaceutical industries due to its significant advantages over other encapsulation techniques. It is highly automated and cost-effective, and produces a good quality product. One of the most remarkable advantages of the spray drying is its capacity to process several kinds of materials to produce fairly dried product with pre-specified properties (Haque *et al*.,2015) In this method, the active ingredient is well mixed in the encapsulating material forming an emulsion or a solution or a suspension. In general, the lipophilic core and hydrophilic shell materials are used to form an emulsion. The shell material is commonly a polysaccharide (e.g. gum or starch) or a protein (e.g. gelatin, milk protein or soy protein) or their synergies. Usually, coarse emulsion is prepared by mixing the core and shell materials in required quantities. It is usually followed by single stage or two-stage homogenisation that yields a fine emulsion. This fine emulsion is atomized in a drying chamber at a pre-defined flow rate. When water from the emulsion is removed by application of thermal energy, it yields a coated dry active ingredient, more stable to moisture, oxygen, light and other environmental stressors (Petrovie *et al*.,2007) Finally, the formation of matrix type micro capsules.

Spray drying technology provides high production rates at relatively low operating costs and the resulting product is stable and easily scalable. Several unstable and sensitive products including polyunsaturated fats (PUFA), vitamins, enzymes and polyphenols can be encapsulated into inert matrices to make them stable and more effective. However, most probiotic strains do not survive well at high temperatures and dehydration during spray-drying process. Loss of viability is principally caused by damage of cytoplasmic membranes and associated proteins (Anal *et al*., 2007).

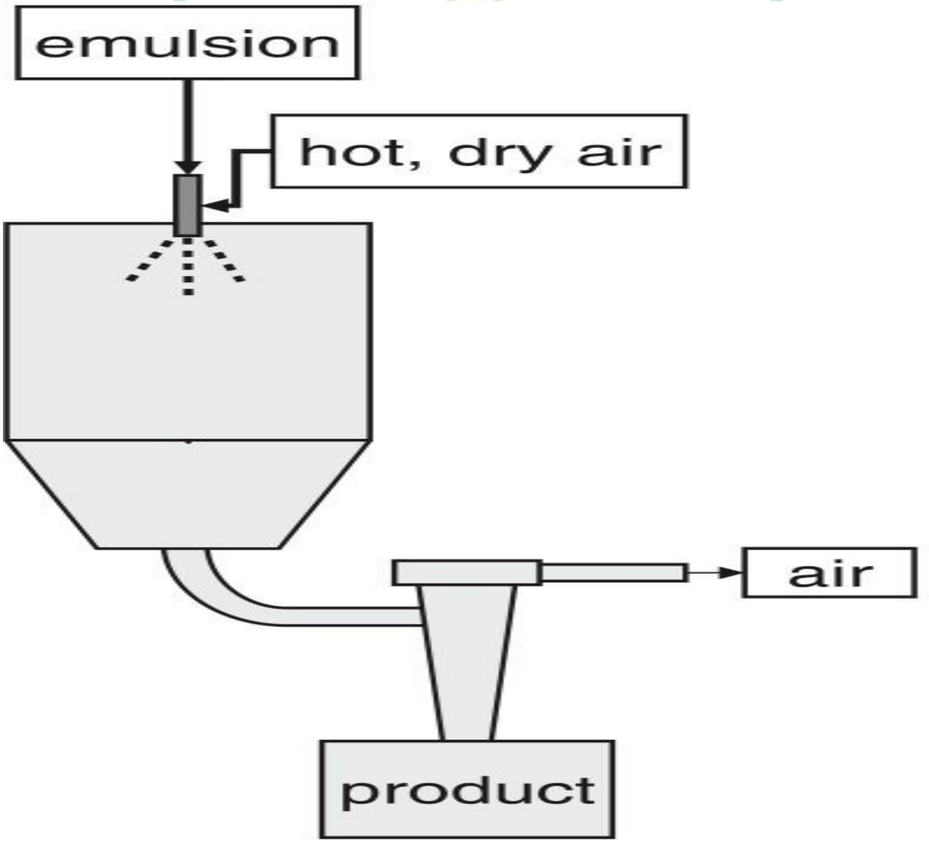


Figure 2. A schematic diagram of microencapsulation process by spray drying

Fluidized Bed Coating/Air Suspension

The process entails preparing the coating solution, fluidizing the core particles, tablets, or granules, and subsequently coating these core materials with the prepared solution. (Dewettinck *et al.,* 1999). The types of materials for fluidized bed coating are water-insoluble and water-soluble polymers, lipids and waxes. The particles/granules are sprayed with coating solution at a specific temperature. Application of high temperature is not required; hence, this method is efficient in saving energy and time. However, this method is commonly used for secondary coating of the primarily encapsulated products to enhance the stability. For example, corn starch coating was used as secondary coating on caseinate encapsulated fish oil.

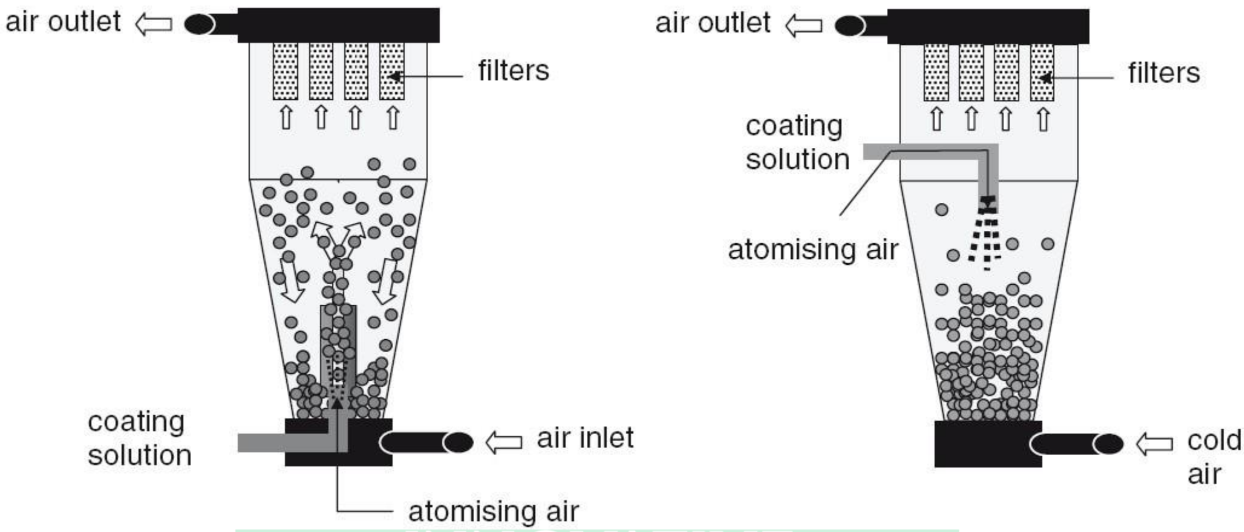


Figure 3. A schematic diagram of a fluidized bed coating

Spray Chilling and Spray Cooling

Spray chilling is the process of solidifying an atomized liquid spray into particles. In these methods, mixture of core and wall is atomized into the cooled or chilled air, which causes the wall to solidify around the core (Oxley *et al*.,2012). Unlike spray-drying, spray-chilling or spray-cooling does not involve mass transfer (evaporation of water). Therefore, it is more energy efficient process. In spray-cooling, the coating materials generally consist of vegetable oils or their derivatives, such as fats and stearin, with melting points ranging from 45°C to 72°C, along with hard mono- and diacylglycerols, which have melting points between 45°C and 65°C. In spray-chilling, the coating material is typically a fractionated or hydrogenated vegetable oil with a melting point in the range of 32˚C - 42˚C. In these processes, a melted lipid, above its melting point, is sprayed onto the core material and allowed to cool; instant solidification of the lipid takes place yielding almost perfect spherical and free-flowing microcapsule powders. Microcapsules prepared by spray-chilling and spray cooling are insoluble in water due to the lipid coating. Consequently, these techniques are utilized for encapsulating water-soluble core materials such as chemical fertilisers, pharmaceutical ingredients, water-soluble vitamins, enzymes, acidulants, and some flavors (Desai *et al*., 2005).

Coacervation

Coacervation refers to the partial desolvation of a uniform polymer solution, resulting in two distinct phases: a polymer-rich phase (coacervate) and a polymer-poor phase (equilibrium phase). The term is derived from the Latin word "acervus," meaning "heap." It was the first encapsulation technique reported for industrial-scale production of microencapsulated products. Coacervation is broadly classified into two types: simple and complex coacervation. Both follow the same basic mechanism of microcapsule formation, differing only in the method of phase separation. In simple coacervation, a desolvating agent induces phase separation, while complex coacervation occurs through the interaction of two oppositely charged polymers. The fundamental steps involved in complex coacervation are: 1) preparation of solution of two polymers; 2) mixing of lipophilic core with a polymer solution to form emulsion; 3) mixing of another polymer solution; 4) change of pH or temperature to induce formation of two immiscible phases; 5) deposition of the coacervates around the core; and 6) rigidization of the coating by cross-linking or application of heat. This method is capable of producing particles with smaller sizes that ranges from 1 to 100 µm. It also gives unusually higher payload (upto 90% for single core and 60% for multicore encapsulation. In complex coacervation, a protein and a carbohydrate (gum) are usually chosen as the shell materials. Protein is a positively charged polymer, whereas gum is negatively charged. Several biopolymers have been explored for encapsulation through complex coacervation. Gelatin and gum arabic remain the most commonly used polymer pair; however, in recent years, gelatin has been increasingly substituted with other proteins, including whey protein isolate, lactoferrin, and bovine serum albumin (Eratte *et al*., 2014). Major disadvantage of complex coacervation based microencapsulation technology is that the coacervates are stable within a very narrow range of pH and ionic strength (Zhang *et al*., 2009). This limits the range of polymers that can be used as shell material in complex coacervation process. Another disadvantage is concentration of solute that can be used to form complex coacervates in solution form. The above discussion concludes that the complex coacervation method has huge application in food and pharmaceutical industry if associated bottlenecks are removed.

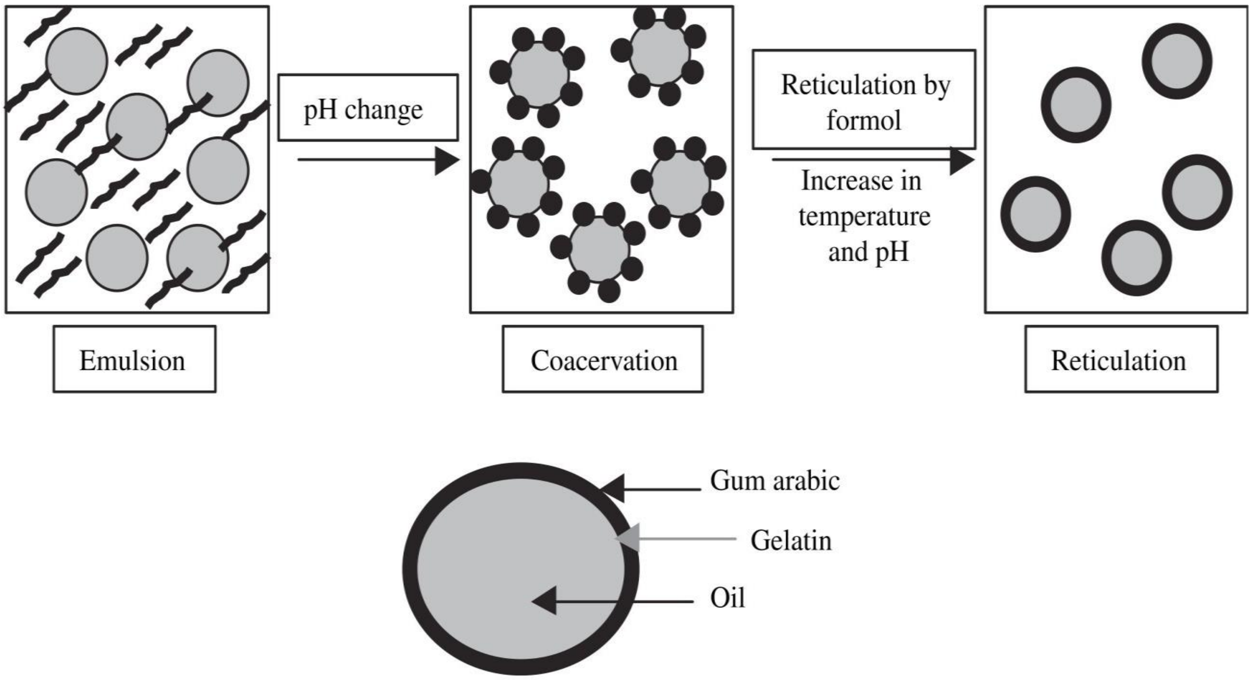


Figure 4. Flow diagram of the complex coacervation process; coating of core material (oil) by forming continuous shell around the core particles.

Interfacial Polymerization

Interfacial polymerization is a chemical encapsulation technique where polymerization occurs at the interface of two immiscible phases, typically oil and water, forming a thin polymeric membrane around the core material. It is widely used for encapsulating flavors, essential oils, vitamins, and bioactive compounds due to its high encapsulation efficiency and controlled release properties. According to Benita (2006), this method allows the formation of micro- and nanocapsules with tailored permeability and mechanical strength. Gouin (2004) highlighted its application in protecting sensitive food ingredients from oxidation and thermal degradation, improving shelf life.

Conclusion

Encapsulation has emerged as a pivotal technology in the food industry, offering significant advantages in enhancing the stability, bioavailability, and controlled release of functional and bioactive ingredients. By entrapping sensitive components within protective matrices of proteins, polysaccharides, or lipids, encapsulation not only improves the shelf life and sensory attributes of food products but also enables targeted delivery of health-promoting compounds such as probiotics, enzymes, vitamins, and polyunsaturated fatty acids. Among the various techniques, spray drying remains the most widely adopted due to its cost-effectiveness and scalability, whereas methods like complex coacervation and spray chilling are gaining attention for specialized applications requiring high payloads and controlled release. Additionally, the utilization of fruit and vegetable processing wastes for developing value-added encapsulated products holds great promise in reducing environmental pollution and promoting sustainable food processing practices. Despite its vast potential, encapsulation technology still faces challenges such as limited polymer stability under varying pH and ionic conditions, thermal sensitivity of probiotic strains, and optimization of process parameters for specific applications. Future research should focus on developing novel wall materials, optimizing process conditions, and integrating green technologies to enhance efficiency and expand the applications of encapsulation in functional and therapeutic foods.

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