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Role of Crop Rotation in Weed Management

Mukesh Vishnoi, Harish Shenoy, Rani Jayadurga Nayak, Sanya Singh Dhillon and A. Meena

Abstract

Crop rotation is a core cultural tactic for weed management. It alters selection pressures, interrupts weed life cycles, and reduces reliance on herbicides. This article reviews mechanisms, design principles, and evidence across agroecosystems. It synthesises results from long-term experiments, meta-analyses, and regional case studies. Rotation changes disturbance timing, resource availability, and mortality factors. It reduces weed density, shifts communities toward more manageable species, and slows the development of herbicide resistance. Diversified rotations often maintain or increase yield with equal or higher profitability while reducing herbicide inputs. Evidence from temperate grain systems and rice-wheat systems supports these outcomes. The article outlines practical rotation designs, integration with cover crops and tillage, and economic and environmental effects. It concludes with a discussion of research needs and clear recommendations for practice.

Introduction

Weed management relies on a set of cultural, mechanical, biological, and chemical tools. Crop rotation sits at the centre of this set. Rotation modifies the timing and type of disturbance. It changes the pattern of resources that weeds can exploit. It also widens the menu of effective tactics. These changes reduce weed pressure and spread risk across seasons and tools (Liebman and Dyck, 1993; Swanton and Weise, 1991).

Herbicide-centric programs improved short-term control but imposed a narrow and stable selection pressure. This led to resistance and shifts to hard-to-control species in many regions (Mortensen *et al.*, 2012; Beckie, 2006). Rotation restores variation in selection. It creates windows for non-chemical suppression. It supports lower herbicide use without yield penalties when well designed (Davis *et al.*, 2012; Weisberger *et al.*, 2019). This article explains how rotation suppresses weeds. It details design rules

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and gives examples. It covers the effects on resistance, seed banks, economics and environmental outcomes. It targets researchers, advisors, and farmers who need clear, tested guidance.

Mechanisms linking rotation and weed dynamics: Disturbance regimes. Each crop brings a unique sequence of tillage, planting dates, canopy closure, and harvest. Changing crops alters the timing and intensity of disturbances. This breaks the match between weed life cycles and predictable management calendars (Liebman and Dyck, 1993). Spring cereals suppress early spring annuals through a dense early canopy. Perennial forages impose long periods of shading and frequent mowing, which kill annuals and deplete seed banks (Anderson, 2005). Resource pulses. Rotations alter the timing and availability of resources. They alter the form and placement of nitrogen, soil moisture use, and light interception. This reduces the resource niches that favoured species exploit. It weakens positive feedbacks that allow a few species to dominate (Smith *et al*., 2010; Moonen and Barberi, 2008). Mortality factors. Rotations diversify mortality. They allow different control tactics across years. These include stale seedbeds, cultivation, grazing, mowing, and distinct herbicide modes of action. Multiple independent mortality events reduce survival. They also reduce selection for any single trait (Norsworthy *et al*., 2012; Harker and O'Donovan, 2013). These drivers act on key demographic processes. Germination timing, seedling survival, fecundity and seedbank persistence all respond to rotation. Effective rotations reduce successful recruitment. They restrict seed rain. They speed seedbank decline (Cardina *et al*., 2002; Nichols *et al*., 2015).

Principles for designing rotations that suppress weeds: Use contrasting crops in sequence. Pair crops that differ in planting date, life cycle length, canopy dynamics, and harvest date. Follow a warm-season row crop with a cool-season cereal. Insert a multi-year forage where feasible. Contrast creates temporal mismatches for weed cohorts (Liebman and Dyck, 1993; Anderson, 2005). Diversify disturbance. Vary tillage intensity and timing across years. Include at least one year with early ground cover and one with late ground cover. Schedule at least one strong non-chemical mortality event within each two-year window. Examples include mowing in alfalfa or interrow cultivation in row crops (Harker and O'Donovan, 2013; Mortensen *et al*., 2012). Rotate herbicide modes of action within and across years. Never rely on one mode for consecutive selection windows. Plan mode sequences across the rotation rather than field by field. Mix or sequence with effective non-chemical tactics to cut selection intensity (Norsworthy *et al*., 2012; Beckie, 2006). Insert cover crops strategically. Use covers to occupy bare periods. Choose functional traits that suppress specific weed groups. Fast autumn biomass suppresses winter annuals. Spring-terminated covers delay early cohorts in soybean or maize (Ryan *et al*., 2010; Nichols *et al*., 2015). Protect the rotation from slippage. Set rotation rules at the farm level. Track compliance. Avoid last-minute changes that repeat

crop types or management windows. Slippage erodes the benefits of contrast and variation.

Evidence from temperate mechanised systems: Long-term Midwestern rotations. A twelve-year Iowa experiment compared a 2-year maize–soybean rotation to 3-year and 4-year rotations that added small grains and a forage phase. The diversified rotations used much less herbicide while maintaining or increasing yields and profitability. They reduced herbicide use and toxicity metrics, decreased weed pressure, and maintained yield stability across years with variable weather (Davis *et al*., 2012). Weed seed rain declined sharply during the forage phases. The small-grain year provided an early planting date and narrow rows that shaded summer annuals. Prairie and Great Plains systems. Rotations that inserted cool-season cereals into warm-season row crops reduced problematic summer annuals such as kochia and pigweeds. Perennial phases resulted in larger and faster declines in the seedbank. Mowing and harvest schedules increased the mortality of broadleaf annuals. Several studies reported lower densities and fewer herbicide applications over four to six-year cycles (Anderson, 2005; Blackshaw *et al*., 2001). Meta-analysis across temperate regions. A quantitative synthesis linked rotation diversification with lower weed biomass, reduced herbicide use, and stable yields. Systems that added at least one crop with a different planting window produced the most potent effects. Rotations that also included cover crops showed the most significant reduction in weed biomass (Weisberger *et al*., 2019). The meta-analysis highlighted consistent benefits across soil textures and climates, with larger gains under moderate fertility and moderate tillage. European arable systems. Rotations that alternated winter and spring crops reduced grass weeds adapted to continuous winter cereals. Spring crops disrupted autumn germination cohorts. Studies across the UK and continental Europe reported lower densities of Alopecurus myosuroides and other winter annual grasses under mixed rotations. Narrow-row spring cereals and undersown clovers increased shading and seed predation (Storkey *et al*., 2015; Moonen and Barberi, 2008).

Evidence from rice–wheat and smallholder systems: Alternate establishment methods. Rotating transplanted puddled rice with dry direct-seeded rice, or inserting a short pulse crop between rice and wheat, changes weed cohorts. It reduces the dominance of Echinochloa and Cyperus in back-to-back puddled systems. It also allows different herbicide modes and non-chemical tools such as stale seedbeds and light tillage before dry seeding (Chauhan and Johnson, 2010; Singh *et al.*, 2008). Introduce pulses or oilseeds. Adding mung beans or mustard between rice and wheat alters calendars and canopy dynamics. It creates a non-host window for grass weeds. Farmers report lower grassy weed pressure in wheat after a pulse break compared to wheat after rice. Trials have shown a reduction in the biomass of Phalaris minor and an improvement in wheat yields following a short-duration mungbean catch crop (Singh *et al.*, 2008).

Smallholder diversification. In low-input systems, rotation leverages hand weeding, grazing, and residue management. Including fodder or forage legumes allows for cutting or grazing events that remove seedheads before they shatter. This suppresses seed rain. Diversification increases year-round ground cover and reduces periods of bare ground. Studies show lower weed biomass and improved labour efficiency in diversified sequences compared to cereal monocultures (Moonen and Barberi, 2008; Nichols *et al.*, 2015).

Rotation and herbicide resistance: Lower selection intensity. Diversified rotations often need fewer herbicide applications. They also allow reduced rates of dependence on a single active. This reduces the likelihood that resistant individuals will dominate (Davis *et al.*, 2012; Weisberger *et al.*, 2019). Heterogeneous selection. Rotations enable alternate modes of action and non-chemical mortality. Weeds face a moving target. This reduces the advantage of any single resistance mechanism. It also slows the spread of metabolic resistance that crosses modes (Norsworthy *et al.*, 2012; Beckie, 2006). Seedbank dilution. Rotations that cut seed rain and increase seed mortality shrink the pool in which resistance can arise and persist. Smaller, younger seedbanks slow the fixation of resistance alleles. This makes other tactics more effective (Cardina *et al.*, 2002; Mortensen *et al.*, 2012). Programs that rotate crops yet repeat the same herbicide mode each spring do not achieve these benefits. The crop must change the management calendar and the modes used. Planning across years is essential.

Weed seedbank and community responses: Size and decay. Rotations with forage years often reduce seedbanks by half or more within two to three years. Mowing and long shading reduce seed rain. Seed predators gain cover and food in diverse canopies. Seed decay increases under moist and biologically active soils associated with multi-species rotations (Cardina *et al.*, 2002; Nichols *et al.*, 2015). Composition. Rotation tends to replace one or two dominant species with a more even mix. This increases management leverage. A diverse community with low densities is easier to suppress with general tactics such as canopy shading and timely cultivation. Studies report declines in specialist species adapted to fixed calendars, and increases in less competitive, opportunistic species that set fewer seeds under crop competition (Légère *et al.*, 2005; Moonen and Barberi, 2008). Emergence timing. Contrasting crop calendars disrupt synchronised emergence. Early spring crops target early cohorts. Late-spring crops with pre-plant stale seedbeds target early flushes before planting. Autumn crops shade winter annuals. This reduces overlap between the windows of weed emergence and crop vulnerability.

Integration with cover crops, tillage, and fertility: Cover crops. Dense, timely cover crops add a suppressive layer. Cereal rye before soybean can reduce early-season weed biomass and herbicide needs. Legume covers before maize add nitrogen and speed canopy closure. Mixtures balance biomass and

N supply. Termination timing must align with soil moisture and planting date targets (Ryan *et al*., 2010; Nichols *et a*l., 2015). Tillage. Vary tillage across the rotation. Occasional inversion tillage can reset shallow seedbanks dominated by small-seeded annuals. Reduced tillage protects soil and supports predator communities. Strategic alternation prevents the selection of surface-germinating species every year (Nichols *et al*., 2015; Mortensen *et al.*, 2012). Fertility and residue. Place nitrogen near crop rows to reduce interception by weeds. Manage residues to retain surface mulch in row crops. Residue slows light cues for weed germination and cools the soil surface. It also protects soil biota that aid seed decay (Moonen and Barberi, 2008; Smith *et al.*, 2010). Herbicides. Use herbicides within the rotation plan, not as stand-alone solutions. Choose modes that fit target species and crop safety. Sequence with non-chemical tactics. Keep rates and timings effective to avoid low-dose selection.

Economic performance and risk: Input savings. Diversified rotations often cut herbicide costs and the number of applications. Some rotations reduce fertiliser needs through legume phases. Savings can offset added operations such as cover crop seeding or mechanical control (Davis *et al*., 2012; Harker and O'Donovan, 2013). Yields and stability. Many diversified rotations maintain or improve yield averages. They also increase stability across variable seasons. Stability arises from better soil structure, improved nutrient cycling, and reduced weed pressure at critical growth stages (Davis *et al*., 2012; Weisberger *et al*., 2019). Labour and machinery. Rotations can smooth labour demand across seasons. They can also require new equipment or attachments. Planning and logistics are essential. Farmers often adopt stepwise changes, adding one new crop or cover at a time. Market access. Profitable rotation crops need reliable markets. Small grains, forages, pulses, or oilseeds can expand income streams. Contracting and local processing capacity can be constraints. Policy and procurement can reduce these barriers. Risk. Rotation spreads agronomic and market risks. It prevents lock-in to a single pest complex or commodity price. Lower resistance risk protects long-term control options and reduces the chance of sudden cost spikes (Mortensen *et al*., 2012; Beckie, 2006).

Environmental co-benefits and trade-offs: Soil health. Diversified rotations increase residue quality and quantity. They enhance aggregation and water infiltration. They increase microbial activity. These changes support weed seed decay and crop vigour that improves competitive suppression (Moonen and Barberi, 2008; Nichols *et al*., 2015). Biodiversity and natural enemies. Rotations and covers support arthropod and vertebrate seed predators. They also support pollinators and beneficial insects. These communities provide additional weed and pest suppression services (Storkey *et al.*, 2015; Moonen and Barberi, 2008). Water quality. Lower herbicide use and better soil structure reduce off-field losses. Mixed rotations reduce the frequency of high-risk application windows.

Trade-offs. Some rotation crops can host weeds that are hard to control in subsequent crops. Residue can hinder planting if not managed. Occasional inversion tillage can increase erosion risk on vulnerable soils. These trade-offs require field-level planning and adaptive management.

Conclusion

Crop rotation is a powerful and practical weed management tool. It works by varying disturbance timing, resource availability, and mortality factors across years. These changes break weed life cycles, limit seed rain, and speed seedbank decline. They also reduce herbicide dependence and slow the development of resistance. The strongest designs alternate crops with calendars of contrasting colours. They integrate at least one non-chemical mortality event every two years. They rotate herbicide modes across and within years. They insert cover crops to occupy bare periods. Long-term experiments and meta-analyses consistently yield similar outcomes. Diversified rotations often reduce herbicide use and weed biomass while maintaining or increasing yields and profits. Evidence spans temperate mechanised systems and rice–wheat systems. Seed banks shrink and communities shift toward more manageable species. Environmental co-benefits include improved soil structure, higher biodiversity, and reduced off-field losses. Adoption requires planning, logistics, and market access for added crops. Stepwise implementation works. Start by inserting a small grain or a short-duration legume. Add a cover crop to fill bare periods. Plan herbicide modes across the whole rotation. Track seedbank trends and seed rain to verify progress. Protect the rotation from slippage.

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Bamboo Tissue Culture: A Revolutionary Technology for Sustainable Agriculture

Pranali M. Bagde and Girish U. Chopade

Introduction

Bamboo, often called "green gold," represents one of nature's most remarkable plants with growth rates reaching up to one meter per day. Despite its immense potential for sustainable development, traditional bamboo propagation faces significant challenges including irregular flowering cycles spanning 30-120 years, low seed viability, and insufficient multiplication rates to meet industrial demands. Tissue culture technology emerges as a revolutionary solution, enabling mass production of genetically uniform, disease-free bamboo plants under controlled laboratory conditions. This biotechnology transforms bamboo cultivation from subsistence farming to industrial-scale production, positioning bamboo as a viable alternative for climate change mitigation and rural economic development.

The Science behind Bamboo Micropropagation

Bamboo tissue culture is founded on the principle of totipotency, the ability of a single plant cell to regenerate into a complete organism when provided with suitable conditions. In practice, the process begins with nodal explants containing meristematic tissues, as these actively dividing cells have a high capacity to initiate shoot development. Under sterile conditions, these explants are cultured on a nutrient medium supplemented with carefully balanced plant growth regulators. Cytokinins such as BAP promote axillary bud break and shoot proliferation, while auxins like NAA or IBA guide subsequent root formation. By adjusting hormone concentrations and culture conditions, researchers achieve consistent regeneration of uniform, disease-free plantlets suitable for large-scale bamboo propagation.

Table 1: Bamboo tissue culture protocol stages with duration and success rates

Stage	Process	Duration	Success Rate
Surface Sterilization	Multi-step chemical treatment	30-45 min	87-90%
Culture Initiation	MS medium + BAP (3-4 mg L^{-1})	8-15 days	83%
Shoot Multiplication	BAP + Kinetin treatment	4-6 weeks	Multiple shoots
Root Induction	NAA/IBA (2-4 mg L^{-1})	3-4 weeks	70-85%
Hardening	Greenhouse acclimatization	4-6 weeks	80-90%
Field Transfer	Plantation establishment	After 6 months	85-95%

Commercial Success and Economic Benefits

Commercial tissue culture facilities now achieve remarkable production capacities exceeding 6 million plants annually. Economic analyses from

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Indian states demonstrate bamboo cultivation's attractiveness with benefit-cost ratios of 2.65 and net present values reaching ₹2, 31,604 ha^{-1} annually. Initial establishment costs include planting material (₹20-30 $seedling^{-1}$), but bamboo's perennial nature generates sustained income streams for decades with mature yields of 10-15 t ha^{-1}.

Environmental Impact and Sustainability

Bamboo's exceptional carbon sequestration capacity up to 12 tonnes of CO_2 ha^{-1} annually-outperforms many traditional tree plantations thanks to rapid growth, high biomass, and efficient photosynthesis. Carbon is stored in above-ground biomass (≈11.9 tonnes CO_2 ha^{-1}) as well as in roots and soil organic matter, while harvested bamboo products used in construction extend storage over decades, maximizing climate benefits. Beyond climate mitigation, bamboo's fibrous root systems stabilize soils, prevent erosion, and reduce landslide risks in fragile landscapes. Its stands enhance water infiltration, recharge groundwater, and maintain watershed balance, even thriving on marginal lands through efficient water use. In addition, dense bamboo ecosystems support rich biodiversity, providing habitats for diverse species-from insects and small mammals to larger animals like the giant panda-making bamboo vital for restoration and conservation programs.

Current Applications in India

India's National Bamboo Mission supports tissue culture laboratories producing millions of plantlets annually across states like Assam, Karnataka and Chhattisgarh. Commercial species including *Bambusa balcooa* and *Dendrocalamus strictus* demonstrate excellent adaptation to micropropagation protocols. The National Certification System for Tissue Culture Plants (NCS-TCP) ensures quality standards, with facilities maintaining minimum production capacities of 5,00,000 plants annually.

Challenges and Solutions

Despite remarkable progress, bamboo tissue culture faces technical challenges including phenolic browning and contamination control. Advanced solutions utilize antioxidant supplementation with ascorbic acid and polyvinylpyrrolidone (PVP), activated charcoal treatment, and sophisticated bioreactor systems. Automated handling systems with High-Efficiency Particulate Air (HEPA) filtration minimize contamination risks while maintaining cost-effectiveness for commercial production.

Conclusion

Bamboo tissue culture has evolved from experimental biotechnology to a mature commercial practice addressing multiple global challenges simultaneously. With technical protocols achieving 83% success rates, economic returns exceeding traditional crops, and environmental benefits including superior carbon sequestration, this technology positions bamboo as a cornerstone of sustainable agriculture. Government support through initiatives like India's National Bamboo Mission, combined with private sector investment, creates unprecedented opportunities for farmers and enviro-

nmental conservation. The convergence of technical maturity, economic viability, and environmental necessity establishes bamboo tissue culture as a transformative solution for sustainable development in the 21st century.

Abbreviations: MS = Murashige and Skoog medium; BAP = Benzylaminopurine; NAA = Naphthaleneacetic acid; IBA = Indole butyric acid; PVP = Polyvinylpyrrolidone; HEPA = High-Efficiency Particulate Air; NCS-TCP = National Certification System for Tissue Culture Plants

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Pulses as a Key Component in Sustainable Agricultural Systems

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Abstract

Pulses, including lentils, chickpeas, beans, and peas, are increasingly recognised as central to sustainable agriculture and food security. These crops provide protein-rich food, improve soil fertility through biological nitrogen fixation, and enhance resilience in diversified cropping systems. Global initiatives highlight the importance of pulses in addressing nutritional deficiencies, reducing dependence on synthetic fertilisers, and supporting climate change adaptation. In India, which accounts for nearly one-quarter of global pulse production, pulses contribute both to farm income and dietary improvement. However, their cultivation faces persistent challenges, including low productivity, water stress, and limited policy support relative to cereals. This review examines the ecological, nutritional, and socio-economic significance of pulses, assesses their role in reducing the environmental footprint of agriculture, and identifies strategies for their integration into future farming systems. Advancing pulse production will require coordinated efforts in research, technology dissemination, and market incentives.

Introduction

Sustainable agriculture requires balancing food production with environmental conservation to foster long-term resilience. Pulses offer multiple benefits within this framework. As some of the most ancient cultivated crops, pulses are adapted to diverse agroclimatic conditions and have been integral to human diets for centuries.

Their low environmental footprint and high nutritional density make them essential for achieving Sustainable Development Goals, particularly those related to zero hunger, good health, and climate action. The United Nations designated 2016 as the International Year of Pulses to emphasise their importance in global food systems. Nevertheless, the role of pulses remains underexplored in policy and

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practice compared with cereals such as rice, wheat, and maize.

Ecological Benefits of Pulses

Nitrogen fixation and soil fertility: Pulses host symbiotic rhizobia that fix atmospheric nitrogen, reducing reliance on synthetic fertilisers. Estimates suggest that pulses can fix 50-200 kg of nitrogen per hectare annually, depending on the species and environmental conditions (Voisin et al., 2020). This process not only lowers input costs but also improves soil structure and microbial diversity. Residual nitrogen from pulse crops benefits subsequent cereals, enhancing overall system productivity.

Crop diversification and agroecological resilience : Intercropping pulses with cereals or oilseeds increases resource use efficiency and stabilises yields under variable climatic conditions. Research in semi-arid tropics demonstrates that pigeon pea intercropped with sorghum or millet improves system resilience by reducing pest incidence and diversifying income sources (Rao *et al.*, 2019). Pulses also function as break crops in monoculture systems, thereby reducing disease pressure.

Water and carbon efficiency: Pulses generally require less water than cereals. For instance, chickpea uses approximately 3,000 to 4,000 litres of water per kilogram of grain, compared with 6,000 to 8,000 litres for rice (FAO, 2019). The relatively small carbon footprint of pulses results from reduced fertiliser use and greater contributions to soil organic matter. Incorporating pulses into crop rotations can mitigate greenhouse gas emissions and enhance soil carbon sequestration.

Nutritional and Health Significance

Role in addressing protein-energy malnutrition: Pulses contain 20 to 25 percent protein, making them a cost-effective alternative to animal protein. In India, where per capita protein intake frequently falls below global recommendations, pulses are a critical dietary component. Consuming pulses regularly, especially in combination with whole grains such as cereals, supports a balanced amino acid intake.

Micronutrient contribution: Beyond protein, pulses provide iron, zinc, folate, and dietary fibre. Iron-deficiency anaemia, affecting nearly 30% of Indian women (NFHS-5, 2021), can be partly addressed through greater pulse consumption. Their low glycaemic index also makes them suitable for diabetes management, a condition that is rising globally.

Dietary shifts and public health: Shifting dietary patterns toward plant-based proteins is increasingly recognised for both health and environmental benefits. The EAT-Lancet Commission (2019) recommends higher pulse consumption to achieve sustainable diet targets. Incorporating pulses into school meals and public distribution systems can enhance nutrition security.

Pulses in Indian Agriculture

Production trends and regional distribution: India produces approximately 25 to 27 million tonnes of pulses annually, representing 23 to 25 percent of global output (GoI, 2023). Major pulse crops include chickpeas, pigeon peas, lentils, and mung beans.

Madhya Pradesh, Maharashtra, and Rajasthan are the leading states, collectively contributing over 60 percent of national production. Despite this significant output, India remains a net importer due to high domestic demand.

Role in smallholder livelihoods: Most pulse growers are smallholders operating in rainfed regions. Pulses mitigate risk through low input requirements and resilience to drought. Residues from pulse crops are used as fodder, supporting mixed farming systems that are essential for rural livelihoods.

Policy and institutional frameworks: Government initiatives such as the National Food Security Mission and minimum support price schemes have sought to increase pulse production. However, investment and procurement support remain limited compared with rice and wheat. Strengthening value chains and improving seed distribution are critical policy priorities.

Global Perspective and Trade Dimensions

Major producing and consuming countries: In addition to India, Canada, Myanmar, Australia, and Turkey are major producers of pulses. Canada is the leading exporter of lentils, while Myanmar dominates the black gram trade. Demand for pulses is increasing in Africa and South Asia due to population growth and shifting dietary patterns.

International trade and self-sufficiency challenges: India imports 3 to 5 million tonnes of pulses annually to address domestic shortfalls, particularly in lentils and peas. Price volatility in international markets affects farmer incentives. Long-term strategies for achieving self-sufficiency include increasing yields and reducing post-harvest losses.

Lessons from global initiatives: Countries such as Ethiopia have increased chickpea exports by utilising farmer cooperatives and improved seed systems. Adopting similar models could support Indian smallholders by facilitating access to global markets.

Barriers and Challenges in Pulse Cultivation

Biotic and abiotic stresses: Pulse crops are susceptible to pests, including pod borers, and diseases such as Fusarium wilt. Climate-related stresses, such as terminal drought and heat, significantly reduce yields.

Yield gaps and technological constraints: Average pulse yields in India remain below global levels, typically ranging from 800 to 900 kilograms per hectare, compared with 1,800 to 2,000 kilograms in developed countries (FAO, 2022). Limited access to quality seed, irrigation, and mechanisation exacerbates these yield gaps.

Market and price volatility: Pulses are subject to wide seasonal price fluctuations, which discourage farmers from expanding cultivation. Inadequate procurement infrastructure further undermines income stability.

Future Pathways for Mainstreaming

Pulses: The development of climate-resilient pulse varieties with traits such as drought tolerance, early maturity, and pest resistance is essential. Advances in genomics and CRISPR-based breeding can accelerate varietal development (Varshney *et al*.,

2021).

Agroecological intensification: Integrating pulses into agroforestry, conservation agriculture, and organic farming enhances system sustainability. Technologies such as precision seeding and microbial inoculants can improve yields while preserving ecological integrity.

Policy incentives and consumer awareness: Expanding MSP coverage, strengthening extension services, and promoting dietary awareness campaigns can raise demand and farmer adoption. Linking pulses with climate finance and carbon credit schemes offers new opportunities for incentivising cultivation.

Conclusion

Pulses are pivotal for achieving sustainable agricultural systems. They enrich soils, reduce fertiliser dependence, and contribute to climate resilience. As nutrient-rich foods, they address malnutrition and support public health. In India and globally, pulses sustain smallholder incomes and reduce environmental footprints. However, challenges of low productivity, pest vulnerability, and weak markets constrain their potential. Future strategies must focus on genetic improvement, agroecological practices, and strong policy support. Promoting pulses requires integrated action across production, consumption, and trade domains. By placing pulses at the centre of agricultural and dietary planning, nations can advance food security, ecological balance, and human well-being.

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Grafting in Papaya: A Successful Propagation Technique

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Abstract

Papaya (*Carica papaya* L.) is a nutritionally rich and economically significant tropical fruit crop. Despite its importance, papaya cultivation faces challenges such as dioecy, inconsistent seed propagation and environmental influence on sex expression. Various vegetative propagation methods used for propagation of papaya viz., grafting, cutting, budding, tissue culture etc. out of them grafting has emerged as a viable vegetative propagation technique to overcome these constraints, ensuring uniformity, improved plant vigor and extended economic lifespan. Among the various grafting methods, cleft grafting has demonstrated high success rates. The process involves intricate physiological and molecular mechanisms. These include callus formation, vascular regeneration and hormonal interactions that facilitate graft union success. Cytokinins and gibberellins play a crucial role in lateral shoot development, aiding scion production by mitigating apical dominance. Factor i.e. Season (winter) and age of rootstock (45-60 days) gave higher rate of success of grafts.

Introduction

Papaya (*Carica papaya* L.) is an important fruit crop of tropical and subtropical region of the world and also known as "Melon Tree." Papaya belongs to the genus *Carica* of the family Caricaceae. India is the leading country in world production of papaya. Papaya is commercially propagated by seeds. Papaya seedlings propagated from seed is hindered by problems because of the inherent heterozygosity, dioecious nature of the crop, large variation in fruit production, low and late fruiting, diminished fruit quality and polygamous nature. Due to high cost of the seed of selected genotypes, some farmers use those seeds from open pollinated flowers of different generations (F_2, F_3 and F_4) and produce plants from those seeds that having low vigour and large variability in fruit quality.

In India, total area under papaya cultivation is around 1.5 lakh per ha, production is 60.63 million ton with the productivity of 40.42 MT ha^{-1}. So, according to cultivated area such huge planting material approx. 340 million plants required for

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cultivation. For these quantity of plants approx. 6000 kg of papaya seeds required in India. Cost of popular hybrid papaya seeds approx. 2.00-4.00 lakh per kg. It is well known India 100 percent depends on popular varieties of papaya on foreign countries. So, this method help to save more than 1800 million Rupees. Vegetative method for propagation (cutting, grafting, budding and tissue culture) save such large amount of money as well as provide disease free quality planting material with employment to youth. Patch budding during August-September month found suitable in papaya plant.

Grafting in papaya has several benefits like increase productivity, phytosanetary, protect from biotic and abiotic stress and sexing purposes. Based on that research work experiment on various aspect of grafting was conducted at Fruit Research Station (ICAR-AICRP on Fruits), NAU, Gandevi (Gujarat). Grafting could be used to improve fruiting and yield in papaya plants as well as to reduce the height of the varieties and hybrids of interest.

Advantages of grafting

- ✓ 100 % female plants produce in dioecious varieties
- ✓ Reduce the requirement of costly seeds
- ✓ Seedless variety also propagate by grafting
- ✓ 10-15 scion sticks should be taken in every 15-20 days interval from 6 month old mother plant
- ✓ Reuse the rootstock for grafting, if fail the graft.
- ✓ The grafted papaya trees bear fruits much lower as compared to seedling plants
- ✓ Earlier and dwarf in stature with longer economic life cycle
- ✓ Grafted plants having higher stem girth which anchored the plant and protect to plants under higher weight (Heavy Fruiting) condition.

Limitations

- ✓ Skilled person required for graft preparation.
- ✓ Grafted plants required extra 40-50 days for graft preparation as compared to seedling.
- ✓ Low tunnel or insect proof net house required for growing of mother plants

Mother Block for Scion preparation

The healthy and disease free 45-60 days old seedlings planted in mother block under insect proof net house for better growth and virus free planting material. During initiation of flowering and confirmation of sex of plant, then after removal of the terminal growing points with retention of remaining leaves. Which is promote to development of the lateral buds. Repeatedly removal of strongly developing, thick growing points. That's is promote to development of many thinner, lateral shoots, lower on the stems, that are used as scion and ideal for vegetative propagation. Parent plants produce many side shoots over the years, as a result of chemical treatment or simply by repeated topping of large side stems. By leaving a stub when a cutting is taken, more small side shoots develop. A combination of growth hormones and different aged seedlings was used to induce lateral shoots on the mother plants to utilize them as scions for graft preparation. Spraying BA @ 100 ppm or cytokinin 150 ppm + GA_3 @ 250 ppm on mother plants could produce more graftable

size shoots. For grafting scion length 8-10 cm and diameter 3-5 mm with or without leaves as well as age of rootstock 45-60 days old with same diameter must be required.

Method of grafting

Papaya grafting generally agreed that the cleft grafting and tongue approach methods are the most successful techniques. The union of scion and stock depend upon proliferation of callus tissue between graft components followed by the union of vascular tissues.

Cleft Grafting: Select healthy, disease free and uniform size rootstock seedling have 2.50 to 4.50 mm girth. Decapitate the terminal portion with a sharp and sterile knife leaving 10 cm at the base. The soft wood of rootstock was split vertically in the form of cleft to a length of 3-4 cm downward with a sharp knife. The cleft looks like a fork or letter "V". Care should be taken while selecting the scion material to match the girth of the stock. Wedge shape cut has been given for the scion. Insert the scion into the cleft cut of the rootstock. Ensure that the scion and rootstock was in close contact. Tie the joint union firmly with 1.5 cm wide and 40 cm long stretchable transparent polythene strip of 100 gauges. Cover the joint union with polythene sleeves to avoid desiccation of the scion and keep it in a polytunnel. After sprouting, the grafts have been transferred to a shade net house for one month hardening before transplanting.

Factors affecting to Graft success: These are the factors to influence to compatibility of grafts *viz.* plant species, method of grafting, environmental conditions (Temperature, Moisture and Light) and growth activity of the rootstock. However, several factors are influence to success of grafts *viz*., age of root stock and scion, season, compatibility, vigour, disease and pest as well as health of the plants and post grafting handling involved.

Effect of season: It is evident from the data presented in Table 1, there significant effect on minimum days taken for sprouting of grafts (7.98 days) was recorded in winter season with 22-25^{0}C. The ideal weather at the time, scion should have lot of carbohydrates and other biochemical components. Moreover, the close contact between the wounded tissues of the rootstock and the scion leads to dedifferentiation of the parenchymatous cells into calli and further bridges the communication linkages between the roots and the shoot system. Later, differentiation of the vascular cambium leads to the formation of a new shoot system from an earlier scion bud. In Table 1 data showed maximum survival (90.19%) in winter season (T_1) at 60 days after grafting. It might be due to favourable climatic condition during active growth stage of the papaya plant and prevailing excellent environment condition (mild winter) which enhance the graft union process by quick cell division following rapid callus formation, intermingling of vascular bundle of both rootstock and mother stock and ultimately giving good survival percentage.

Effect of Rootstock Age: The data presented in Table 1 clearly showed that 45 days old rootstock

Table 1: Effect of season and rootstock age on papaya grafts

Treatments	Days taken for sprouting	Success of grafts (%)		Survival of grafts (%)
		30 DAG	45 DAG	60 DAG
Effect of season				
T_1	7.98	93.89	86.67	90.19
T_2	8.89	91.11	83.89	88.36
T_3	11.42	73.89	57.22	61.66
S.Em. ±	0.126	1.470	1.361	1.401
C.D. at 5 %	0.378	4.401	4.075	4.196
Effect of rootstock age				
D_1	8.91	93.33	82.22	85.43
D_2	9.40	85.00	76.67	81.51
D_3	9.98	80.56	68.89	73.27
S.Em. ±	0.126	1.470	1.361	1.401
C.D. at 5 %	0.378	4.401	4.075	4.196
Interaction effect				
S.Em. ±	0.219	2.546	2.357	2.427
C.D. at 5 %	0.655	7.623	7.057	7.268
CV %	4.02	5.11	5.38	5.25

Note: Season (T_1-Winter, T_2-Summer and T_3- Mansoon) and **Age of rootstock** ($D_{1\ to\ 3}$-30, 45 and 60 days old)

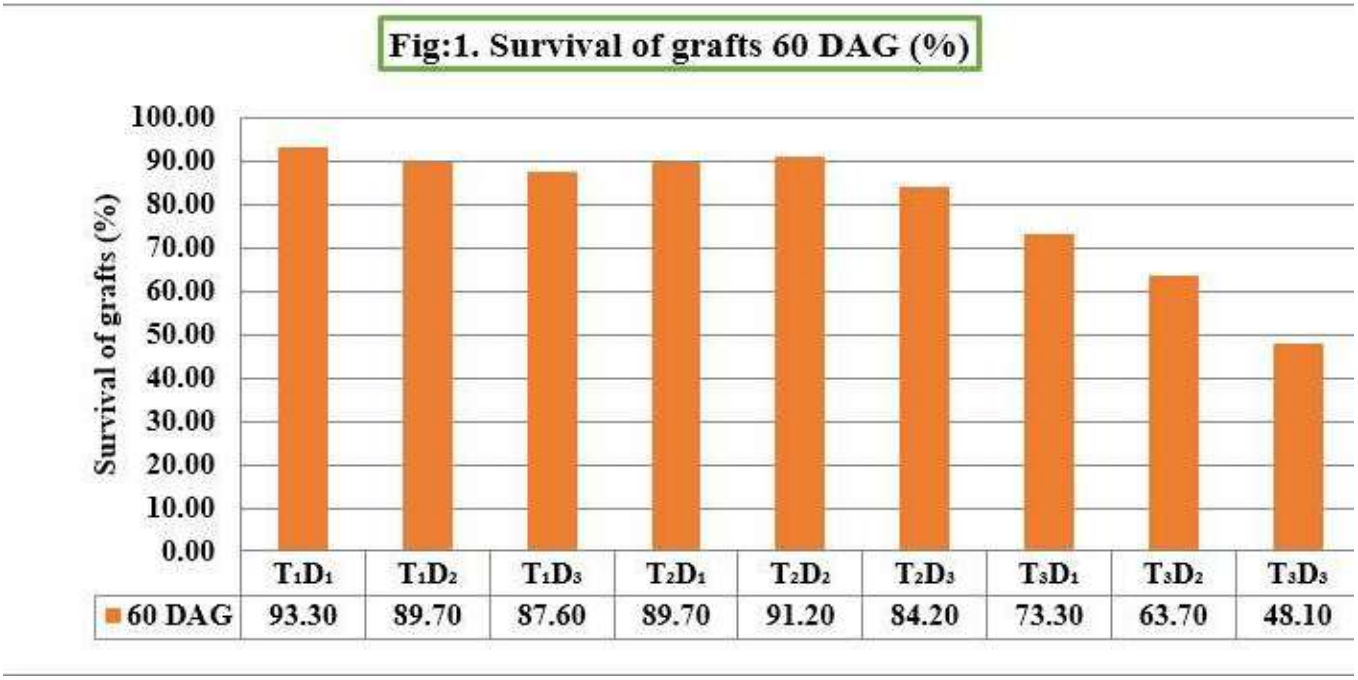
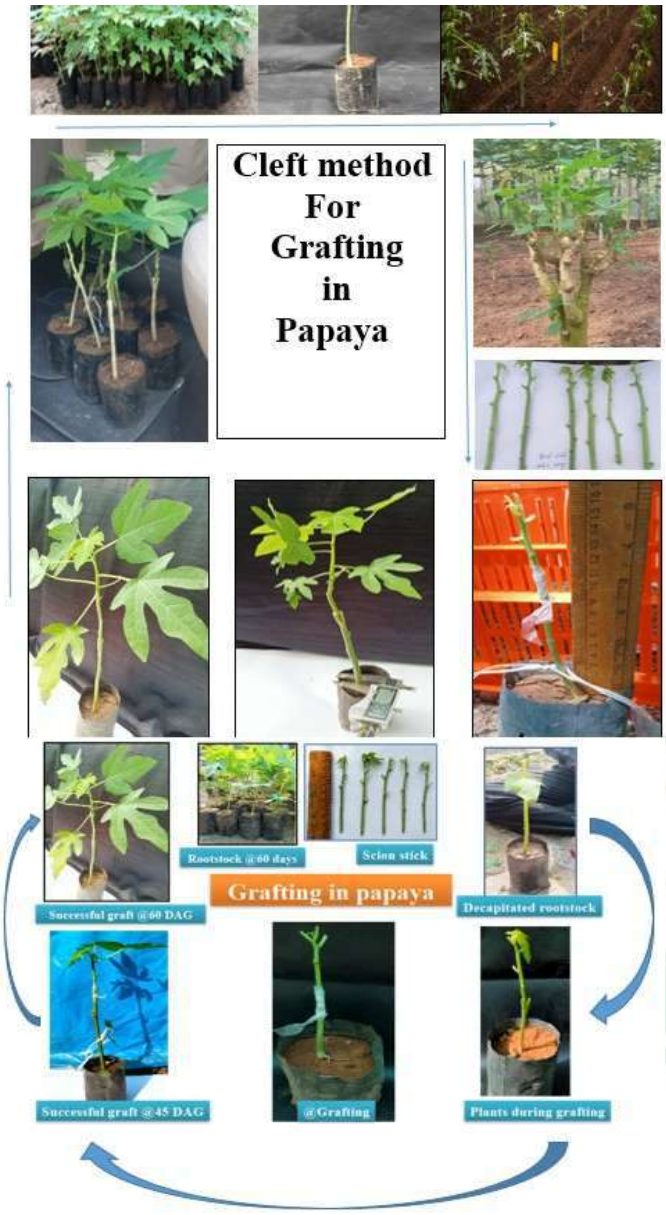


Fig. 1: Effect of season and rootstock age on Survival of papaya grafts

take minimum days for sprouting of grafts (8.91) was recorded. It may be due to younger rootstock has a higher meristematic activity. Which, leads to high meristematic division that make a rapid growth in callus formation. Moreover, papaya has a scattered or hollow stem shows that longitudinal section of 3-month-old papaya stem showing hollow pith cavity and 1-year-old papaya stem showing complete pith cavity. That's shows that the papaya plants in old aged the possibility of grafting or any chances of any vegetative propagation is reduced due the formation of pith cavity. During initial stage the pith cavity are not formed so young rootstock formed quick healing of graft as compared to old rootstock.



Conclusion

Vegetative propagation, especially through grafting, holds transformative potential for improving papaya cultivation. Grafting enables the production of true-to-type plants, reduces variability and eliminates the challenge of managing male and female plants in dioecious cultivars. The plants propagated by cleft grafting in winter season (February with 22-25^{0}C) on 45 days old rootstock resulted minimum days required for sprouting of graft and highest survival of papaya grafts. In the future, papaya grafting could serve as a reliable solution to major cultivation challenges offering uniformity, major diseases and virus resistance and adaptability to climate variability by the best suitable rootstock and scion varieties. Therefore, the wider adoption and commercialization of grafting practices should be prioritized to ensure sustainable and profitable papaya production system.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT to use to improve language and readability, with caution. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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Protected Cultivation of Vegetables and Flowers: Greenhouses and Polyhouses

Dinesh Kumar Meena, Sanjay Kumar, Sunil Kumar Rawat, Diksha Sangh Mitra and Ratan Kumar Pal

Introduction

Protected cultivation refers to growing crops under controlled or semi-controlled environments such as greenhouses, polyhouses, shade nets and tunnels, where temperature, humidity and light can be regulated. This technology ensures higher yields, better quality and year-round production, irrespective of external climatic conditions. It has emerged as a sustainable solution to address challenges like climate variability, shrinking arable land and rising consumer demand for safe, high-value vegetables and flowers (FAO, 2013). Vegetables such as tomato, cucumber, capsicum and leafy greens and flowers like rose, gerbera, chrysanthemum and carnation are widely cultivated under protected systems due to their high market value and export potential (Choudhary *et al*., 2019).

Types of Protected Structures

Greenhouses: Greenhouses are framed structures covered with transparent cladding materials such as glass, polycarbonate sheets or UV-stabilized polyethylene. They allow for maximum light penetration while providing protection from wind, rain and extreme temperatures. High-tech greenhouses may include automated systems for irrigation, fertigation, temperature and CO_2 control, enabling precision crop management (Kumar *et al*., 2021).

Polyhouses: Polyhouses are simplified structures covered with polyethylene film, often naturally ventilated through side and ridge vents. They are more affordable and suitable for small and medium farmers. While they lack sophisticated climate-control systems, polyhouses still enhance crop yield, quality and market value compared to open-field conditions (Reddy and Reddy, 2022).

Structural Features

The effectiveness of greenhouses and polyhouses depends largely on design and materials used.

Frame: GI pipes, steel, aluminium or bamboo.

Cladding: Glass or polyethylene film (200-micron UV-stabilized).

Ventilation: Side vents, insect-proof nets and roof vents.

Cooling/Heating: Forgers, fans, evaporative cooling pads, heaters.

Shading/Screening: Shade nets or thermal screens to regulate light and temperature.

Irrigation/Fertigation: Drip systems with automated nutrient supply.

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Well-designed structures ensure energy efficiency, reduce disease incidence and provide optimal growing conditions (Singh *et al*., 2018).

Environmental Control in Protected Cultivation

Temperature and Humidity: Vegetables like tomato perform best at 18-28 °C, while gerbera and rose flowers require 20-25 °C with 60-70% RH. Proper ventilation and fogging help maintain suitable microclimate (Yan *et al*., 2024).

Light Management: Polyethylene or polycarbonate sheets regulate light intensity. Shade nets (35-75%) are used in summer to prevent scorching, while supplemental lighting (LEDs) supports off-season flowering.

CO_2 Enrichment: Enrichment up to 800-1000 ppm can increase yields of tomato, cucumber and lettuce by 20-30%. This is widely adopted in commercial greenhouses for maximizing photosynthesis (Singh *et al.,* 2020).

Soil, Soilless and Hydroponic Systems

Soil-based beds: Traditional but prone to soil-borne diseases.

Soilless substrates: Cocopeat, perlite or rockwool improve root aeration and reduce pathogens.

Hydroponics: Nutrient film technique (NFT), deep water culture and aeroponics are increasingly used for lettuce, cucumber and cut flowers, providing high yields and clean produce (Farvardin *et al*., 2024).

Irrigation and Fertigation

Protected cultivation relies on drip irrigation and fertigation systems for efficient input use.

- ✓ Saves up to 50% water compared to open-field farming.
- ✓ Delivers nutrients precisely at root zone.
- ✓ Allows automation and recycling in hydroponics.

Closed-loop fertigation systems reduce nutrient leaching and environmental impact (Nair *et al.,* 2023).

Pest and Disease Management

While protected cultivation reduces many open-field pests, it also creates favourable microclimates for fungal and bacterial diseases.

Preventive measures: Insect-proof nets, double-door entry, sanitation and pathogen-free seedlings.

Monitoring tools: Sticky traps, pheromone traps and routine scouting.

Biological control: Predatory mites, parasiticides and bio-pesticides.

Climate management: Proper RH control to prevent Botrytis and powdery mildew (Dutta *et al.,* 2023).

Advantages of Protected Cultivation

High yield and quality: 2-5 times more than open field.

Year-round availability: Suitable for off-season production.

Efficient input use: Saves water, fertilizer and reduces pesticides.

Premium market value: Uniform, residue-free produce fetches higher price.

Employment generation: Skilled and unskilled labour in crop care, marketing and post-harvest.

Constraints

- ✓ High initial investment.

- ✓ Requires skilled management.
- ✓ Energy use for cooling/heating in extreme climates.
- ✓ Plastic waste disposal from cladding materials.
- ✓ Strong market linkages essential for profitability (NHB, 2022).

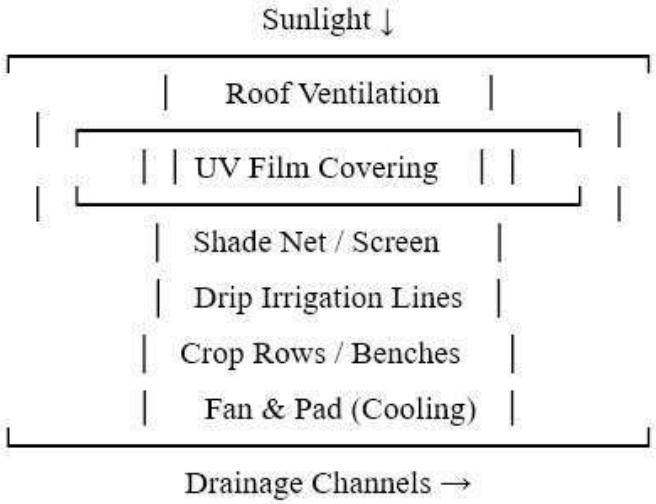
Future Prospects

Protected cultivation is expanding globally with focus on:

- ✓ Low-cost polyhouses for smallholders.
- ✓ IoT-based smart greenhouses with sensors and AI for climate monitoring.
- ✓ Renewable energy integration (solar panels and geothermal heating).
- ✓ Vertical farming and urban agriculture combining hydroponics and aeroponics.

With rising climate uncertainty, this technology is expected to play a major role in ensuring sustainable food security and higher farmer incomes.

Simple Diagram of Polyhouse



Conclusion

Protected cultivation of vegetables and flowers through greenhouses and polyhouses is a transformative approach that enhances yield, quality and sustainability. Despite challenges of cost and technical expertise, the benefits in terms of productivity, water efficiency and market value outweigh limitations. With innovations in low-cost structures, automation and renewable energy, protected cultivation can significantly contribute to food security, export growth and farmer prosperity.

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Greening the Concrete: Terrace Farming for Urban Living

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Abstract

India is the world's second most densely populated country, after China. As population is increasing geometrically, while food supply and energy for food production rise arithmetically. As the farm lands are being converted into residential areas, there results the lack of land for cultivation. However, if we examine the bright side of this circumstance, we find that every building has an empty rooftop. "Roof cultivation" or "terrace gardening" refers to the process of cultivating and maintaining vegetation on a roof. In other words, this rooftop farming is also known as urban agriculture. Therefore, Rooftop vegetable cultivation can meet food demand by supplying high-quality, hygienic produce, decreasing household expenditures on agricultural products, enhancing air quality, capturing carbon from the atmosphere, and mitigating the impacts of climate change.

Introduction

Terrace gardening is the art of growing plants, vegetables, or flowers on the terraces or roof-tops of buildings, especially in urban areas where ground space is limited. By integrating agric-ulture into cityscapes, terrace gardening promotes self-sufficiency, enhances biodiversity and improves the overall well-being of urban residents. In the face of current global challenges, including climate change and disrupted food supply chains, terrace gardening is gaining attention as a sustainable practice that can reshape the future of urban living. Fruit crops suitable for terrace gardening are Banana, Guava, Acid lime, Pomegranate, West Indian Cherry, Aonla, Pineapple, Strawberry, Litchi, Water melon, Custard apple and Papaya. Vegetable crops such as tomato, brinjal, chilli (transplanted vegetables) and Okra, amaranthus, Mint, Spinach, Curry leaf, cucurbitceo-us vegetables like bitter gourd, snake gourd, ridge gourd and bottle gourd (direct sown vegetables) are suited for growing in terrace gardens. Turmeric, Coriander and Fenugreek are the spice crops suited for terrace gardening. However, Vegetables are seen as the best option for growing on terraces as they have shorter life duration, gives output quickly and they are also widely regarded as "protective foods" because they contain vitamins, minerals, and profuse anti-oxidants. The minimum terraced area of 30 x 20 ft is sufficient for a family of 5 to 6 persons in order to grow required vegetables.

Site: The plants must get adequate sunlight for proper growth and yield. Atleast 6 hours of direct sunlight is needed. The site must be easier to meet out water requirements and the roofs are checked for drainage facilities.

Selection of Containers: The containers can be

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Grow bags, Earthen pots, Cement pots, broken cans or buckets, plastic containers, polythene bags, Coconut fibre boxes etc. Though pots of any size and shape can be used for growing vegetables but generally pots of 45, 60 and 75 cm diameter and 20 to 30 cm depth are most suitable. For fruits, 18-24 inches deep bags are suitable.

Tools Required: Hand hoe, Shovel, Rose can, Hose pipes, Hand sprayer. For Gourds which have climbing nature, supporting structures like poles or wires are needed.

Pot Mixture: It is a mixture of soil and compost. Generally, the top soil of loamy nature from a cultivated land mixed with equal amount of good compost will be sufficient to be used as pot mixture. In case the soil is clayey mix sand, clay and compost in 1:1:1 proportion. The more the compost the better for the mixture. The pot mixture may be enriched with bone meal, leaf mould or decomposed wood or barks or well decomposed animal dung or well decomposed coir pith.

Planting Material

As far as vegetables are taken, it can be planted as either seeds or Transplanting.

Direct sown vegetables: Cucurbitaceous vegetables, Egg plant, Spinach, Okra.

Transplanted vegetables: Tomato, Brinjal, Chilli. For the transplanted vegetables, protray can be employed for raising the nursery.

In fruits, Seeds can be directly sown or planted as seedlings purchased. Grafted plants also serves as the best source. Dwarf natured varieties are more preferred.

Method of Cultivation: For Direct Sowing, Seeds are sown at 5 cm / 1.5-2 inches depth and they should be watered immediately. In transplanting the vegetables, seedlings of 12-14 days old or at 3-4 leaf stage are transplanted to the containers. Avoid damaging the roots while transplanting. Immediate watering must be given.

After Care: Watering can be done based on the soil moisture. Weeding should be done regularly. Heavy dosage of fertilizers are not needed in terrace gardening, also it causes phytotoxicity. For organic nutrients management nutrients organic source like vermi wash, cow dung supply bio-fertilizer formations, household composed wash can be used a lot of organic nutrient source. A compost bin can be used to convert the kitchen waste to compost a part from the compost the liquid which oozes out of the compost can also be used. In addition, application of vermicompost, farmyard manure and decomposed coir pith is enough for the plant growth. Along with this Panchakavya or Fish aminoacid @15-20 ml per litre of water can be sprayed over the plants at 15 days interval, to increase the microbial population in the soil and to prevent plants from pest attacks. However, the inorganic fertilizers can be substituted by top dressing with Complex fertilizers @ 5-10 g promotes the plant growth and yield of vegetables. Spray Neem oil @ 3 ml litre^{-1} of water or Neem Seed

Kernel Extract @ 3% to avoid pest attacks. Avoid spraying of plant protection chemicals.

In case of Fruit plants, regular training and pruning is required. Staking should be done to avoid lodging problems.

Harvest

Vegetables	Days taken from sowing or transplanting
Tomato	90-115 days
Brinjal	60-80 days
Okra	50-65 days
Microgreens	10-12 days
Spinach	20-30 days
Cucurbits	50-70 days
Chilli	60-90 days

Avoid planting the same plant in the same pot and soil even after harvest. Once the season is over or plant growth is completed, the plants should be removed out from the pot. The soil is to be dumped in a place and broken free. Organic manures can be supplemented after 15 days, mixed and repotting needs to be done for next plant growth.

Advantages of Terrace Garden

- ✓ Provide fresh fruits and vegetables for consumption which are high in nutritive value.
- ✓ Provide fruits and vegetables free from toxic chemicals, as they are mostly grown in organic way.
- ✓ Help to save expenses on purchase of vegetables.
- ✓ Create awareness among children on dignity of labour.
- ✓ Better taste of home garden harvested vegetables than from the market purchased one.
- ✓ Contribute to environment by absorbing carbon dioxide and reduce the temperature.
- ✓ Minimize ecological imbalance in urban areas.
- ✓ Minimizes the need or demand of agricultural products.
- ✓ Gardening is a good practice of exercise and it connects one with nature.

Conclusion

Gardening on a terrace is more than just a hobby; it's a sustainable and satisfying way to get back to nature, especially in cities. It enables people to effectively utilise unused rooftop space, resulting in a decreased temperature, cleaner air, and easier access to fresh, organic vegetables. By growing herbs, fruits and vegetables, terrace gardening encourages self-sufficiency, mental health, and environmental consciousness. Terrace gardening is a modest but significant step towards creating greener and healthier communities as cities continue to expand.

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Architect of Library Development in India: S.R. Ranganathan

Aditya Arunkumar Bikkannavar, Manjula N. and Prarthana R.

If there is one name that echoes with reverence in the halls of libraries across India and beyond, it is Shiyali Ramamrita Ranganathan. Born on 12 August 1892 in the small town of Sirkazhi, Tamil Nadu, Ranganathan's journey from a mathematics lecturer to the "Father of Library Science in India" is nothing short of extraordinary. His life's work revolutionized how libraries function, making them centers of learning, inclusivity and accessibility.

From Mathematics to the World of Books

Ranganathan's early ambition was to teach mathematics. After completion of his Master's M.A. in Mathematics from Madras Christian College, he worked as a lecturer in Mangalore, Coimbatore, and Madras Universities. His scholarly bent was evident in his research papers on the history of mathematics. Yet, fate had a different path for him.

In 1923, the University of Madras advertised the post of University Librarian. Ranganathan, with no background of library science and only a brief glance at an Encyclopædia Britannica entry on the subject, applied almost absent-mindedly. To his surprise, he was selected. Initially reluctant and even bored with the position, he was offered the opportunity to study librarianship in London that experience of studying library science might have ignite his life passion to develop interest.

The Birth of a New Vision

While studying at London University, Ranganathan found himself fascinated by the challenge of classification systems in the library science. He somehow not happy with the already exciting Dewey's Decimal Classification, he began developing a more logical and flexible system, later it was popularly known as the Colon Classification, his innovation, inspired by something as simple as a Meccano toy set in a London shop, that became one of his lasting contributions to library science.

On his return to India, Ranganathan served as University Librarian at Madras University for twenty years. In the University Ranganathan transformed entire library management system from handling the book to new avenues to introduction of open access to bookshelves, championed free public libraries and worked tirelessly to make libraries accessible to all, including women and marginalized communities.

The five laws that Shaped Modern Librarianship

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In 1931, Ranganathan articulated what would become the bedrock of library science worldwide his

Five Laws of Library Science

- ✓ Books are for use.
- ✓ Every reader his book.
- ✓ Every book its reader.
- ✓ Save the time of the reader.
- ✓ The library is a growing organism.

These simple yet profound principles shifted the focus from libraries as static book repositories to dynamic institutions serving the needs of people. These laws remained relevant even today in the digital age as they were nearly a century ago.

A Relentless Work Ethic

Ranganathan was a true workaholic known to work 13-14 hour a day, all seven days of week, without vacations. Even on the day of his wedding in 1928, he returned to work that very afternoon. His dedication went beyond professional duty; it was a calling. He personally classified more than one lakh books during his career and drafted ambitious plans for a nationwide library network.

National and International Recognition

- ✓ Awarded the Padma Shri in 1957 by the Government of India for his outstanding contributions to the field of library science.
- ✓ Served as President of the Indian Library Association from 1944 to 1953.
- ✓ Held honorary positions at the University of Delhi.
- ✓ Appointed Vice-President for life of the Library Association of Great Britain.
- ✓ Appointed as National Research Professor by the Government of India.
- ✓ Founder of the Documentation Research and Training Centre (DRTC) in Bangalore, a premier institution for library and information science research and training.

Later Life and Enduring Legacy

On 12th August every year celebrated as National Librarian's Day in India, as a mark of tribute to the man who believed that libraries were not just about books, but about people, ideas, and the democratization of knowledge

After a prolific career, Ranganathan spent his later years in Bangalore, continuing to write and mentor till ill health confined him to bed. He passed away on 27 September 1972, leaving behind an intellectual legacy that continues to shape library science globally.

Why Ranganathan Still Matters Today

In the age of Google and digital libraries, one might wonder why remember Ranganathan? The answer lies in his timeless philosophy. His Five Laws apply equally to modern information systems, e-learning platforms, and online databases. They remind us that technology should serve users, information should be accessible, and knowledge should continue to grow and evolve.

As India advances into a knowledge-driven economy, Ranganathan's vision serves as both a blueprint and a moral compass. His life's work is a reminder that libraries are not warehouses they are gateways to empowerment.

S.R. Ranganathan was more than a librarian he was a teacher, reformer, innovator, and visionary**.** His belief that “every reader his/her book, every book its reader” transcends the pages of any library and speaks to the very heart of education and equality. As we celebrate his legacy, we also renew our commitment to the ideals he cherished making knowledge free, fair and for everyone.

Smart Farming Technologies for Sustainable Development of Agriculture

Dikshika Thakur and Deepa Sharma

Abstract

Smart farming technologies are transforming agriculture by addressing the growing challenges posed by climate change, resource scarcity and environmental degradation. By integrating advanced tools such as the Internet of Things (IoT), Artificial Intelligence (AI), robotics and remote sensing, smart farming enables data driven decision making, precision in resource use and improved crop and livestock management. These innovations enhance productivity, reduce environmental impact and support sustainable agricultural practices. Despite its potential, smart farming faces challenges including high costs, poor rural connectivity, small landholdings and limited technical skills among farmers. Overcoming these barriers through infrastructure development, policy support and farmer education through different trainings is essential to achieve a climate resilient and sustainable agricultural future.

Introduction

Agriculture is increasingly threatened by climate change, with rising temperatures, erratic rainfall and extreme weather events affecting crop yields, food security and rural livelihoods. These stresses, both direct (e.g., water scarcity, heat) and indirect (e.g., pests, diseases) are particularly severe in tropical and mid latitude regions. The Green Revolution once boosted productivity through high yield crops, fertilizers and irrigation, but it also caused environmental issues like soil degradation, waterlogging and biodiversity loss. Modern farming now faces diminishing returns due to poor resource efficiency and ecosystem strain. In response to these concerns, smart farming technologies have emerged as a viable solution for sustainable agricultural development. Smart farming focuses on precision, efficiency and data driven decision-making. It leverages tools like the Internet of Things (IoT), sensors**,** artificial intelligence (AI), drones and robotics to monitor and manage farm operations in real time. These technologies help answer critical questions such as what the crop needs, when it needs it, in what quantity and at which location thus enabling targeted interventions. By integrating Information and Communication Technologies (ICTs) into agricultural practices, smart farming transforms traditional large scale production into climate smart, precision agriculture. This approach allows for optimal use of water, fertilizers and pesticides, minimizes waste, reduces environmental impact and enhances productivity.

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For example, IoT based systems can monitor soil moisture and climate conditions to improve irrigation efficiency, while drones and satellite imagery can assist in pest detection and crop health assessment. Growing interest in smart farming signals a move toward more resilient and sustainable agriculture, supported by collaboration among policymakers, researchers and industry stakeholders especially in climate vulnerable regions.

Does Smart Farming Promote Sustainable Agriculture?

Yes, smart farming plays a key role in promoting sustainable agriculture. Both smart farming and sustainability depend heavily on the availability and use of accurate data. Smart farming combines technology such as satellites, sensors and digital tools to help farmers make better and faster decisions. This makes farming not only more efficient and cost effective, but also more environmental friendly. Smart farming is a modern approach to farm management that uses advanced tools to improve both the quality and quantity of agricultural production. For example, using sensors helps farmers decide how, when and where to use water, fertilizer or pesticides, leading to better crop health and less waste. It also supports eco-friendly practices by reducing the overuse of natural resources. Through smart farming, farmers can also monitor animals more closely, adjusting their nutrition based on real time data. This helps prevent diseases and improves overall animal health. The use of Information and Communication Technologies (ICT) in agriculture is seen as part of a third green revolution, aiming to make farming more innovative and sustainable. Unlike traditional methods, today's farmers can gather real time data, such as soil fertility or moisture levels and make informed decisions. For instance, satellite images can be used to analyze land fertility and estimate yield potential allowing precise planning and better land use. In short, smart farming not only boosts productivity but also ensures that agriculture is more sustainable, environmentally responsible and future ready.

Significance of Smart Farming

Smart farming is essential for improving agricultural efficiency, enabling informed decision making and promoting sustainable, eco-friendly practices. Traditional farming is labor intensive and require more resources thus pushing farmers toward smart solutions.

Changing consumer preferences: Rising demand for healthier food can be met through precise, quality driven production using smart technologies.

Resource accuracy: Smart sensors provide more accurate and efficient resource assessments than manual testing.

Advanced spraying: Drones and variable rate technology enhance productivity through precise application of inputs.

Labour shortages: Urbanization has reduced available farm labor, making automation crucial.

Environmental concerns: Farm automation lowers chemical use, helping preserve ecological balance without reducing yield.

Increased yields: By optimizing growing conditions and managing resources effectively smart technologies can contribute to higher crop yields.

Smart Farming Technologies

Agricultural Cyber-Physical Systems (ACPs)

Agricultural Cyber Physical Systems (ACPSs) integrate physical agricultural components with computational algorithms to enhance farm management systems. Unlike traditional embedded systems, ACPSs offer advanced features such as autonomy, scalability, adaptability and security. Utilizing wireless sensor networks, they continuously monitor key cultivation factors (e.g., temperature, humidity, soil moisture, plant health) and automate operations. They also support system reliability and user friendly interfaces, making them vital for modern precision agriculture.

Cloud Computing: Cloud Computing, introduced in the early 2000s, Cloud computing helps smart farming by storing and processing data from devices like sensors and drones. Farmers can see real time information about their crops, soil and weather, which helps them make better decisions and use water, fertilizer and other resources more wisely. It also allows them to manage farm from anywhere using phones or computers. Although there are some problems like weak internet in villages, cloud computing still makes farming easier, smarter and more efficient.

The Agricultural Internet of Things (AIoT): The Agricultural Internet of Things (AIoT) uses smart devices like sensors and machines connected through the internet to help farmers collect and monitor data in real time. This lets them check things like soil moisture, weather and crop health from anywhere and even control machines remotely. AIoT systems are smart and can work together to make decisions and adjust to changes on the farm. They improve farm management by making it easier to gather, combine and use data, helping farms become more efficient, flexible and connected to the whole food production process. AIoT is a big part of making farming smarter and more data driven. In AIoT systems, sensors are essential for real time data collection, enabling smart decision making and automation in farming. They convert physical conditions into digital signals for monitoring and control.

Temperature Sensors: Monitor soil and air temperatures, helping manage crop stress and optimize greenhouse conditions.

pH Sensors: Measure soil acidity/alkalinity to ensure nutrient availability and healthy plant growth.

Humidity Sensors: Track atmospheric moisture to guide irrigation schedules and prevent diseases.

Soil Moisture Sensors: Assess water content in soil, helping optimize irrigation and conserve water.

Rainfall Sensors: Measure precipitation levels to manage flood risks and adjust irrigation needs.

Wind Speed Sensors: Provide wind data for safe pesticide spraying and harvest timing.

NPK Sensors: Analyze soil for nitrogen, phosphorus and potassium levels to optimize fertilization.

Camera Sensors (RGB): Capture crop images for

health monitoring, growth tracking and harvest readiness.

Light Dependent Resistors (LDR): Control sun-light exposure in greenhouses to maintain ideal light levels for plant growth.

Remote Sensing, Drones and Satellites Images

These sensors collectively enable precision farming, improving crop yields, conserving resources and promoting sustainable agriculture through data driven management. Remote sensing and satellite imagery have revolutionized smart farming by enabling farmers to monitor large agricultural areas efficiently. Using drones and satellites, high resolution images provide detailed insights into crop health, disease outbreaks, soil conditions and moisture levels helping detect problems early and reduce crop loss. These technologies support site specific management, allowing precise application of water and fertilizers based on varying field conditions, thus improving productivity and resource efficiency.

Agricultural Robotic and Autonomous Systems

Agricultural Robotic and Autonomous Systems are advanced, integrated technologies designed to automate tasks like sowing, pruning, fertilizing, harvesting and sorting. These systems improve productivity, reduce farmer workload and optimize resource use, while also enhancing soil health and crop quality. Operating in unstructured and harsh environments (e.g., dust, temperature extremes and vibration), these robots require robust, intelligent designs.

Artificial Intelligence (AI) and Machine Learning (ML): Artificial Intelligence (AI) and Machine Learning (ML) are transforming agriculture by enabling precise and efficient farming. They analyze data from satellites, drones and sensors to monitor crop health, soil conditions and predict yields, helping farmers make smarter decisions. AI supports precision farming by optimizing irrigation and fertilizer use, reducing waste. AI powered robots automate tasks like planting and harvesting, improving efficiency. Predictive analytics help anticipate weather and market trends, while AI monitors livestock health for early disease detection. Drones with AI provide detailed crop images for better management. Overall, AI and ML boost productivity, sustainability and resource use in farming.

Challenges of Smart Farming

Small Land Sizes: Many farmers in India have small farms, which makes it hard to use expensive smart farming tools effectively.

Difficult Sensor Setup: Setting up sensors and connecting them to machines for automatic work can be complicated and needs technical skills.

High Cost of Internet Setup: Building the required network systems for smart farming can be very costly.

Poor Internet in Villages: Many rural areas don't have strong internet or mobile signals, which makes smart farming tools hard to use.

Lack of Knowledge: Most farmers are not familiar with new technologies and need training to use them

properly.

Fewer Jobs for Laborers: As machines take over farm work, there may be fewer jobs for people who depend on manual labor.

Conclusion

Smart farming technologies are revolutionizing agriculture by promoting efficiency, sustainability and resilience in the face of climate change and resource limitations. By leveraging tools like IoT, AI, robotics and remote sensing, farmers can make informed decisions that optimize input use, increase yields and reduce environmental harm. These innovations mark a shift toward climate-smart and data driven agriculture. However, barriers such as high implementation costs, poor rural connectivity, small landholdings and limited technical awareness must be addressed to ensure inclusive adoption. With proper investment in infrastructure, farmer training and policy support, smart farming can drive a sustainable agricultural transformation ensuring food security while protecting natural resources for future generations.

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The Emerging Role of Machine Learning in Sire Evaluation

Kachave Mukund R., Komal, Rajesh Kumar and Amit Kumar

Introduction

Animal breeding has always relied on selecting superior sires (males) to pass on desirable traits such as milk yield, growth efficiency, fertility, and disease resistance. The sire contributes half of the genetic makeup to offspring, making his evaluation critical in livestock improvement programs. Over the decades, sire evaluation methods have evolved dramatically from subjective selection based on physical appearance to pedigree analysis, progeny testing, statistical modeling, genomic tools, and now, machine learning (ML) algorithms. This transformation marks a shift from traditional record-based approaches to data-driven, predictive, and highly accurate breeding decisions.

Historical Perspective: From Pedigree to BLUP

Early livestock selection relied mainly on phenotypic observations, where sires were chosen based on body conformation, milk yield of daughters, or growth performance. However, such methods suffered from environmental biases, making it difficult to isolate genetic merit. The development of pedigree-based selection in the early 20th century improved accuracy by incorporating family records. Later, progeny testing became the gold standard, where the performance of a sire's daughters provided a reliable estimate of his genetic worth. Yet, this process was slow often taking 5-7 years to complete. A major breakthrough came with Best Linear Unbiased Prediction (BLUP), introduced in the 1970s. BLUP used statistical models to simultaneously account for genetic and environ-mental effects, offering more precise sire evaluati-ons. This method is still widely used globally, forming the backbone of genetic improve-ment programs.

Genomic Selection: A Precursor to Machine Learning

The early 2000s witnessed the integration of molecular markers and genomic data into sire evaluation. Genomic selection (GS), based on thousands of single nucleotide polymorphisms (SNPs), allowed breeders to estimate genomic breeding values (GEBVs) even before progeny data were available. While GS improved accuracy and reduced generation intervals, it also generated large,

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complex datasets requiring advanced analytical methods. This set the stage for the adoption of machine learning algorithms in animal breeding.

Why Machine Learning in Sire Evaluation?

Traditional statistical models like BLUP assume linear relationships between traits and genetic markers. However, livestock traits are often complex and polygenic, influenced by gene–gene interactions (epistasis), gene–environment interactions and non-linear effects.

Machine learning offers key advantages

- ✓ Ability to capture non-linear relationships between genotype and phenotype.
- ✓ High-dimensional data handling, especially with genomic and environmental datasets.
- ✓ Improved predictive accuracy compared to conventional models.
- ✓ Adaptability to integrate multiple data types (genomic, phenotypic, environmental, management).

Thus, ML has become a powerful tool to complement or even surpass classical genetic evaluation methods.

Machine Learning Techniques in Sire Evaluation

Regression-Based Models: Ridge Regression, Lasso, and Elastic Net help manage high-dimensional genomic data by reducing overfitting and improving prediction accuracy, while Random Regression Models are valuable for analyzing longitudinal traits like lactation curves, enabling more precise genetic evaluation in animal breeding.

Tree-Based Algorithms: Random Forests (RF) capture complex interactions among SNPs and traits through ensemble learning, while Gradient Boosting Machines (GBM) and XGBoost offer highly accurate predictions that often surpass traditional linear models in genomic prediction.

Support Vector Machines (SVMs): These methods are particularly effective in binary classification tasks, such as distinguishing between disease-resistant and susceptible sires.

Artificial Neural Networks (ANNs): Inspired by brain function, learn hidden patterns between genotype and phenotype, while Deep Learning models such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) are increasingly applied to multi-omics datasets, image-based phenotyping, and sire fertility prediction.

Bayesian Learning models: It combine prior biological knowledge with genomic data to provide probabilistic predictions of sire merit, enhancing accuracy and interpretability in genetic evaluation.

Procedure: How Machine Learning is applied in Sire Evaluation

- ✓ Data Collection involves integrating multiple sources of information, including genomic data (such as SNP chips and whole-genome sequencing), phenotypic records (like milk yield, growth rate, fertility, and disease resistance), and environmental or management factors (such as nutrition, housing, and climate), to ensure comprehensive and accurate genetic evaluation.
- ✓ Data Preprocessing includes quality control of genomic markers to remove errors or unreliable

variants, handling missing values to maintain dataset integrity and normalization of phenotypic records to ensure consistency and comparability across individuals and environments.

- ✓ Feature Selection focuses on identifying the most informative markers by applying machine learning techniques such as LASSO, recursive feature elimination or Random Forest importance scores, thereby improving prediction accuracy and reducing model complexity.
- ✓ Model Training involves splitting data into training and validation sets, followed by applying machine learning algorithms to effectively learn and capture the genotype–phenotype relationships.
- ✓ Model Validation is carried out using cross-validation or independent datasets to assess predictive accuracy, with performance measured through metrics such as the correlation between predicted and observed values, mean squared error, or classification accuracy.
- ✓ Deployment Implementation in Breeding Programs involves integrating ML-based predictions into national or farm-level sire evaluation systems and selecting top sires for breeding programs based on their predicted genetic merit.

Applications of ML in Sire Evaluation

Milk Yield Prediction: Machine learning models combine genomic data (e.g., SNP markers) with management factors such as feeding and housing to predict the genetic potential of sires for higher milk yield, enabling farmers to select bulls that pass on superior productivity to their daughters.

Fertility and Semen Quality: Advanced models use genomic information along with image-based analyses of sperm morphology and motility to predict semen quality and conception success rates, helping identify sires with better reproductive efficiency.

Disease Resistance: ML approaches can detect genetic markers associated with resistance to common livestock diseases such as mastitis, foot-and-mouth disease (FMD), or parasitic infections, supporting the selection of healthier sires and reducing dependence on medications.

Growth and Carcass Traits: By analyzing genomic and performance data, models can predict important production traits like feed conversion efficiency, meat quality, and growth rate in beef cattle and sheep sires, aiding in the selection of animals suited for meat production.

Precision Breeding: Integrating genomic profiles with environmental factors such as climate conditions, nutrition, and farm management practices, ML tools provide sire recommendations tailored to specific production systems, ensuring optimal performance under local conditions.

Challenges and Limitations

Data Availability and Quality: In many developing countries, large-scale genomic datasets are limited, and phenotyping practices are often inconsistent across herds, reducing the reliability of ML-based predictions.

Computational Demands: Machine learning mode-

ls particularly deep learning approaches, require substantial computational power and specialized expertise, which may not be readily accessible in all research or breeding programs.

Interpretability: While effective, complex models like deep neural networks often act as "black boxes," making it challenging to derive clear biological insights from their predictions.

Overfitting Risks: With small or unbalanced datasets, ML models may overfit, performing well during training but failing to generalize effectively in real-world breeding scenarios.

Ethical and Socioeconomic Issues: The high costs of genomic and ML technologies can exclude smallholder farmers, highlighting the need to adapt these tools to low-resource settings to ensure equitable benefits.

Future Perspectives

Integration of Multi-Omics Data: The future of sire evaluation lies in combining genomics with other layers of biological information such as transcriptomics, metabolomics, and microbiome profiles. This holistic approach can capture complex genotype-phenotype relationships more accurately, leading to improved prediction of traits like fertility, disease resistance, and productivity.

Image-Based Phenotyping: Advances in computer vision and deep learning enable automated collection and analysis of visual traits, such as body conformation, locomotion, and overall health status. This reduces human error, speeds up phenotyping, and provides objective, large-scale data for breeding programs.

Climate-Resilient Breeding: With climate change posing new challenges to livestock farming, ML models that integrate genomic information with environmental variables can help identify sires that are not only productive but also resilient to heat stress, disease outbreaks, and variable feed availability.

On-Farm AI Tools: The development of user-friendly mobile and cloud-based platforms will allow farmers to directly access ML-driven sire rankings and recommendations. Such tools democratize advanced breeding technologies, making them practical even for small- and medium-scale farmers.

Conclusion

Sire evaluation has advanced from pedigrees to machine learning, offering powerful tools to utilize big data, model complex traits, and accelerate genetic gains. Despite challenges of data and computation, ML integration enables more accurate and tailored breeding decisions. Adopting these technologies can revolutionize livestock productivity, sustainability, and global competitiveness.

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Epigenetic Regulation and Multi-Omics Integration in Development, Stress Response and Adaptation

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Introduction

Omics technology, representative of collective technologies, refers to the methods used to study the functions, mechanisms, and interactions as well as relationships between genes, transcripts, proteins, lipids and other biomolecules in a certain biological sample in an objective, non-targeted approach (Horgan and Kenny, 2011). The completion of the Human Genome Project marked the start of a new era and paved the way for new sequencing and omics technologies. To understand and solve specific issues, different "omic" methods have been developed over time, including transcriptomic, proteomic, metabolic, and genomic approaches. High-throughput screening approaches provide insight into the overall view of certain biological molecules, including the genes (genomics), messenger RNAs (transcriptomics), proteins (proteomics), lipids (lipidomics), and metabolites (metabolomics) underlying and enabling cellular life (Horgan and Kenny, 2011). The main reasons behind the growing popularity of 'omics' technology in biological research are the ability to provide the following satisfactory information to the researcher: a comprehensible view of a complex biological system as a whole; exploration of the global status of biological molecule/s inside the organelle/cell/tissue/ organ under a defined condition; identification of the key molecule/s in the biological system/ process/ sample being studied; revelation of the reason for the differences in expression/behaviour of biomolecules under the experimental condition. Another reason for the growing importance of 'omic' approaches is their potential application diversity. 'Omics', therefore, may be used to explore normal biological processes as well as for understanding the aetiology, screening, diagnosis and prognosis of a disease (Horgan and Kenny, 2011). The future of biological research is based on integrative 'omic' technologies or system biology for developing new approaches that are predictive, preventive and personalised in the fight against diseases (Evans, 2000). A framework known as "multi-omics integration" combines proteomics, metabolomics, transcriptomics, and genomes to offer a systems-level view of fish biology. While transcriptomics will provide insight into changes in gene expression, genomics will show variations in DNA. For instance, we discovered many genes implicated in sea lice resistance in Atlantic salmon (Salmo salar) when combining GWAS with RNA-

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Seq. Osmoregulatory mechanisms have been proposed by transcriptomic profiling of tilapia (Oreochromis niloticus) under salinity stress. Combining proteomic and metabolomic analyses provides a deeper understanding of aquatic systems by linking protein and metabolite profiles to physiological traits. This multi-omics approach reveals how organisms respond to stressors like osmotic and thermal changes, as seen in zebrafish and clarifies host resistance mechanisms, such as in common carp. Integrating these data sets helps in mapping genes and pathways to observable traits like stress resilience and disease resistance, which can advance selective breeding for sustainable aquaculture (Di *et al.*, 2017). Despite some challenges with data integration, this approach offers a powerful framework for improving global aquaculture production.

DNA methylation and Histone acetylation: DNA methylation is a fundamental epigenetic mechanism that directly modifies DNA. It involves the addition of a methyl group to cytosine bases, typically within CpG sequences, a process catalyzed by DNA methyltransferase enzymes. While first discovered in mammals, its definitive role in gene regulation and cell differentiation was confirmed in 1975. Today, it's recognized as a major factor in controlling gene activity, impacting how genes are expressed without changing the underlying DNA sequence. CpG islands are most often in promoter regions and are significant loci of epigenetic modification because about 70% of gene promoters are located in CpG islands (Saxonov *et al.,* 2006). When methyl groups are added to the cytosines in the promoter regions, they will attract repressor proteins and prevent transcription factors from binding (Moore *et al.*, 2013). In addition, methylation is considered to promote heterochromatin formation, which will make nucleosomes more tightly packed, blocking access to transcriptional machinery (McMahon *et al*., 2017). As such, methylation of promoters is generally associated with a silencing of gene expression. The second epigenetic mechanism involves post-translational alterations to histone proteins and the resulting structural consequences for chromatin, which ultimately alter gene transcription. Post-translational modifications of histones can involve acetylation, methylation, phosphorylation, and ubiquitylation (Shvedunova and Akhtar, 2022). Histone acetylation takes place, typically on lysine amino acid residues, modifying the overall histone positive charge, which facilitates a rarer interaction with DNA, thereby promoting practical transcription (for instance, the presence of H3K9ac and H3K27ac is consistent with active genes) (Esteller, 2008). More complicated, histone methylation can activate or silence transcription depending on the residue and level of methylation; H3K4me is related to activation, while H3K27me3 is related to silencing (Bannister and Kouzarides, 2011). It does not change the charge. Histones can also add a negatively charged phosphate group in phosphorylation, which can also work in DNA damage signalling, especially H2A(X) phosphorylation (Rossetto *et al.,* 2012).

Ubiquitylation adds ubiquitin to lysine residues; H2AK119ub relates to transcriptional activation and H2BK123ub relates to silencing (Bannister and Kouzarides, 2011). The effects of methylation, phosphorylation, and ubiquitylation are dependent on context and interactions of neighbouring chromatin, while the effects of acetylation are relatively predictable on gene expression (Bannister and Kouzarides, 2011). A recently recognised epigenetic pathway is the silencing of genes related to noncoding RNA (ncRNA). While ncRNAs have homologous protein-coding genes, ncRNAs were previously termed "genomic junk" but are now used to stress the contributions made by ncRNAs in controlling gene expression, thereby creating phenotypic diversity. By suppressing gene expression, ncRNAs are related to DNA methylation, histone modification, and heterochromatin (Chisholm *et al*., 2012).

Epigenetic mechanisms, especially DNA methylation, are key regulators of fish development and adaptation. They are established during embryonic development and influence organogenesis, gene expression, and sexual differentiation. For example, in fish, DNA methylation of the aromatase gene (cyp19a1a) was correlated with temperature-dependent sex determination, such as the European sea bass species (Navarro-Martin *et al*., 2011). Genes involved in stress responses (e.g., heat shock proteins, antioxidant enzymes) may be modulated by environmental stressors such as temperature, salinity, hypoxia, or pollution, all of which could impact DNA methylation and patterns of histone acetylation. Changes to DNA methylation and histone acetylation patterns could elicit rapid physiological responses to changes within the environment, such as those associated with heat stress (Metzger and Schulte, 2016). Epigenetic modifications enable fish to adapt to stressors like climate change through phenotypic plasticity, without changing their DNA. This process, essential for their survival, involves altering gene expression in response to environmental cues. For instance, when Atlantic salmon are subjected to stress, their DNA methylation changes have long-term effects on their immune and growth characteristics (Moghadam *et al.,* 2017). As seen in zebrafish and medaka, many epigenetic modifications are inherited, meaning that parental stress or exposure to the environment may prepare offspring for a similar stress or environment (Anastasiadi and Beemelmanns, 2023). Fish epigenetic modifications act as a bridge between environmental cues and genome function; they are crucial drivers of development, stress resilience, and ecological adaptation.

Genomics for improving fish growth: Genomics was used for improving the growth, such as gene knockout, which has been carried out in fish species, enhancing growth in these species. Using pomc (which is essential for regulating feeding) knockout zebrafish made it possible to examine how pomc-knockout affected survival, growth, feed conversion ratio (FCR), tissue and liver histology, and the expression of genes related to the synthesis of fatty

acids and cholesterol. The zebrafish with pomc knocked out genes showed higher body weight and lower FCR, and histological analysis showed that they produced more skeletal muscle without showing any symptoms of obesity (Yang *et al.*, 2023). Similarly, four lepr genes (receptor for leptin hormone) were successfully knocked out in tiger pufferfish, causing them to eat more and gain weight more quickly. As a result, the altered fish weigh 1.9 times as much as the original tiger pufferfish, which allows them to grow to market size faster (Wang *et al.*, 2025). Targeting the mc4r gene (Melanocortin 4 receptor) in channel catfish embryos with three sgRNAs and the Cas9 protein, researchers were able to achieve a 33% mutation rate, with 33% of the fish becoming homozygous or bi-allelic for the mutation. Approximately 71% of the offspring inherited this mutation, making them grow more than control fish in a variety of stages and environments. According to a study, Nile tilapia with the mstnb (Myostatin) gene knockdown showed considerably improved growth performance metrics. Deletion of the t1r1 gene greatly enhanced zebrafish growth performance and uptake of plant proteins, according to a study which suggests that aquaculture species may be able to use feeds with more plant-based proteins if t1r1 is edited (Cai *et al*., 2021).

Conclusion

Developments in omics technology and epigenetics are revolutionizing aquaculture research by offering thorough understandings of stress responses, gene regulation and growth enhancement. By connecting molecular pathways to physiological features, multi-omics integration facilitates a systems-level understanding of fish biology and improves selective breeding for productivity, illness resistance, and stress resilience. Fish development, adaption, and transgenerational plasticity are significantly influenced by epigenetic changes, especially DNA methylation and histone acetylation, which may provide coping mechanisms for environmental and climatic stressors. Additionally, targeted gene knockouts and other genomic manipulations show a lot of potential for increasing aquaculture species' growth and feed efficiency.

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IPR in Food Industries: Types and Challenges

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Introduction

One of the most important industries in the world is the food sector. The food business employs 10% of all workers. The food industry brings approximately USD 1.4 trillion annually. In this enormous industry, many food businesses have their own unique recipes, products, flavors, marketing strategies, packaging designs, etc., and they invest time and resources into honing their concepts in order to draw clients. By defending their original ideas, they could differentiate themselves from other sectors. Because of this effective IP protection, they may make money off of their ideas and win over clients (Yadharthana and Parkkavi, 2024). Legal protections offered to people or organizations for their discoveries or creative works are known as intellectual property rights, or IPRs. These rights confer exclusive control, command, and economic benefits over intangible assets. IPRs are crucial for safeguarding innovations, encouraging innovation, and promoting financial advancement in the food technology sector (Cockburn *et al*., 2009).

Any food product with intellectual property protection increases in value as well, and consumers feel that it is too expensive and that they have no other option for getting similar foods. Though there are certain internal and external barriers, the food business does profit from this intellectual property protection. Intellectual property rights (IPRs) are a powerful weapon in the fight for food safety because they encourage innovation, protect trade secrets, provide product traceability and authenticity, and facilitate the enforcement of laws and regulations. Additionally, protecting intellectual property rights can aid in the security of private information about formulas, production procedures, and quality assurance techniques (Stjepandić *et al*., 2015). By minimizing the likelihood of misuse or unlawful access, this protection improves food safety procedures (Bhurat, 2025).

IPR Types in Food Technology

Patents: Patents are crucial for protecting inventions and technological advancements in the food industry. They grant inventors the exclusive right to their creative and non-obvious ideas and the ability to stop others from creating, using, or commercializing their protected discoveries (Tunick, 2009). Improvements that can be covered by food technology patents include new food compositions, processing techniques, machinery, and equipment.

Trademarks: Trademarks are crucial for increasing brand awareness and customer loyalty in the food

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industry (Klein, 2021). They safeguard names, logos, package designs, and other distinctive characteristics that make products and services stand apart from competitors. By securing trademark protection, companies may effectively communicate their brand identity and make a lasting impact on consumers.

Copyrights: As unique forms of literary, artistic, and creative expression, copyrights protect written works, images, artwork, and audiovisual content. In the food technology sector, copyrights are crucial for safeguarding marketing materials, product labels, recipe books, and culinary photos.

Industrial Designs Rights: Industrial design rights are crucial to maintaining the distinctiveness and visual attractiveness of items in the food industry. They protect certain components, such as product shapes, packaging designs, and appearances that enhance consumer appeal and brand awareness.

Trade Secrets: Trade secrets are crucial in the food industry, particularly when it comes to protecting confidential information such as client databases, production processes, formulas, and recipes. Unlike patents or trademarks, trade secrets rely on maintaining the confidentiality of information rather than seeking official registration or protection. The formula that The Coca-Cola Company uses to manufacture its famous beverage is one of the most well-known trade secrets in the world. It has been kept under wraps for almost a century, giving the company a competitive advantage and maintaining its market dominance (Markoff, 2016). Coca-Cola has been able to preserve its unique flavor and prevent competitors from replicating its success because the recipe is kept a secret.

Geographical indication: Food and agricultural products, which are often identified by their geographic locations, have long been closely associated with the distinctive characteristics and customs of their home regions. These designations have historically been used to identify products of very high grade. Notable examples of Indian origin include delicacies like Agra petha, Tirupati laddu, Hyderabadi Biryani, Hyderabadi Haleem, Agra dalmoth, and Ratlami sev, in addition to international products like tequila and champagne (Bhurat, 2025).

Obstacles Small-scale food industries face

Lack of knowledge about intellectual property protection in small food sectors 5 is not legally protected by the rules described above, and as will be discussed later, they often face legal and social barriers from both domestic and foreign sources.

Breaking the law: Due to their ignorance of intellectual property regulations, small-scale food enterprises may inadvertently infringe against the intellectual property of other food companies. For example, they might use any trademarked name, slogan, or logo; patented food products; food manufacturing techniques; copyrighted packaging designs; or recipes, all of which could result in injunctions, fines, legal problems, or product recalls. This infringement also affects their reputation and commercial operations. Small-scale food businesses must therefore be aware of intellectual property in

order to avoid such risks.

Counterfeiting: In the food industry, fake labels are commonly used to mislead consumers and entice them to buy their products. For example, basmati rice can occasionally be imitated with less expensive rice. Small-scale food businesses are often impacted by this issue, which damages consumer confidence and causes a precipitous decline in food product marketing. For example, small businesses may have a wonderful reputation with consumers, but when their products are duplicated, their marketing efforts suffer. Counterfeiting food products endangers the health of customers because local products are infrequently offered. Small-scale food enterprises consequently lose money as a result of a drop in sales caused by the deceptions of others. In contrast to other food industries, many invest time and resources in educating customers about their products.

The consequences of ignorance

Many food companies are aware of the different protections that intellectual property offers. If this isn't done, many industries will steal unprotected breakthroughs' formulas, procedures, and branding. This indicates that the food industry is not unique because it has been copied by numerous other sectors. This was commonly seen in small-scale food businesses since the majority of them are unaware of IP protection. Sometimes, other sectors steal and preserve the formulas of small enterprises, which makes it illegal for them to produce their own products. Therefore, innovation protection is essential in the small-scale food industry. Since many businesses copy their own recipes and other content, ignorance of intellectual property protection hurts them.

Disclosure of confidentiality: Workers or workers in small-scale food businesses have challenges. Their employees often reveal their trade secrets or personal information, which results in significant losses for those sectors and harms the brands' image. While some workers might intentionally divulge information for personal benefit, others might unintentionally do so as a result of carelessness or poor data management. If the proprietary recipe is made public, other industries may try to copy it and produce similar products, which will damage the company's brand by eroding consumer trust. In order to ensure that nothing has been disclosed, small-scale food firms should have non-disclosure agreements signed by every employee. They should also give their employees training and explicit confidentiality policies.

The challenge of enforcement

Enforcement is a challenge for the food business, especially in the protracted lawsuit process. Regulatory agencies usually overlook inspecting IP-protected products in small enterprises due to a lack of funding and staff, focusing instead on large industries while disregarding smaller ones. 7. On sometimes, authorities allow companies to use other industries' protected goods for their own benefit. When food goods travel across borders, they face jurisdictional problems and a lack of international cooperation. The sale of fake goods is one example

of how technological advancements create potential for infringement. Additionally, consumers select less costly products without taking quality into account.

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Golden Threads Under Stress: Factors Shaping the Rearing Performance of Muga Silkworm (*Antheraea assamensis* Helfer)

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Muga silk, known as the "Golden Silk", is a unique gift of nature, renowned worldwide for its natural golden luster, durability, and cultural significance. Produced exclusively by the semi-domesticated silkworm *Antheraea assamensis* Helfer, Muga rearing is deeply woven into the traditions and livelihoods of the people of Assam and other parts of Northeast India. However, the performance of Muga silkworms in the field is far from uniform. While some rearing seasons bring abundant harvests of healthy cocoons, others see heavy losses due to environmental, biological, or management-related stresses. This article explores the predisposing factors that determine the success or failure of Muga silkworm rearing, based on recent research and field observations.

Climate: The Master Regulator

Muga silkworms are highly sensitive to changes in temperature, humidity, and rainfall. Being outdoor rearers, farmers cannot completely control the climate, and even small deviations can result in significant crop loss.

Temperature: The optimum range for Muga silkworm development is 22-28°C. Extreme heat during summer or cold waves in winter can disrupt larval growth.

Humidity: High humidity (70-80%) favors healthy feeding and molting. Dry weather often causes poor appetite and stunted growth, while excessive dampness leads to disease outbreaks.

Rainfall & storms: Heavy rainfall, floods, or cyclones damage host plants and directly wash away or injure larvae.

Thus, the performance of Muga rearing is closely tied to the unpredictable climatic behavior of Northeast India.

Host Plant Health: The Foundation of Rearing

The leaves of Som (*Persea bombycina*) and Soalu (*Litsea polyantha*) are the primary food sources for Muga silkworms. The quality, quantity, and nutritional value of these leaves determine larval health and silk yield.

- ✓ Poor plantation management, soil degradation, or pest attack on host plants reduces leaf quality.
- ✓ Nutrient deficiency (especially nitrogen, potassium and micronutrients) directly lowers leaf pala-

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tability and silk yield.

- ✓ Seasonal sprouting of tender leaves is vital; without proper pruning and care, host plant availability becomes a limiting factor.

Healthy plantations, therefore, are the backbone of successful silkworm rearing.

Diseases and Pests: The Invisible Threat

Like any livestock, Muga silkworms are vulnerable to pathogens and parasites.

- ✓ Pebrine, flacherie, virosis, grasserie, and muscardine are major diseases that can wipe out entire crops.
- ✓ Uzi fly (*Exorista sorbillans*), a notorious parasitoid, lays eggs on the larvae, leading to heavy mortality.
- ✓ Ants, wasps, and birds also prey on larvae, reducing survival rates.

Inadequate disease monitoring, late detection and lack of timely control measures predispose the crop to heavy losses.

Rearing Practices: The Human Factor

Even under favorable climate and good host plant conditions, rearing management plays a decisive role.

- ✓ Improper spacing of larvae on host plants causes overcrowding and weak growth.
- ✓ Unscientific handling during molting stages leads to high mortality.
- ✓ Timing of brushing (transferring newly hatched larvae to host plants) affects survival, late brushing exposes them to predators and harsh weather.
- ✓ Lack of awareness and adoption of improved technologies often limits productivity.

Training farmers in scientific rearing protocols is key to improving consistency and success.

Genetic and Physiological Factors

Not all Muga silkworm batches perform the same, even under similar conditions. Factors include:

Seed quality (DFLs): Disease-free layings, genetically pure seed are essential for uniform performance.

Fecundity and fertility: Healthy mother moths produce more viable eggs.

Larval vigor and adaptation: Some strains are more resilient to stress, while others are fragile.

Seed health and quality certification remain a critical determinant of rearing outcomes.

Socio-Economic and Policy Influences

Beyond biology, socio-economic realities shape Muga culture:

- ✓ Small and marginal farmers often lack resources for proper host plant management.
- ✓ Limited access to credit, insurance, and market support increases their vulnerability.
- ✓ Government schemes such as Silk Samagra-2 provide support, but adoption varies across regions.

Thus, the farmer's capacity and external support system indirectly affect rearing performance.

Climate Change: An Emerging Challenge

Recent years have seen erratic rainfall, extended dry spells, and higher temperatures, adding new stress to Muga rearing. Studies indicate that

climate change may alter pest dynamics, reduce host plant availability, and increase crop loss risks. Unless adaptive strategies are developed, the golden silk tradition faces significant threats.

The Way Forward

To safeguard the heritage of Muga silk, an integrated approach is needed:

- ✓ Improved host plant management through organic manures, pruning schedules, and pest control.
- ✓ Disease monitoring systems and timely supply of quality DFLs.
- ✓ Community-based Uzi fly management using traps and biocontrol.
- ✓ Climate-resilient strategies, such as micro-climatic modifications and adaptive rearing practices.
- ✓ Skill upgradation of farmers through training, demonstrations, and extension services.

Conclusion

The performance of Muga silkworm rearing is not determined by a single factor, but by the delicate interplay of environment, host plants, pest pressure, rearing practices, and socio-economic support. By addressing these predisposing factors with science-backed interventions, India can not only protect but also revitalize the golden legacy of Muga silk for generations to come. Muga is more than silk it is a symbol of heritage, resilience, and pride of the Northeast. Strengthening its rearing practices ensures that this "golden thread of India" continues to shine on the global stage.

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Agroforestry for Restoring and Improving Soil Health

Dayanand Sai Painkra, Shivam Dinkar and S. Deivasigamani

Introduction

Soil is the basis of production in agriculture and forestry, the nourisher of mankind and an important component of the human environment. Health/quality of soil is considered to be an important factor for the success of agricultural production. Soil health has been defined as the continued capacity of soil to function as a living system, which sustained biological productivity, environmental quality, and plant and animal health. Since the last few decades, land managers have realized the value of the soil health and quality for long-term human existence and future sustainability (Anderson and Udawatta 2019). Soil fertility is the key factor that affects the crop productivity and soil biodiversity. Soil quality is "the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health". The fertility of soil is depleting continuously due to various factors such as erosion, over utilization of land, wrong agricul-tural practices, and other anthropogenic activities. Intensive agriculture practices such as mono-cropping and shifting cultivations have immensely contributed to soil degradation. These practices not only damage the soil and its environment but also reduce biodiversity and decline the quantity of nutrients, resulting to low soil productivity (Tsufac *et al.*, 2021). Agroforestry is a collective name for land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) and/ or livestock in a spatial arrangement, a rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system. The combination of trees, crops and livestock mitigates environmental risk, creates a permanent soil cover against erosion, minimizes damage from flooding and acts as water storage, benefitting crops and pastures. Agroforestry systems can reverse land degradation problem in the tropics through their beneficial effects on soil resource. The amount of litter addition, litter quality, their decomposition rate and an improvement of soil physico-bio chemical properties is controlled by kind of tree species, age and density of tree species (Xiong *et al.*, 2008).

Characteristics of Good Trees in an Agroforestry

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System for Soil Improvement

In the agroforestry system, selecting a suitable tree is one of the most important factors for the farmers. The selected trees play a key role in determining the production and providing protection to the farm. It also helps in the management and improvement of soil health (Saha *et al*., 2010). The following characteristics are given priority while selecting the trees for agroforestry system:

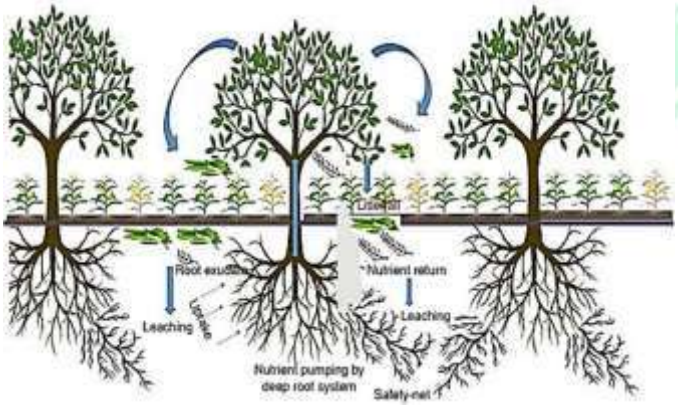
- ✓ The tree should be fast growing with deep root system.
- ✓ The tree should have high rate of nitrogen fixation capacity.
- ✓ Higher production of leafy biomass (avoid thorny species in farmland).
- ✓ Low invasiveness and capacity for soil reclamation.
- ✓ Trees should have both productive as well as protective functions.
- ✓ It should have the capacity to grow in poor soil, water scarcity, as well as drought condition and should have resistance against a wide range of pest and diseases.
- ✓ The tree should not have any toxic substance or allelopathic effect in its litter or root exudate.

Agroforestry for Restoration of Degraded Soil

The short-term or long-term decline in the land's capacity to produce and provide ecological services and functions is known as land degradation. Negative human activities include deforestation, over agriculture, overgrazing, inefficient irrigation systems, and industrial pollution and population expansion are just a couple of the natural factors that lead to land degradation. The Food and Agricultural Organization (FAO) has identified 13 distinct types of soil degradation that deteriorate land, with soil erosion being one of the most common causes of land degradation globally. There are several advantages to having trees, and in addition to meeting farmer needs, there are a number of agroforestry strategies for repairing and increasing land productivity. The rehabilitation or restoration of degraded lands caused by soil erosion, salinization, waterlogging, reduced soil organic matter, and mining, as well as enhancing the agricultural crop's resistance to the negative effects of climate variability as well as pests, diseases, and weeds, are suitable for a number of agroforestry systems, including agro-silvopasture, silvopasture, and agro-silvopasture. Singh *et al.* (2010) investigated soil fertility in a variety of farming systems and found that a poplar-based agroforestry system improved several soil parameters, including organic carbon and available nitrogen, phosphorus, and potassium, in comparison to a monoculture system. Subabul, Siris, and Shisham plantations had more accessible nutrients. Therefore, by enhancing the physico-chemical and biological characteristics of the soil, the tree component in agroforestry systems contributes to maintaining the soil's health. By obstructing the flow channel, the agroforestry system can help lessen runoff by lowering the potential quantity of debris it may carry.

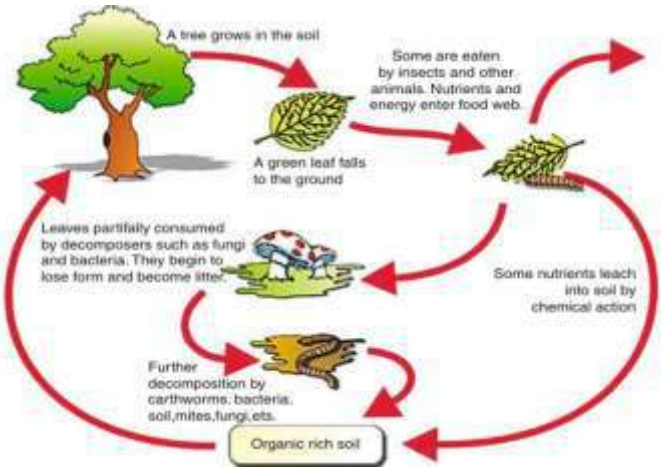
Nutrient Recovery of Soil through Agroforestry

Nutrients are absorbed by plants and stored as biomass in different plant sections. Nutrient loss from the system frequently occurs with crop harvest. Productivity is predicted to decrease in the absence of any external nutrient inputs in the form of inorganic fertilizers since nutrient losses cannot be compensated for by recycling nutrients through agricultural waste. Harvesting eliminates a large portion of the crop biomass in an agricultural system. Plants and soil are in a state of constant and dynamic nutrient transfer, whereby plants take up nutrients from the soil for metabolic processes and then return those nutrients to the soil by adding organic matter. As a safeguard against nutrient losses, trees' deep root systems absorb and pump back the nutrients that have leached from the soil, contributing significantly to the nutrient cycle (Fahad *et al*., 2022).



Agroforestry for Soil Biota

The majority of soil biogeochemical processes depend upon soil microbial communities, which are found in the soil and rhizosphere. The integration of tree in agroforestry not only enhances the physical and chemical properties of soil but also plays a significant role in the enhancement of soil micro-organism. The "demand side" for soil resources is represented by root systems, while the "supply side" is influenced by soil microbes and fauna, which play a key role in the degradation and stabilization of soil organic matter as well as the breakdown of litter and other organic components in the soil. They are crucial for biogeochemical cycles, nitrogen cycling, mineralization and nutrient delivery, chemical degradation, maintenance of aboveground biodiversity, soil formation, and maintenance soil health. The agroforestry system was found to have higher soil enzyme activity, microbial diversity, and macro fauna activity when compared to grazing and row crop management. Because they provide above- and below-ground organic inputs that give soil organisms the food and nutrition they need for nutrient cycling and soil fertility maintenance, agroforestry trees play a vital role in soil ecosystem services. By shading the soil and understory, transpiring water absorbed by the roots, and covering the soil with dead or clipped leaves or branches to add nutrients, trees change the soil environment in a number of ways.



Conclusion

Restoring livelihoods on degraded land, improving food security, reducing pressure on trees,

and restoring ecosystem services are all possible with agroforestry approaches. By combining locally appropriate trees with crops and animals on the same piece of land, agroforestry can contribute to the intensification and diversification of the current farming system. Agroforestry techniques considerably reduce soil erosion compared to agricultural monocultures, improve the soil's organic carbon and nitrogen status, raise the availability of inorganic nitrogen, and marginally raise its pH and inorganic phosphorus levels. By reducing soil erosion and leaching, agroforestry trees contribute to a decrease in soil nutrient loss.

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Microbial Metabolites in Plant Disease Management

Anjali Suansia, Shridhar Nivas Banne and Sumana K.

Introduction

India is known as growing economic giant but the benefits of this progress are mostly confined to urban or semi-urban areas. More than 65% of the population in the country lives in rural areas and depends on agriculture and related avenues for their sustenance. Hunger and poverty persists because of lack of work opportunities, thus inadequate income for farming communities. Indian agriculture, basic-ally characterized as a means of subsistence, is changing fast as per market demands both domestic-ally and international. Modern high input mono cropping based intensive agriculture has resulted in loss of biodiversity, outbreaks of pests and diseases, degradation of soil and water, which has ultimately led to stagnating agricultural production and productivity. Climatic changes are becoming a major factor in the present scenario (Kumar, 2013). The crop yield losses, on field and during post harvest period, caused by pests, diseases and weeds are of paramount importance. The crop losses due to pests, diseases and weeds are approximately assessed to be ranging between 10 to 30% of crop productions. If we consider, on average, crop loss of 20%, and the present gross value of our agriculture produce as Rs. 7 lakh crore, the loss comes to Rs. 1,40,000 crore, which is colossal (Kumar and Gupta, 2012). Even if we could save 50% by using plant protection, it will add Rs. 70,000 core additional income to our farmers. At a same time, when all of us are concerned about National Food Security, can the country afford these losses? Various type of direct and indirect losses caused by plant diseases include, reduced quality and quantity of crop produce, increased cost of production, threat to animal health and environ-ment, limiting the type of crops/varieties grown, loss of natural resources and less remuner-ative alternatives adopted. In order to combat the losses caused by the plant diseases, it is mandatory to define the problem and seek solutions. At the biological level, the requirements are for fast and accurate identification of the causal organism, accurate estimates of the severity of diseases and its effect on yield, and identification of its virulence mechanisms. Plant diseases caused by pathogenic microorganisms such as bacteria, fungi and virus can be controlled so as to protect plants from being infected with the help of certain microorganisms inhabiting rhizosphere, endosphere and phyllosphere (Mathivanan *et al.*, 2008).

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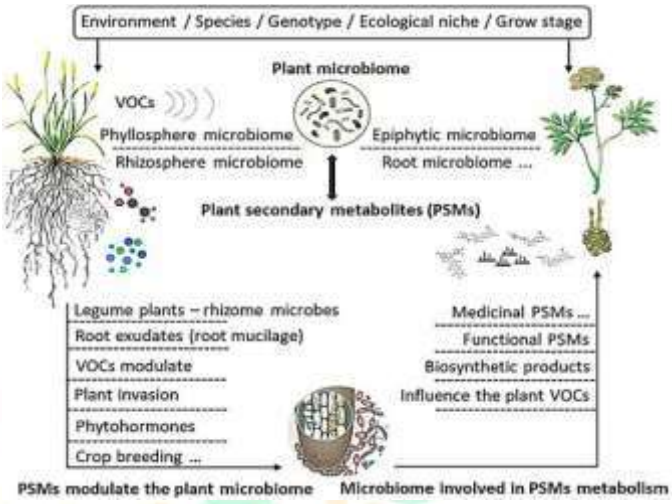
Biological control is an eco-friendly and effective means of reducing or mitigating plant diseases through the use of natural enemies i.e., microorganisms. These microbe-based agro agents are used as either whole organism or their metabolites. Interestingly, some of the micro-bial metabolites that are used in plant disease control programme are of great importance. Microbial secondary metabolites are low molecular bioactive compounds synthesized during a subsequent production stage (idiophase) of microbial growth. The secondary metabolite production is controlled by special regulatory mechanisms in micro-organisms, as their production is generally repressed in logarithmic phase and depressed in stationary growth phases. It is commonly observed during microbial interaction of antagonistic microorganisms and pathogens.

Microbial secondary metabolites in plant disease management

It has been discovered that microbial metabolites of bacterial, fungal, and actinomycetes antagonists can stop the growth of a number of phytopathogens. Secondary metabolites generated by the following are some types of microbes:

Siderophores: Siderophores, the iron-binding molecules produced by many rhizobacteria were responsible for inhibition of many phytopathogens. Examples of siderophores produced by BCAs are pyoverdin and pyochelin, which have been reported to contain antimicrobial activity on their own. However, in most of the studies, the Siderophores have been reported to inhibit the pathogens by iron competition only. Siderophore-mediated biocontrol potential of *Rhizobium meliloti* against *Macro-phomina phaseolina*, causal agent of charcoal rot of groundnut has been demonstrated (Arora *et al*., 2001).



Viridin: Viridin has been first described in 1945 as an antifungal metabolite of the fungus *Gliocladium virens* (*Trichoderma virens*). This compound has been detected in other *Trichoderma* species such as *T. koningii*, *T. viride* and *T. virens* and prevents the germination of spores of *Botrytis allii*, *Colletotrichum lini* and *Fusarium caeruleum* (MIC of 0.003-0.006 lg ml^{-1}), *Penicillium expansum*, *Aspergillus niger* and *Stachybotrys atra* (6 lg ml^{-1}).

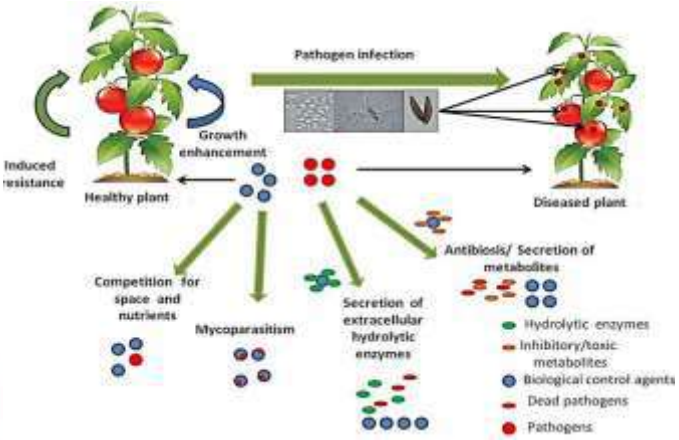
Azole compound: Recently, the disease-control potential of an azole chemical produced by *B. licheniformis* MML2501 against *M. phaseolina*, the cause of dry root rot in groundnuts, was thoroughly described. With the exception of *R. solani*, the purified azole molecule has remarkable antifungal efficacy against a variety of soil-borne fungal phytopathogens (Prashanth, 2007).

Koningins: A series of complex pyranes named koninginins A-E and G have been discovered in some species of *Trichoderma*. Koninginin D has also affected growth of other soil-borne plant pathogens such as *Rhizoctonia solani, Phytophthora cinnamomi, Pythium middletonii, Fusarium oxysporum* and *Bipolaris sorokiniana*.

Phenazine-1-carboxylic acid (PCA): Phenazine-1-carboxylic acid (PCA). It has been reported from *P. fluorescens, P. chlororaphis, P. aeruginosa* and *P. putida*. PCA has been reported to inhibit fungal pathogens such as *Gaeumannomyces graminis* var. *tritici*, *Pythium* sp., *Rhizoctonia solani*, *Polyporus* sp., *Sarocladium oryzae, Macrophomina phaseolina, Pestalotia theae,* various species of *Colletotrichum* etc. and bacterial pathogens, *Actinomyces viscosus, Bacillus subtilis* and *Erwinia amylovora* etc.

Pyrrolnitrin (PRN): Pyrrolnitrin (PRN) has been reported from *P. aureofaciens* and *P. fluorescens*. PRN has been found to be active against a wide range of fungi belonging deuteromycota, ascomycota and basidiomycota. Hence, PRN is widely used as fungicide in agriculture. PRN producing *Burkholderia cepacia* showed a broad-spectrum antifungal activity towards phytopathogenic fungi including *R. solani.*

Hydrogen cyanide (HCN): It is the strongest volatile substance that many soil bacteria make. It has been demonstrated that the HCN generated by antagonistic fluorescent pseudomonads (FPs) exhibits excellent antifungal action against phytopathogens. HCN in *P. fluorescens* CHA0 was essential in suppressing the take-all disease of wheat produced by *G. graminis* var. tritici and black root rot of tobacco caused by the fungus *Thilaviopsis basicola*. The protective properties of HCN generated by *P. aeruginosa* against *Meloidogyne javanica*, the tomato root-knot worm, have been amply demonstrated by Siddiqui *et al*. (2003).



Future Perspectives of Microbial Metabolites in Plant Disease Control

High throughput screening methods are revolutionizing the discovery of novel metabolites of microbial origin with novel bioactivities (Zhang *et al.,* 2007). However, the successful use of this advanced technology in identifying novel agroactive metabolites is yet to be followed vigorously. This would save the time required for discovering and developing agroactive molecules into a commercial scale. Microbial metabolic engineering is another field where the generation of well-characterized parts and the formulation of biological design principles in synthetic biology are laying the foundation for more complex and advanced engineering of synthetic microbial metabolism. Mapping out the regulatory networks that govern microbial metabolism through metabolic system biology research is

never easy. In metabolic engineering, on the other hand, metabolic pathways, networks, and regulation information in databases are combined with microbial genomic information to develop genomic engineering techniques that are implemented to maximize the microbial production of metabolites. The world has become greener in recent years, and environmental safety is seen as a crucial concern in every way. Even though synthetic chemicals like fungicides provide adequate control over plant diseases, their toxicity to the environment, persistence in the environment, and development of resistance have compelled us to focus more on microbial metabolites for a variety of applications, including the control of plant diseases. Furthermore, structural analyses are crucial for the initial screening process to determine whether the compounds are unique or not. The creation of an extensive database that contains the structures of every purified metabolite in connection with its function is necessary for these kinds of investigations. Even though there are a lot of these structural databases available right now, the importance of structure and function has not yet been taken into account.

Conclusion

We can conclude that employing the microbial metabolites produced by antagonistic bacteria to biologically control plant diseases is an appealing alternative to chemically created pesticides. Their uniqueness and lack of persistence made it possible to handle plant diseases in an environmentally benign manner and allow us to grow crops in an organic manner without endangering the environment. Additionally, the production of plant protection compounds using these microbial metabolites as lead molecules opens up new opportunities for manufacturers and entrepreneurs. The identification of novel agroactive metabolites using more recent scientific techniques, including microbial metabolic engineering, has not yet been actively pursued.

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Value Added Products of Millets

Archana Bhagat, Ragini Modi and Ajay Baldaniya

Introduction

Millets also called small millets are cultivated for their small kernels which are the products of small grassy plants belonging to the Poaceae family. The other name minor millets may indicate them to be minor crops yet are important for their nutritional values, medicinal benefits, feed for animals, and saviors during food crisis (Yenagi *et al*., 2010). The term "millet" comes from the French word "Mile" which means "thousand," implying that a handful of millets can contain thousands of grains. Millets are typically farmed in semi-arid areas. Conditions such as little rainfall and degraded fields with poor nutritional content. Millets provide a more consistent harvest than other crops in low rainfall areas, benefiting people in famine-prone areas (Tadele, 2016). Millets are C_4 plants with high photosynthetic efficiency, short duration, high dry matter production capability, and resistance to heat and drought. They can easily adapt to degraded saline, acidic, and aluminum-contaminated soils. The modern sedentary lifestyle associated with several health issues has urged people to seek for healthy and nutritious diets. Small millets satiate these requirements of modern society by being a healthy food choice because millets are a storehouse of nutrient and, in particular, finger millet grains contain remarkably high calcium content (>350 mg/100 g); foxtail millet, barnyard millet, and proso millet are prosperous in protein (>10%); little millet and foxtail millet are well-off in fat (>4.0%); foxtail millet, barnyard millet, and little millet are superior in crude fiber (6.7-13.6%), barnyard millet and little millet contain high amount of iron (9.3-18.6 mg/100 g) in comparison to other major cereals like rice, wheat, barley, maize, and sorghum (Dwivedi *et al*., 2012). The important millets cultivated in African and Asian countries include Sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), barnyard millet (*Echinochloa frumentacea*), kodo millet (*Paspalum scrobiculatum*), proso millet (*Panicum miliaceum*), and little millet (*Panicum miliare*). Although millets have a high nutritional content, their hard seed coat, presence of anti-nutritional agents, low digestibility, and limited bioavailability of micronutrients pose significant challenges in their processing and cooking.

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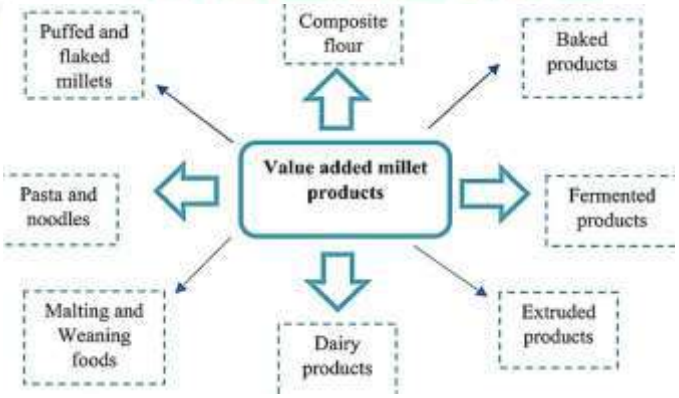
Table: 1 Millets grown in India and their uses

Crop	Scientific name	Common name	Uses
Sorghum	*Sorghum bicolor*	Jowar	Potential source of biofuel; used to brew gluten-free beer Used as a wheat substitute for people on a gluten-free diet Commonly used in agriculture as feed for livestock
Pearl Millet	*Pennisetum glaucum*	Bajra	Rich in protein, fiber, phosphorous, magnesium and iron
Finger Millet	*Eleusine coracana*	Ragi/Mandua	Rich in calcium and polyphenols
Foxtail Millet	*Setaria italic*	Kanngani/kakun	Food for diabetics and poultry food
Barnyard Millet	*Echinochloa frumentacea*	Sawa	High in crude fiber and iron
Little Millet	*Panicum sumatrense*	Kutki	High in iron content and dietary fiber

In light of this, the Indian government proposed making 2023 the "International Year of Millets". It was supported by FAO Governing Bodies and the United Nations General Assembly at its 75th session. The following are the objectives of declaring 2023 the 'International Year of Millets': 1) Elevate awareness of the contribution of millets to food security and nutrition. (2) Inspire stakeholders on improving sustainable production and quality of millets. (3) Draw focus on enhanced investment in research and development and extension services to achieve the other two aims.

Processing of Millet

Generally speaking, the main step in processing grains and coarse cereals is to remove the offal, or portion that is unfit for human consumption. Offal is made up of the pericarp and occasionally the germ. The removal of offal is referred to as dehulling or decortication. The primary causes of millets' lower appeal among consumers of wheat and rice include their tough outer coat, a flavor that is similar to that of other grains, and the lack of processed millets that resemble rice and wheat. Numerous machinery are available for processing cereals, but no tried-and-true technique exists for turning colored millets into white products. For decortication, abrasive dehullers such as rice dehullers are occasionally employed. There was relatively little loss of minerals. Additionally, decoration increases nutrient availability and customer appeal. When cooked whole or decorated, millets can be consumed as a traditional grain or as a unique dish. They can also be ground into flour using conventional or industrial methods. However, it's necessary to look for other applications. Unlike wheat and rice flour, which can create an elastic, cohesive, and extended dough when mixed with water, millet flours cannot do so because they lack gluten.



Value added products of Millets

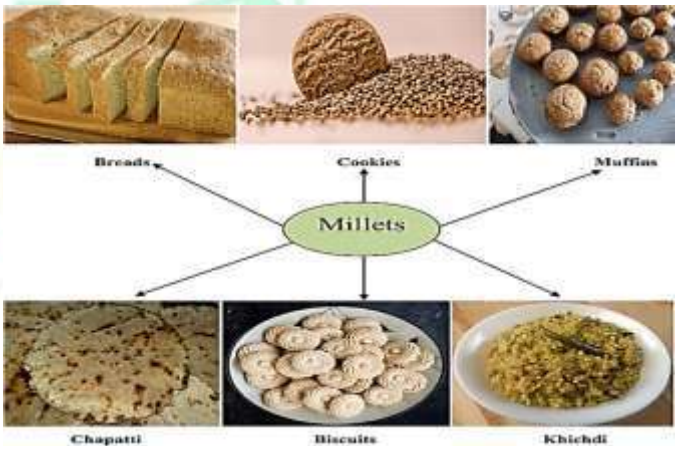
Millet flakes: Quick cooking cereals should be developed by using the beneficial property of millets to cook soft within 5 10 min when dropped in boiling water. For preparing the flakes pearled grains are cooked at high pressure, to gelatinize the starch completely, after drying to moisture content as 18%

it pressed between heavy duty rollers (Rao *et al*., 2016). The small size of millets is suitable for flakes production. When flakes are added to milk or water they hydrate quickly.

Puffing or popping: For preparing the ready to eat products puffing or popping is a simple processing technique. Popped grain is a porous, precooked and crunchy product and also has a good taste by adding flavour. For preparing expanded millet decorticated finger millet required a high temperature short-time treatment. For maximum expansion ratio the two factors play an important role first is flattening the grains to the desired shape and second is the moisture content.

Bakery products: A lot of bakery goods, including nankhatai, biscuits, bread, and muffins, are made with millet flour. To make the dough elastic and extendable Gluten is a crucial component of millet grains, but their lack of gluten renders them unsuitable for handling pure millet solid food products, especially those made in bakeries or noodles. Millets with exceptional micronutrient and fiber content have good potential as a result of their debut into the bakery industry. In recent years, finger millet flour has drawn interest, and efforts have been undertaken to make it accessible to customers in convenient formats (Singh *et al*., 2012).

Bread: Bread constitutes a bakery product comprised primarily of water, flour, salt, yeast, sugar, and fat. These components undergo mixing and fermentation to generate a vis coelastic dough, subsequently subjected to baking. The characteristics of bread made from blended flours with varying proportions of wheat and pearl millet (PM) (10, 20, 30, & 40%) were investigated by Nehra *et al*. (2021) While there was a negative trend observed for loaf volume, the physical parameter of loaf weight increased with the addition of PM flour. A satisfactory sensorial score was found for bread compositions containing up to 30% PM flour to WF. However, after this point, the bread's unacceptable quality was caused by the added PM flour. The overall sensory score of bread made with wheat flour was 7.9, while that of bread made with PM ranged from 5.1 to 7.1.



Millet Cereals: Extruded millet cereals are a quick and nutritious breakfast option. They often come in different shapes and are fortified with vitamins and minerals.

Millet Pasta: Extruded millet pasta provides a gluten-free alternative to traditional wheat-based pasta. It retains a pleasant texture and pairs well with various sauces.

Millet Snack Mix: A mix of extruded millet shapes, combined with nuts, seeds, and dried fruits, creates a wholesome and flavourful snack mix.

Millet Ice-cream: It was discovered that the millet-based ice creams included a significant quantity of calcium, phosphorus, protein, fat, and carbohydrates. People with lactose intolerance, milk protein allergies and vegans can all drink this non-dairy ice cream made with barnyard millet, soy, and coconut extract, which has demonstrated improved accept-ability (Amritha *et al*., 2021).

Millet Based Beverages: Millet-derived beverages, encompassing both alcoholic and non-alcoholic varieties such as malwa, Bantu, pombe, and opaque or kaffir beer, exhibit greater prevalence in comparison to alternative products. Millets are used to generate a range of beverages in addition to food items. Millet-based milk substitutes, like millet milk or millet-based dairy-free drinks, are a well-known example. To make these drinks, millet grains and water are combined, then the combination is strained to produce a creamy, smooth liquid. Drinks made from millet can be consumed on their own or substituted for cow's milk in recipes and beverages, making them appropriate for people on a vegan or dairy-free diet. Furthermore, millet grains can be used to create traditional fermented drinks that are popular in various cultures, such as millet beer or alcoholic cocktails made from millet. These drinks are produced using fermentation techniques that are comparable to those used to make wine or beer.

Conclusion

In the quest for a wholesome and sustainable food landscape, millet processing and value addition become essential elements. The variety of processing methods presented in this analysis helps to preserve the natural nutritional advantages of millet-based products while also making them more accessible. Investing in millet processing and value addition becomes essential as we manage the difficulties of a rapidly evolving global food chain. Millets are cheaper but less convenient to use as it is not so popular among the people and its use in food is limited to only poor and traditional people. There are different methods and processes for preparing the products from millets only and mixing the millets with other ingredients, these methods can same as that of wheat and rice and may be different from that as the physical chemical properties of the millets are different from the other cereal grains.

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Climate Change: Factors, Reasons, Consequences and Mitigation Strategies

Bhumit Lakra, Rohit Gill and Ajay Baldaniya

Introduction

Climate change is defined as the shift in climate patterns mainly caused by greenhouse gas emissions. Greenhouse gas emissions cause heat to be trapped by the earth's atmosphere, and this has been the main driving force behind global warming. The main sources of such emissions are natural systems and human activities. Natural systems include forest-fires, earthquakes, oceans, permafrost, wetlands, mud volcanoes and volcanoes (Yue and Gao 2018), while human activities are predominantly related to energy production, industrial activities and those related to forestry, land use and land-use change. Climate changes and global warming of our planet are one of the most debated topics in Earth, Atmospheric and Space sciences in the last 30 years. There are numerous components to climate change, and they have varying effects on human and biological systems. The significant regional variation in the effects of climate change has been extensively researched; significant variations in temperature rise between land and sea, as well as between high and low latitudes, are obscured by global average temperature increases; precipitation is likely to increase in high latitudes while decreasing in the majority of tropical and subtropical land regions (IPCC, 2007). It is generally predicted that climate and weather variability will rise in tandem with global warming. Both natural and human systems will be significantly impacted by changes in the frequency and intensity of extreme climate events as well as in the variability of weather patterns. Increasing frequencies of heat stress, drought and flooding events are projected for the rest of this century, and these are expected to have many adverse effects over and above the impacts due to changes in mean variables alone. An understanding of the severe impact of climate change on natural and human systems as well as the risks and associated vulnerabilities is an important starting point in com prehending the current state of climate emergency. Changes in climate indicators, namely temperature, precipitation, seal-level rise, ocean acidification and extreme weather conditions have been highlighted in a recent report by the United Nations Climate Change Secretariat (UNCCS). Climate hazards reported included droughts, floods, hurricanes, severe storms, heatwaves, wildfires, cold spells and landslides.

Factor and Reason of Climate Change

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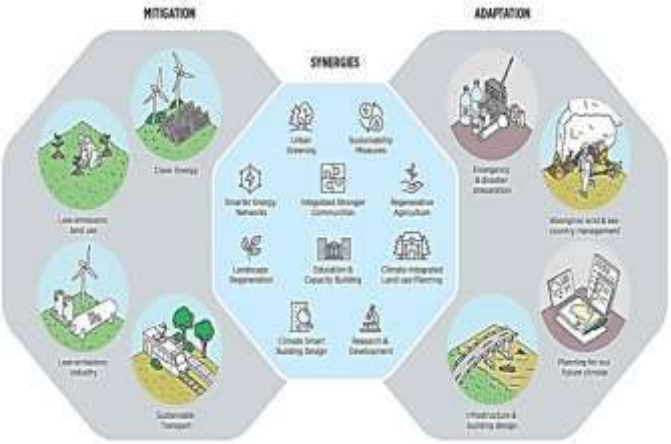
Agriculture is both a victim and a contributor to climate change. Agriculture in India is directly responsible for 14% of total green-house gas emission. Deforestation currently accounts for an additional 18% emission. Large scale changes such as deforestation, soil erosion or machine intensive farming methods may contribute to increased carbon concentration in the atmosphere. Farm animals also contribute significantly to greenhouse gas emissions worldwide. Methane and nitrous oxide are two potent greenhouse gases that are released in large quantities, especially during farming. Livestock create methane during digestion as a result of intestinal fermentation, which is then expelled through belches. Additionally, it escapes from organic waste and manure that are kept in landfills. Other than livestock, paddy fields also favor methane emission due to anaerobic conditions generated because of their continuous flooding. Nitrous oxide emission are an indirect product of organic and mineral nitrogen fertilizers.

The cooling industry is important, but it is also incredibly polluting accounting for around 10% of global CO_2 emission. As the temperature around the world continues to rise due to climate change, the demand for cooling is increasing too. The impact of refrigeration and air conditioning installations on climate change has been principally through energy consumption (produced in general by burning fossil fuels that emits CO_2 into the atmosphere) and the past emission of CFCs. CFCs were the most common type of coolant/ refrigerant used in these devices. But after they were found to be depleting the ozone layer they were replaced by new generation fluids such as HFCs and HCFCs. These refrigerants break down ozone molecules far less, but are extremely potent green-house gases. Their capacity to warm the atmosphere is thousands of times greater than carbon dioxide. Poorly designed, badly maintained installations or refrigeration units abandoned at the end of their life without recovering or recycling the refrigerant fluid can lead to emissions into the atmosphere.

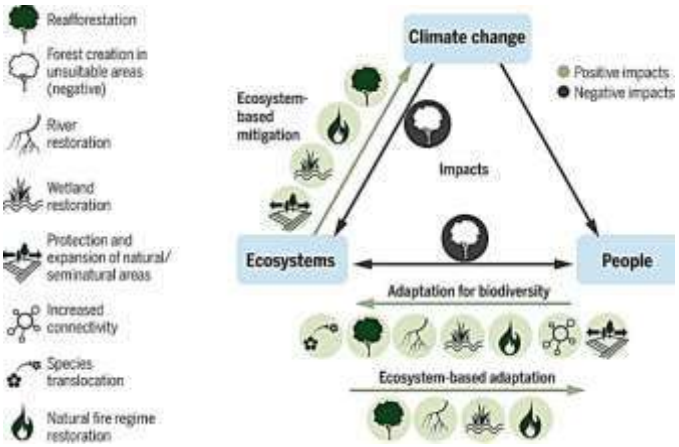


Impacts of climate variability and extremes

Biological systems: Warmer climates will generally accelerate the growth and development of plants, but overly cool or hot weather will also affect productivity. Earlier flowering and maturity of several crops have been documented in recent decades, often associated with higher temperatures. Increases in maxi mum temperatures (as climate or weather) can lead to severe yield reductions and reproductive failure in many crops. In maize, each degree day spent above 30 °C can reduce yield by 1.7% under drought conditions. Impacts of temperature extremes may also be felt at night, with

rice yields reduced by 90% with night temperatures of 32 compared with 27 °C (Mohammed &Tarpley, 2009). In contrast to the effects of temperature and photoperiod at optimum and suboptimum temperatures, crop response to temperature and photoperiod at supra optimal temperatures is not well understood. Extreme weather events and climate variability may also have an impact on yield quality. It has been demonstrated that variations in the average and variability of temperature and precipitation have an impact on the protein content of wheat grain; in particular, high temperatures during grain filling can have an impact. Future projections of increased rainfall variability will have a significant effect on primary productivity as well as the ecosystem provisioning services that forests and agroforestry systems offer. Climate variability must be taken into consideration notwithstanding the uncertainty surrounding the specific changes. For instance, if only changes in climatic conditions are taken into consideration and climate variability is noted, the effects of climate change on crop yields in portions of East Africa towards the middle of this century may be underestimated by 4% to 27%, depending on the crop (Rowhani *et al*., 2011).

Food systems, health and nutrition: Climate variability has both direct and indirect impacts on human health. Extreme heat affects health, especially among the elderly. Other direct effects are mostly manifested in the way that temperature and precipitation interact with infectious and vector-borne diseases.



For instance, variations in the seasonal distribution of precipitation, especially shifts in patterns of flooding and drought, have a significant impact on cholera, dengue, and malaria. The steady rise in temperature will cause changes in malaria vectors, but variations in precipitation will also have a significant impact on illness incidence. As the vector spreads to new locations, we may witness an increase in epidemics if shifts in climate variability result in modifications to the temporal and geographical variation of vegetation and water distribution. Human displacement from extreme events, especially floods, could become more frequent with an increase in climate variability. This also often has negative consequences for human health, not least because of crowded conditions with poor sanitation. Good health outcomes are linked to nutrition, and getting enough calories, as well as enough protein and variety in one's diet, is crucial. As previously mentioned, there is a link between climate variability and overall food availability. The study by Lloyd *et al*. (2011) expands on earlier research by Nelson (2009) to demonstrate unequivocally that by affecting food production, climate change and incre-

ased climate variability will have a detrimental effect on the prevalence of under-nutrition, increasing severe stunting by 62% in South Asia and 55% in East and Southern Africa by the 2050s.

Mitigation strategies

After the United States and China, India is the third-largest emitter of greenhouse gases. Our communities, economy, security, health, and the future of our children are already under danger due to the effects of climate change. based on a recent assessment by the Intergovernmental Panel on Climate Change (IPCC). To prevent the most disastrous consequences of global warming, we must drastically and promptly reduce greenhouse gas emissions. Only when people take action does change occur. If it doesn't begin with the people, there is no other option. We need to extract some carbon from the atmosphere and dramatically reduce emissions in order to fight climate change. Thankfully, CO_2 is naturally absorbed and stored by plants. We can store billions of tons of this "living carbon" by planting trees, preserving wetlands and forests, and safeguarding natural habitats. The Telangana Forest Department is an excellent example for all of us. With the assistance of villagers, they restore a 160-acre damaged and encroached forest piece in the center of the Kawal Tiger Reserve to its lush splendor. In this respect, our meager efforts could have a huge impact. We might limit the use of electricity, private automobiles, air conditioners, heaters, and freezers in order to further cut emissions. In addition, farm operations ought to be more environmentally friendly. Methane emissions can be decreased in irrigated rice fields without sacrificing output by controlling water use (allowing the land dry after irrigation as opposed to continuously flooding it). This method also uses less energy for pumping water (where groundwater is used to irrigate rice fields), managing manure and livestock feed better, using nitrogen fertilizers efficiently, implementing zero tillage techniques, preventing the burning of rice crop residue, and lowering farm energy consumption and substituting it with green energy, all of which can effectively reduce greenhouse gas emissions from farming.

Conclusion

Changes in climate Due to recurring changes in the earth's climate, it has caused significant changes in the weather pattern. It has detrimental effects on the world's water supply, ecosystem, and human health, among other things. The ingenious and imaginative approaches to mitigating and adapting to climate change must be acknowledged immediately. Anthropogenic greenhouse gas emissions must be managed to achieve net zero emissions in order to lower the hazards involved, facilitate sustainable development, enhance human health, and lessen long-term vulnerability.

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Role of Polyamines in Fruit Ripening and Senescence

Harish Menpadi, Chandrakant Dhum and Shrikrishna Balaso Narale

Introduction

Fleshy fruits are rich in sugars, vitamins, minerals, antioxidants, and fibers, which are essential components of food and contribute to human nutrition and health. Fruits ripen via a cascade of complex physiological, biochemical, and molecular processes that coincide with changes in the texture, color, flavor, and aroma of fruits. Based on their respiration rate, ethylene emissions, and ripening process, fleshy fruits can be classified into climacteric and non-climacteric types. In climacteric fruits, such as the prototype model species tomato (*Solanum lycopersicum*), ripening is controlled by ethylene (Alexander and Grierson, 2002). In non-climacteric fruits, such as strawberry (*Fragaria ananassa*), ripening is largely controlled by ABA. Polyamines (PAs) are the aliphatic, cationic organic compounds participating in the growth and development of living organisms. Naturally found PAs include putrescine (PUT), spermine (SPE) and spermidine (SPD). PAs exist both in free and conjugated forms in plants. The amine functional group in these compounds leads to their varying functional properties in the physiology of living organisms and plant systems.

Market potential is diminished when senescence appears in the fruits after harvest. Following harvest, ethylene production peaks, causing the fruit's outer peel to shrivel and losing flavor and other quality characteristics, ultimately reducing shelf life. By removing free superoxide radicals, which are basically necessary for the conversion of ACC to ethylene, PAs inhibit the transcriptional synthesis of ethylene and 1-aminocyclopropane-1-carboxylic acid (ACC)-synthase, which in turn inhibits the activity of ACC oxidase. PAs imparts the firmness to the fruit under storage by developing the electrostatic bonding with the negatively charged pectic substances in the cell walls of fruits. Therefore, when PAs are applied exogenously, they play a vital role in enhancing the shelf life of fruits. This has been discussed in few reviews but with a lack of comprehensive approach regarding the postharvest physiological roles of PAs in enhancing the shelf life. Early reviews on PAs have focused on the role in mitigating chilling injury (CI) in fruits and vegetables, stress tolerance under diverse stresses.

Importance of Polyamines

Flower Bud Differentiation: Exogenous applicatio-on of polyamines helps for flower bud differentiation

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Especially in horticultural crops for example, Chrysanthemum.

Somatic Embryo Development: In sugarcane, polyamines induce somatic embryo development.

Grain Filling and Weight: Polyamines contribute to increased grain filling rates and grain weight in wheat.

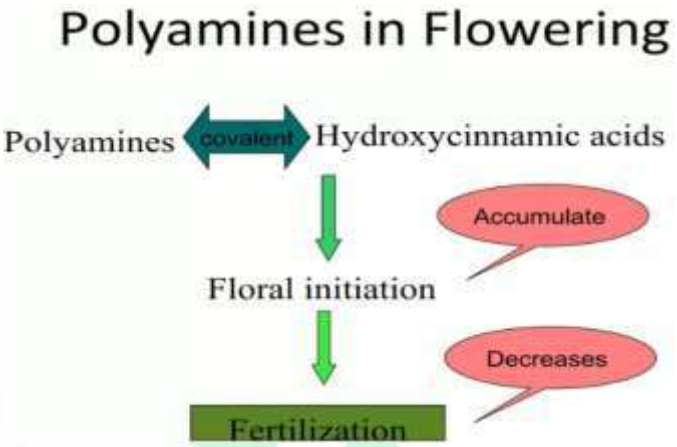
Senescence delay and Quality improvement: Exogenously applied polyamines leads to inhibition of ethylene biosynthesis thereby delay senescence and enhance the quality of various crops. *E.g.*: Cut-flowers like Anthurium, Gerbera.

Abiotic and Biotic Stress Tolerance: Polyamines actively in maintainenace of abiotic and biotic stress in crops (Chen *et al.*, 2018). Their stress-protective role involves improving stress tolerance through both exogenous application and genetic manipulation of endogenous polyamine levels. Under abiotic stress conditions, polyamines improving various defense mechanisms. Specifically, they enhance seed germination, shoot growth and root growth, facilitating better adaptation to adverse environmental conditions. Polyamines also contribute to the enhancement of photosynthesis, ensuring continued energy production even under stress. Polyamines increase ROS scavenger enzymes activity, help alleviate oxidative stress and maintain cellular homeostasis, thus promoting plant survival and resilience under adverse environmental conditions (Paul and Arthanari, 2022).

Water Loss Regulation: Polyamines play a role in controlling water loss in plants.

Salt Tolerance: Plants rich in polyamines exhibit strong salt tolerance, as observed in Panax ginseng, citrus seedlings and cucumber.

Heavy Metal Tolerance: Exogenous application of polyamines enhances tolerance to heavy metals in crops.



Regulation of Oxidative stress: Polyamines improving the reactive oxygen species (ROS) scavenging enzymes. Polyamines act as important regulators in the plant's antioxidant defense system by upregulating the activity of various ROS-scavenging enzymes such as superoxide dismutase (SOD) the dismutation of superoxide radicals into hydrogen peroxide and oxygen while catalase (CAT), peroxidases (POX) and ascorbate peroxidase (APX), work together to decompose hydrogen peroxide into water and oxygen, thus neutralizing ROS and preventing oxidative damage. ROS are generated as natural by-products of metabolic processes or as a response to stressors such as drought, high salinity, or extreme temperatures.

Biosynthesis of Polyamines

The polyamine biosynthesis pathway involves direct synthesis of putrescine from ornithine by

ornithine decarboxylase and indirect synthesis of arginine through the cooperation of several enzymes. Spermidine and spermine are then formed by adding an aminopropyl fragment to putrescine and spermidine, respectively. Enzymes such as diamine oxidase and polyamine oxidase promote the breakdown of polyamine. This biosynthetic pathway is linked by SAM to the ethylene biosynthetic pathway, which acts as a precursor to both polyamines and ethylene. Putrescine in particular can be synthesized directly from ornithine or indirectly from arginine.

Roles in Metabolic Process of Fruit Ripening and Senescence

Polyamines are a new class of plant biostimulants with significant effects on plant growth, development and response to environmental stressors. Due to advances in molecular biotechnology, there is increasing evidence that polyamines, whether applied externally or produced internally through genetic engineering, can improve plant growth, yield and stress tolerance. The metabolic pathways of polyamines in plants are complexly linked to many other metabolic processes. Hydrogen peroxide (H_2O_2) generated during polyamine oxidation promotes plant signaling during both biotic and abiotic stress and affect abscisic acid induced stomatal closure. S-adenosylmethionine (SAM), the ethylene precursor of the polyamine biosynthetic pathway, competes with ethylene production. In addition, polyamine metabolism is involved in the formation of nitric oxide (NO), an important signaling molecule in plant development. Thus, by studying the interaction between polyamine metabolism and plant hormones and the effects of polyamine metabolism on plant signaling molecules, researchers can study the role of polyamines in plant growth and development and the processes that control their activity. Polyamines promote embryonic development, flowering and aging, and improve plant tolerance to temperature fluctuations, water shortage, salinity, oxidative stress and other environmental effects. During fruit ripening a series of physiological, biochemical and molecular changes occur that lead to changes. In terms of texture, color, taste and aroma. Ethylene regulates ripening in climacteric fruits, while abscisic acid regulates ripening in non-climacteric fruits. Polyamines play a crucial role in this process. S-adenosylmethionine decarboxylase (SAMDC) converts Putin to Spd/Spm, which coincides with the onset of fruit ripening, which is triggered by Spd in climacteric fruits and Spm in non-climacteric fruits. When polyamine oxidase (PAO) initiates polyamine catabolism, the coordination of polyamines, hydrogen peroxide (H_2O_2), abscisic acid (ABA), ethylene, nitric oxide (NO) and calcium ions (Ca^{2+}) promotes fruit ripening and aging of (Gao *et al.*, 2021).

Conclusion

Polyamines being biodegradable and environmental friendly organic compound, will promote sustainability by mitigating the postharvest losses of fruits. Stage of application and optimisation of concentrations of these compounds are of utmost

importance and of great consideration when exogenously applied. Their application at pre- and post-harvest phases will make a difference by mitigating the biotic and abiotic stress in horticultural crops as well. Polyamines contribute to various stages of plant development, including embryo growth, flowering and senescence, while also enhancing plant resilience to environmental adversities. They also play a crucial role in fruit ripening, with their metabolic pathways tightly regulated to orchestrate the ripening process effectively.

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Role of Salicylic Acid in Plant Diseases Management

Harish Menpadi, Ajay Baldaniya and Shrikrishna Balaso Narale

Introduction

Agriculture faces the formidable challenge of ensuring food security and sustainability in a world marked by a growing population and changing climatic conditions. The ability to mitigate the impact of abiotic and biotic stressors on crop productivity has become a critical pursuit in contemporary agriculture. Crops are being subjected to an increase in stressors (biotic and abiotic stress) as a consequence of the impact of human activity and the intensification of climate change, which has become the main factor in the deterioration of agricultural systems and the loss in grain output. Among the multifaceted strategies employed, the role of salicylic acid (SA) has emerged as a subject of increasing importance. SA, a naturally occurring plant hormone, has gained recognition for its pivotal contributions to enhancing stress tolerance and productivity in crops (Khan *et al*., 2015). The significance of SA in plant physiology lies in its capacity to orchestrate a myriad of responses to environmental stress. Abiotic stress factors, including drought, salinity, temperature extremes, and heavy metal toxicity, have been known to exact a toll on crop yields. Similarly, biotic stressors such as pathogens and pests pose substantial threats to agriculture. It is in the context of these adversities that SA has demonstrated its remarkable potential (Mana e*t al*., 2023).

"Salicylic acid (SA) is a naturally occurring small molecule phenolic compounds that possesses an aromatic ring and a hydroxyl group. It functions as a signal sensor to control plant response. Through the control of procedures including antioxidant defense, nitrogen metabolism, photosynthesis, and water stress, it shields plant cells from the toxicity of ion buildup and cell death" Because of its numerous physio-biochemical and developmental activities in hormonal interactions as well as its antioxidant characteristics, salicylic acid (SA), a common plant phenolic molecule, is an efficient stress reliever. It has been shown to increase tolerance and defense against pathogen attack, as well as to mitigate the harmful effects of several environmental stresses on plants, including low temperature and chilling, high temperature and drought, and salinity. Additionally, it improves seedling emergence and germination rates and percentages, ensuring adequate crop stand under a variety of environmental circumstances (Peng *et al*., 2021).

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Role of Salicylic Acid in Plant Disease Management

Salicylic acid (SA) plays a significant role in plant disease management due to its involvement in the plant's defense mechanisms against pathogens.

Induction of Systemic Acquired Resistance (SAR): Salicylic acid is a key signaling molecule involved in the activation of SAR, which is a systemic response that enhances the plant's resistance to a broad spectrum of pathogens. When a plant is infected by a pathogen, it produces SA as part of its defense response. SA then travels to other parts of the plant, inducing resistance against subsequent pathogen attacks.

Activation of Pathogenesis-Related (PR) Genes: Pathogenesis-related (PR) genes, which encode proteins involved in defense responses to pathogens, are activated by salicylic acid. These proteins might strengthen the plant cell wall and make it harder for pathogens to infiltrate, or they might have antibacterial qualities.

Interference with Pathogen Growth: Salicylic acid can directly inhibit the growth and development of certain pathogens. It disrupts the metabolism of pathogens or interferes with their ability to colonize plant tissues, thereby reducing disease severity.

Crosstalk with Other Defense Signaling Pathways: Salicylic acid interacts with other defense signaling pathways, such as jasmonic acid (JA) and ethylene signaling pathways, to coordinate the plant's response to different types of pathogens. While SA primarily activates defenses against biotrophic pathogens (which rely on living plant tissue for their nutrition), JA and ethylene are involved in defenses against necrotrophic pathogens.

Enhancement of Plant Immunity: Overall, salicylic acid enhances the immune response of plants to pathogen attacks, leading to reduced disease incidence and severity. It primes the plant's defense mechanisms, making it more effective at recognizing and responding to pathogens.

Mechanisms of Salicyclic Acid mediated Stress Mitigation

Salicylic acid (SA) exerts its role in mitigating both abiotic and biotic stress through a complex array of molecular and biochemical mechanisms. Understanding these mechanisms is essential for appreciating the diverse ways in which SA enhances stress tolerance in crops and improves their overall productivity.

Signaling Pathways: At the heart of SA-mediated stress mitigation lies its interaction with signaling pathways. SA acts as a pivotal signal molecule, initiating a cascade of responses that enable plants to withstand environmental stress. These pathways include SA-specific signaling, the mitogen-activated protein kinase (MAPK) cascade, and hormonal crosstalk.

Gene Expression Modulation: One of the fundamental mechanisms through which SA enhances stress tolerance is the modulation of gene expression. SA triggers the expression of stress-related genes, which results in the production of stress-responsive proteins and enzymes. These gene products play a

Table 1: Response of Salicylic acid to plant abiotic stress

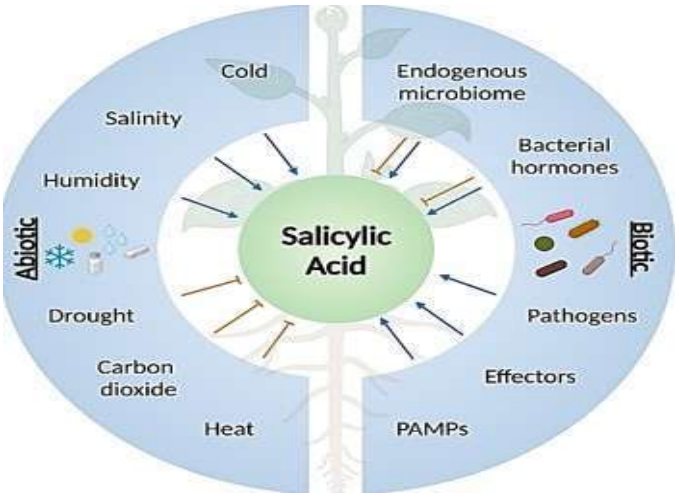
Stress factor	Plant species	Salicyclic acid role
Heat/Cold	Citrus	Involvement in fruits' heat-induced cross-adaptation to chilling
Heavy metals	Rice	Regulation of stomatal aperture through the OsWRKY45-reactive oxygen pathway; regulation of adaptation to soil salinity and drought stress
Heat	Maize	Significant elevation of transcripts of SA biosynthesis and signaling, and heat stress-responsive genes in SO_2 pretreated seedlings; improvement of seedlings' thermotolerance
Cadmium	Tomato	Significant reduction of cell wall Cd accumulation; changes in Cd distribution
Deficient irrigation	Potato	Significant enhancement of growth characteristics, yield components and photosynthetic attributes
Saline stress	General plants	Induction of saline stress tolerance
Water logging stress	Soybean	Reduction of some physiological indexes by SA and KN; enhancement of antioxidant defense by SA and KN; effective improvement of ROS metabolism and waterlogging stress tolerance

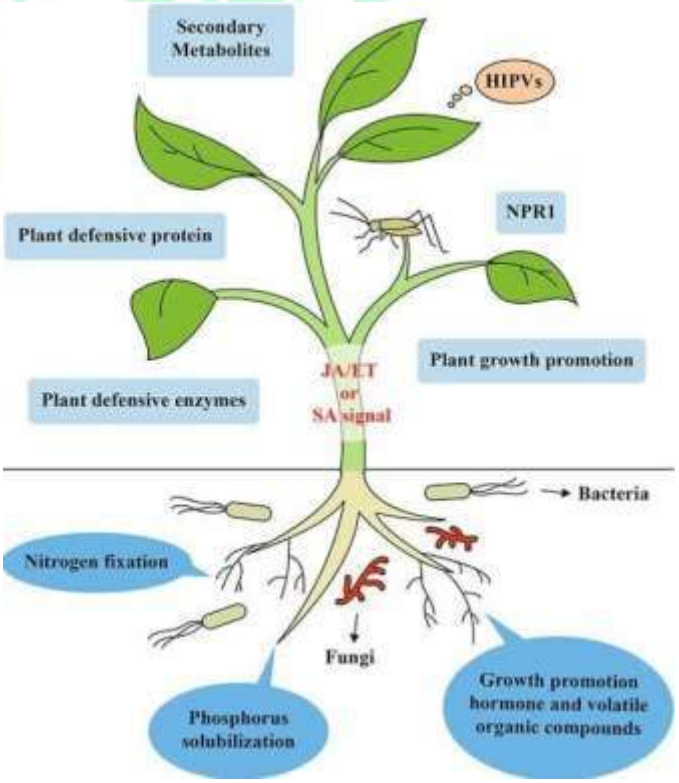
Table 2: Enhanced disease resistance upon exogenous SA application in different plants

Host Plant	Pathogen	Effect	Reference
Tomato	*Fusarium oxysporum*	~55% reduction in disease incidence	Jendoubi *et al*. (2017)
Pepper	*Ralstonia solanacearum*	*R. solanacearum*-induced seedling growth inhibition is recovered.	Chandrasekhar *et al*. (2017)
Rice	*Magnaporthe grisea*	~70% reduction in disease severity	Daw *et al*. (2008)
Orange	*Xanthomonas axonopodis*	~45% reduction in disease incidence	Wang and Liu (2012)
Black gram	*Mungbean yellow mosaic Indian virus*	~71% reduction in disease severity	Kundu *et al*. (2011)

crucial role in stress adaptation and the defense against pathogens.

Antioxidant Defense: Under stressful conditions, plants often accumulate reactive oxygen species (ROS), leading to oxidative stress. SA helps counteract this by stimulating the synthesis and activation of antioxidant enzymes. Superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) are among the enzymes that neutralize ROS and reduce oxidative damage.





Conclusion

Salicylic acid and its derivatives as one of the plant hormones produced by the plant naturally belong to the group of phenolic acids and consist of a ring linked to the group of hydroxyl and carboxyl

group, and the starting ingredient to form the cinnamic acid. Salicylic acid plays a multifaceted role in crop production by promoting growth, enhancing stress tolerance, improving nutrient uptake and utilization. It also plays a multifaceted role in plant disease management by activating defense mechanisms, inhibiting pathogen growth, and enhancing overall plant immunity. Its involvement in SAR and PR gene expression makes it a crucial component of the plant's defense arsenal against pathogens.

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Stevia: An Alternative to Artificial Sweeteners

Shivam Dinkar, Ramdas Bhimrao Shende and Ajay Baldaniya

Introduction

Stevia rebaudiana is a small perennial growing up to 65-80 cm tall, with sessile, oppositely arranged leaves. Different species of Stevia contain several potential sweetening compounds, with *S. rebaudiana* being the sweetest of all. Stevia is a semi-humid subtropical plant that can be grown easily like any other vegetable crop even in the kitchen garden. The soil should be in the pH range 6.5-7.5; well-drained red soil and sandy loam soil. Saline soils should be avoided to cultivate this plant. Stevia has been successfully cultivated in recent years in many areas of Indian states: Rajasthan, Maharashtra, Kerala and Orissa. The increasing demands for natural sweeteners have driven the farmers in India toward large-scale Stevia cultivation. Diterpene glycosides are the group of natural sweeteners that have been extracted from Stevia. It was reported that there are around 150 species within the Stevia family including *Stevia dianthoidea, Stevia Phlebophylla, Stevia anisostemma, Stevia bertholdii, Stevia crenata, Stevia enigmatica, Stevia eupatoria, Stevia lemmonii, Stevia micrantha, Stevia ovata, Stevia plummerae, S. rebaudiana, Stevia salicifolia, Stevia serrata* and *Stevia viscida* with all plants being sweet but *S. rebaudiana* having the highest sweetness levels. According to Carakostas *et al.* (2008), it is also referred to as honey yerba, sweet herb, sweet leaf, honey leaf, and candy leaf. It was native to the wilds of South America and grew in semi-arid environments that ranged from mountains, grasslands, and scrub forests. In the southern hemisphere, this short-day plant blooms from January to March. The flowers have a faint purple throat and are white in color. They are grouped into tiny corymbs and are not very large. It is grown commercially in China, Thailand, Brazil, Korea, Paraguay, and Central America and is used as a sweetener in many countries (Kim *et al*., 2002). In 1952 saw the establishment of the chemical structure as a diterpene glycoside. Eight delicious diterpene glycosides, including isosteviol, stevioside, rebaudiosides (A, B, C, D, E, F), steviolbioside, and dulcoside A, are naturally present in the complex composition of stevia leaves (Rajasekaran *et al*., 2008). The two main metabolites of the several steviol glycosides (SGs) are stevioside and rebaudioside A. These substances are 250-300 times sweeter than sucrose and may have health benefits. Stevia contains flavonoids, tannins and certain essen-

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tial oils, which contribute to its sweetness and bitter aftertaste.

Phytochemicals in Stevia Leaves: According to reports, stevia contains the following phytochemicals: riboflavin, steviol, stevioside, thiamine, β-carotene, dulcoside, nilacin, rebaudi oxides, and austroinullin (Jayaraman *et al.*, 2008). There have also been prior reports on the detection of rutin, trans-ferulic acid, caffeic acid, and chlorogenic acid in stevia leaves extracted by the maceration procedure. It was discovered in the published literature that the solvents and the extraction techniques utilized affect the stevia leaf extracts' composition and the concentration of the bioactive chemicals. In fact, alkaloids, tannins, flavonoids, glycosides, saponins, quinone, and triterpenes were found in the first screening of the phytochemicals of stevia leaf extract (Milani *et al.*, 2017). Glycosides were the main component of the ethanol leaf extract, with alkaloids and tannins following in larger amounts but less prominently than glycosides. Lastly, triterpenes and saponins were found in the lowest concentrations, but flavonoids and glycosides were found at moderate levels. However, the main components of the ethyl acetate leaf extract were tannins and glycosides, with alkaloids and flavonoids coming in second and third, respectively, to glycosides. Quinone was found in the smallest quantity, whereas triterpenoids and flavonoids were found in moderate amounts.

Applications of Stevia: Stevia is utilized in various food products (Sauces and pickles, ice creams and iced cakes etc.) and also being utilized in certain pharmaceutical formulae due to possessing a non-fermenting property of stevia. So, the product can be utilized in many industries as natural sweetener. FSSAI has recently approved use of stevia glycoside as a non-calorific sweetener in various food items, the dairy products, non-carbonated beverages, jellies, marmalades; ready to eat cereals, carbonated water and soft drinks.

Health Benefits of Stevia: Stevia has anti-fungal and anti-bacterial properties. Stevia is demonstrated to decrease the Type II diabetes and its complications. Thus, sugars and artificial sweeteners can be replaced with stevioside to support healthy glucoregulation. Stevioside and stevia extract have the ability to prevent microbial growth, and polyphenolic compounds found in stevia leaf extracts have been demonstrated to have an inhibitory effect on the development and spread of malignancies. Studying the effects of stevioside (250 mg three times per day for three months) in human volunteers with moderate hypertension revealed a decrease in blood pressure.

Stevia Instead of Sugar and Artificial Sweeteners

There is a growing interest in the food industry to replace sucrose in foods, beverages and other consumables due to its public health con cern. However, it is a difficult task to reduce sucrose from

foods because it has a unique profile of sweetness that is difficult to replace, and it is crucial for texture, structure, flavor and preservation of food products. Therefore, food manufacturers face a great challenge to reduce sucrose in food products without influencing sensory perception.

Stevia can act as a great substitute for sugar. Because it is low calorie sweetener, it may helps to lower the blood sugar and cholesterol levels. Stevia (steviol glycosides) is 200-250 times sweeter than regular sugar and it is a popular choice for many people looking to lose weight and decrease sugar intake. Replacing sugar with stevia also reduces the Glycemic Index (GI) of foods i.e., they lowers blood sugar levels. Whereas table sugar has a GI of 65, with 100 being the highest GI, causes the rapid increase in blood sugar level but stevia contains GI of zero. Inflammation, obesity, and the onset of chronic diseases including type II diabetes and heart disease have all been related to sugar and its various forms, such as sucrose and high fructose corn syrup (HFCS). In human peripheral lymphocytes, aspartame, acesulfame-K and sacch-arin caused DNA damage. Scientific experiments have demonstrated that sucrase reduces the number of helpful microorganisms. At high dosages, neotame can cause hepatotoxicity, headaches, and changes in body weight, among other adverse consequences in humans. It's ideal to use less sugar and fewer sugar replacements overall, although utilizing tiny amounts of this calorie-free sweetener may reduce sugar intake.

Conclusion

Stevia is a sweet and nutrient-rich plant that has been commercially cultivated in many countries. It has been used in food, beverages, and medicine, and still its benefits and use remains controversial due to conflicting studies. Besides its use in food and drug industry, studies have shown promising health benefits of stevia against diabetes, obesity, hyper-tension, cancer, dental caries, oxidative stress and as antimicrobial. However, most of the studies were either con ducted in vitro and animals or under-powered, making it impossible to make conclusive statements about its health benefits. Apart from sweet taste, stevia provides several health benefits and stevia can be used as a general-purpose sweetener in foods and beverages. Stevia can be used to develop new functional foods, because of its nutritional and therapeutic properties.

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E-Extension Service: Bridging the Information Gap for Sustainable Agriculture

Anuradha Subhashrao Lad, Rajesh Parbhatrao Kadam and Renuka Umeshrao Bangar

Introduction

Agricultural development has always relied heavily on the effective dissemination of knowledge and innovation to farmers. Agricultural extension services have played a pivotal role in ensuring this transfer of information, bridging the gap between research institutions and rural producers. Agricultural extension systems have undergone significant transformations over the decades (Norton *et al*., 2020). Furthermore, it helps to improve the livelihood of farmers and contributes to the development of rural communities (Alabi, 2021). Initially grounded in personal communication and field demonstrations, the earliest form of extension relied on village-level workers or local leaders who transmitted knowledge from research institutions to farming communities. The 1950s to 1970s witnessed the formalization of extension structures under national and state programs. The Training and Visit (T&V) system, introduced in the late 1970s with support from the World Bank, focused on professionalizing extension services by creating structured schedules and feedback mechanisms. With the Green Revolution in the 1960s and 1970s, extension services emphasized productivity enhancement through the dissemination of high-yielding variety seeds, chemical fertilizers, and irrigation techniques. The focus remained largely on production-centric messages. E-Extension represents a transformative shift in the way agricultural knowledge is shared with farming communities. By leveraging digital tools, it enhances the accessibility, accuracy, and timeliness of agricultural information. The term "e-Extension," which stands for "Electronic Extension," describes the use of digital tools to provide agricultural advising services. It entails the methodical sharing of innovations and knowledge with farmers through the use of information and communication technologies (ICTs), including satellite systems, digital videos, mobile applications, mobile phones, and internet platforms. E-extension encompasses more than just content digitization. Extension services are organized and delivered in a variety of forms, with the ultimate aim of increasing farmers' productivity and income. The question is how farmers can gain access to knowledge and information on improved practices along the value chain to adopt, and increase

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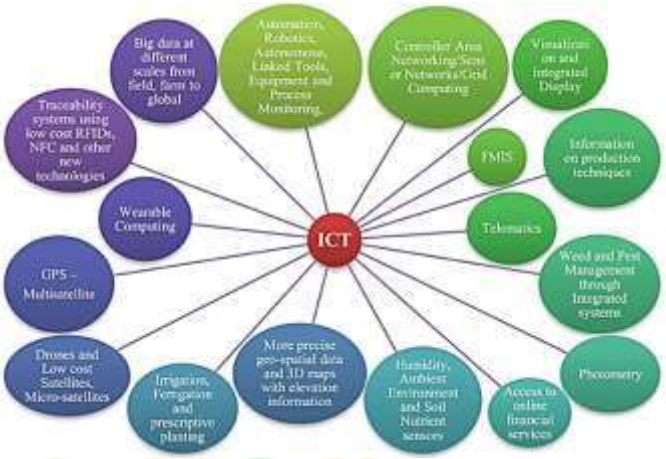
yield and income. The success of extension in achieving this will however depend on the extension approach that is being used to reach or communicate with farmers. The use of innovative approaches and strategies to increase coverage is therefore a concern for all involved in agricultural extension and advisory services.

Transition from Traditional Extension Systems to ICT-Based e-Extension

E-Extension refers to the use of Information and Communication Technologies (ICTs) to deliver agricultural advisory services and knowledge to farmers and stakeholders. It represents a shift from conventional extension methods, which relied heavily on face-to-face interactions, printed materials, and resource-intensive field visits, to ICT-enabled systems that leverage mobile phones, online platforms, and digital tools. Traditional extension systems have often been criticized for their limited reach and scalability, as a single extension officer serves several hundred to thousands of farmers (Agwu *et al*., 2023). This ratio has hindered the effectiveness of agricultural advisory services, especially in remote areas. e-Extension addresses these limitations by using ICTs to disseminate information at scale, providing real time, location-specific solutions to farmers. Mobile-based advisory platforms like mKisan and iCow reach millions of farmers, offering advice on crop management, weather updates, and market prices at the click of a button. The transition to e Extension has also democratized agricultural knowledge. ICT-based systems reduce dependence on intermediaries and ensure that even smallholder farmers have direct access to critical information. Research indicates that farmers using e-Extension services are 25-30% more likely to adopt innovative farming practices compared to those relying solely on traditional methods.



Area of Application

Crop advisory: Farmers can get detailed advice on crop choice, seed treatment, when to plant, when to schedule irrigation, and how to manage nutrients from digital platforms. Through web portals and mobile apps, tools like FarmRise, Krishi Network, and RML AgTech provide real-time crop management guidance.

Weather forecasting: Services like IBM's The Weather Company, Skymet, and the Indian Meteorological Department provide hyper-local weather forecasts to help farmers make timely decisions on sowing, irrigation, and harvest. These forecasts are delivered via SMS, apps, and automated voice calls.

Pest and Disease alerts: Mobile-based applications and AI-driven platforms are being used to detect

early signs of pest infestations or disease outbreaks. Platforms like Plantix and CABI's PestSmart provide image-based diagnostics and offer treatment suggestions in local languages.

Market Price Information: E-Extension enables farmers to access daily updates on market prices for various crops across different markets. AGMAR KNET and eNAM (National Agriculture Market) are key examples that reduce the risk of price exploitation and improve bargaining power.

Financial Services (insurance, loans): Farmers can access lending facilities, mobile banking services, and crop insurance through integration with financial instruments. Mobile-phone weather-indexed insurance is provided by platforms such as Digital Financial Services Lab and ACRE Africa, which connect farmers with service providers.

Training and Capacity Building: Online training modules, webinars, podcasts, and digital certification courses have become increasingly popular. Platforms like Shiksha, e-Samarth, and MANAGE's e-learning portal provide structured learning materials for farmers and extension agents.

Stakeholders Involved

Farmers: Primary beneficiaries who receive timely, relevant, and actionable information through various digital media.

Extension workers: Use E-Extension platforms to increase their reach, update their technical knowledge, and maintain continuous contact with farmers.

Agripreneurs and private companies: Startups and agritech firms play a critical role by developing innovative tools, offering custom solutions, and investing in scalable business models to support agriculture.

Government bodies and research institutions: Create and verify material, construct infrastructure, and create regulations that facilitate E-Extension deployment (Gichamba *et al*., 2017). Organizations that provide scientific inputs and technical knowledge include state agriculture agencies, SAUs, and ICAR.

NGOs and international organizations: Act as intermediaries and capacity builders by conducting training programs, promoting adoption of digital tools, and implementing community-level projects.

Challenges and Constraints in E-Extension Services

Digital Divide: Most of the rural farmers face limited access to reliable high-speed internet connectivity and digital devices, together with low levels of digital literacy, which lessens their power to fully benefit from e-extension services. This can be bridged through targeted infrastructural development and digital education initiatives.

Data Security and Privacy: The growing use of digital tools in agriculture poses data privacy and security risks, where personal and farm-related data might be collected and shared without authorization or misused.

Sustainability: The operations and scaling of e-extension services require continuous funding, regular up-gradation in technology, and institutional

support for long-term efficacy and relevance to evolving agricultural needs.

Language and Cultural Barriers: Development of intuitive, multilingual, and culturally appropriate user interfaces is the need of the hour to ensure access and usability among diverse farming communities, especially in multilingual regions.

Conclusion

E-Extension services will potentially revolutionize agricultural extension with even smallholder farmers. They could promote resource-friendly practices, improve livelihoods, and ensure sustainability, provided that such initiatives can address technological, infrastructural, and policy-related challenges by creating an inclusive and resilient agricultural advisory system that meets the evolving needs of smallholder farmers in the digital age.

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Medicinal Properties of Cucurbits

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Introduction

Consumption of some fruits is strongly associated with several health benefits due to their high nutritional value and properties in risks reduction of certain illness such as cancers, cardiovascular diseases and cataracts fully justified and attributed to the presence of bioactive compounds (BCs) in the plant matrices (Shofian *et al*., 2011). Due to their centuries-old medicinal properties, vegetables are utilized as medicine in many nations; their use has grown to be a significant component of daily diets throughout individuals. Any vegetable's ability to heal depends entirely on its phytochemicals and various chemical components. The term “phytochemical” refers to substances that are not recognized as food nutrients but that have therapeutic properties for a variety of human ailments. Various vegetable parts, including flowers, fruits, leaves, stems, petioles, and roots, are employed as medicines in traditional medical systems. The Cucurbitaceae family has gained increasing attention in recent years due to the growing global interest in plant-based diets and functional foods. As more people em brace a plant-based approach and look for natural, nutrient-dense foods, cucurbits have become a relevant part of contemporary dietary patterns. The growing popularity of functional foods that provide additional health benefits beyond basic nutrition has further highlighted the potential of cucurbits for disease prevention and health management. Cucurbitaceae (Cucurbit) is an important family comprising one of the most genetically diverse groups of food plants. Most of the plants belonging to this family are frost sensitive and drought-tolerant. Some important Cucurbit family members include gourd, melon, cucumber, squash and pumpkin. Nearly all of the nutrients needed for human health are found in cucurbits, including sugar, protein, carbohydrates, vitamins, minerals, and other nutrients (Vanam, 2007). The various species within this family are rich in phytochemicals that exhibit a broad spectrum of bioactivities. These plants were used in ancient civilizations for healing wounds, detoxifying the body, and treating conditions such as

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Table 1: Some of the cucurbits common name, scientific name, family and uses

Common name	Scientific name	Family	Uses
Cucumber	*Cucumis sativus* L.	Cucurbitaceae	Eaten fresh, in salads and pickling
Pumpkin	*Cucurbita pepo* L.	Cucurbitaceae	Cooking, soups, pies and animal feed
Bottle gourd	*Lagenaria siceraria* (Molina)	Cucurbitaceae	Cooking, juice and medicinal use
Bitter gourd	*Momordica charantia* L.	Cucurbitaceae	Cooking and medicinal (diabetes control)
Ridge gourd	*Luffa acutangula* (L.)	Cucurbitaceae	Cooking and medicinal use
Sponge gourd	*Luffa cylindrica* (L.)	Cucurbitaceae	Cooking and making bath sponges
Water melon	*Citrullus lanatus*	Cucurbitaceae	Fresh consumption and juice purpose
Musk melon	*Cucumis melo* L	Cucurbitaceae	Fresh consumption, juice and desserts
Ash gourd	*Benincasa hispida* (Thunb.)	Cucurbitaceae	Cooking, medicinal and candied sweets

jaundice, kidney disorders, and respiratory diseases (Chen *et al*., 2024). In regions like India, China, and Africa, cucurbit-based formulations have been included in traditional healing practices for generations, often in combination with other herbs to enhance their effectiveness.

Bitter Gourd: The fruit acts as an anthelmintic, stomachic, antibilious and laxative. In fact, it is a tonic fruit, used in rheumatism, gout and also for diabetes. The juice of fresh leaves is given to children as a mild purgative but is not un-attended with danger. In case of migraine, the juice of a leaf is prepared in which a little salt is mixed, and then a drop is put into nostril, the same side as the migraine just once. In case of burning soles, the juice of tender leaves is just applied at bed time for seven days. The root of bitter gourd has an abortifacient effect. A decoction of the root extract is helpful in abortion, hemorrhoids and also in biliaesness.

Cucumber: The excessive internal heat is supposed to be detrimental to body system. If the body keeps burning continuously more than necessary, the effect on the person is in extreme exhaustion. Cucumber juice is highly recommended. For quick symptomatic cooling of the head, hand and feet, cucumber paste when applied on the body part is very effective in bringing a refrigerator effect. It should be noted that cucumber juice is frequently used to treat gum and tooth disorders. Its juice continues to be beneficial for rheumatism and healthful hair growth. The seed possesses diuretic and tonic qualities that make it useful in medicine.

Ridge Gourd: In case of jaundice, the juice is prepared from the leaves and every morning 2-3 drops are put into nose for four days. Anus tag: A paste of root is prepared with a little water. Then it is applied at the anus for ten nights. In local treatment, leaves are used as poultice in haemorrhoids, leprosy and splenitis; juice in conjunctivitis; decoction for uraemia and amenorrhoea. Ripe seeds are emetic and purgative.

Sponge Gourd: The plants contain a compound called luffein. Juice from the leaves are use to cure conjunctivitis of the eye. The leaves and fruits are good remedies for Jaundice. Roots have laxative effects and the oil from the seeds is used for cutaneous complains.

Snake Gourd: While the fruits are served as an appetizer, the leaves and stems are utilized to heal skin conditions. The seeds have the ability to deworm.

Sweet Gourd: While seeds are used to cure chest

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issues and encourage urine production, fruits are used to treat ulcers, piles, sores, and obstruction of the liver and spleen. Pile removal, migraines, excessive perspiration, coughing, and stones can all be effectively treated with roots.

Pointed Gourd: Commonly used for digestive issues, the leaves and stems include hypocholesterolemic, hypoglyceridimic, hypoglycemic, and hypophospholipemic properties. Fruits are excellent mouth fresheners and can be used to cure blisters, wounds, and fever. The roots are an effective treatment for ascites and a diuretic. *Trichosanthes dioica* herbage is widely used to cure a variety of human ailments.

Bottle Gourd: The leaves are used to control skin disease. Roots are used against osteoarthritis. The fruits are widely used as antidiabetic, anti-anaphylactic and antihistaminic. Fruits are also used for the treatment of leprosy, fever, asthma, bronchitis and jaundice.

Ash Gourd: Ash gourd has strong therapeutic and restorative qualities and is nutritious and healthful. People with diabetes and obesity can benefit from it because the fruit has a low calorie content. The fruit has cooling, diuretic, styptic, purgative, and tonic properties. As a blood coagulant, the fruit juice helps treat respiratory issues, peptic ulcers, hemoptysis, and other internal hemorrhage discharges from the kidneys, lungs, and stomach. Regular use reduces inflammation in the digestive system, diabetes, and piles dyspepsia. It also relieves in periodic attacks of hysteria, convulsion and other nervous diseases. The fruit increase the secretion and discharge of urine, washing out toxins from body system. In case of general debility, a delicacy from fruit pulp by boiling its pieces in water and water and adding sugar to it is used as a domestic recipe to increase weight, in T.B., heart weakness, heart in the body, thinness of semen and anaemia.

Pumpkin: While fresh pulps can be used as a poultice for boils, burns, and inflammations, seeds have diuretic and tonic properties. Young branches and leaves have a slight laxative effect. To alleviate night blindness, the year-old pumpkin is simply cooked with water and taken on a regular basis for approximately a week.

Watermelon: Due to its 90% water content, which acts as a natural diuretic to cleanse the kidneys and bladder, it is consumed all over the world. Especially advised for pregnant and menstruating women who retain fluids. Malnutrition, typhoid fever, tiredness, and scanty urination are all treated with the plants.

Muskmelon: The plants are used against scanty urination, anaemic scanty urination, loss of appetite, vomiting, problems in prostate gland and wound in urinary tract.

Conclusion

India has a climate that is ideal for growing a variety of cucurbitaceous crops. There is a wide variety of cucurbits in the farmhouse gardens of many states and communities. Crop species and cultivars vary in a variety of morphological characteristics. This varied biodiversity has several ehymetic qualities that could help the most underprivileged members of society with their basic medical requirements. A rich source of bioactive substances with enormous therapeutic potential are cucurbits. They are an essential component of both conventional and contemporary medicine because to their anti-inflammatory, anti-cancer, antibacterial, antioxidant and cardioprotective qualities. Nevertheless, despite their many health advantages, cucurbits also carry a toxicity risk since they contain cucurbitacins, which can upset the stomach and, in extreme situations, harm organs. Cucurbit-based goods, particularly those in pharmaceutical form, should be consumed with caution by people who already have health issues.

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Genetically Modified Crops: Balancing Innovation with Ethics

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Abstract

Genetically modified (GM) crops represent one of the most significant agricultural innovations in recent decades, offering solutions to issues like food insecurity, climate change, and sustainable agriculture. However, their development has also stirred significant ethical concerns. These concerns include potential health risks, environmental impact, socioeconomic issues, and corporate control over biotechnology. This article explores the complex interplay between the benefits and ethical challenges of GM crops. It emphasises the importance of regulating GM technology responsibly and ensuring that the benefits are equitably shared across global societies. The article outlines the current state of GM crop technology, its advantages, the ethical considerations, and the role of regulation in balancing innovation with societal welfare. Through careful management, GM crops can contribute significantly to the future of global agriculture without compromising ethical standards.

Introduction

Genetically modified (GM) crops have revolutionised modern agriculture. Through genetic engineering, crops are altered to improve traits such as pest resistance, drought tolerance, and nutritional value. The promise of GM crops is compelling: higher yields, reduced environmental impact, and enhanced food security. However, the introduction of GM crops into global food systems has sparked a range of ethical questions. From concerns about human health and environmental risks to the influence of large biotech companies, these moral dilemmas must be addressed for GM crops to realise their full potential. This article explores both the innovative possibilities and the ethical challenges posed by GM crops, aiming to identify a path forward that balances technological advancement with social responsibility.

History and Development of GM Crops: The history of genetically modified (GM) crops dates

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back to the 1980s, when scientists first succeeded in inserting foreign genes into plant genomes to confer desired traits such as pest resistance and herbicide tolerance. This technological breakthrough marked the beginning of a new era in agricultural biotechnology. The first commercially cultivated GM crop, *Bt* cotton, was released in 1996. It contained a gene from the soil bacterium *Bacillus thuringiensis* (*Bt*), which enables the plant to produce a protein toxic to certain insect pests, primarily bollworms. Before the introduction of *Bt* cotton, bollworm infestations caused major yield losses and required repeated applications of chemical insecticides. The adoption of *Bt* cotton led to a sharp decline in pesticide use, improved yield stability, and enhanced farmer income in many cotton-growing regions, especially in India, China, and the United States. In India, *Bt* cotton was approved for commercial cultivation in 2002. Within a decade, it transformed the cotton sector, increasing productivity and reducing crop losses from insect attacks. Studies by Qaim and Zilberman (2003) reported that smallholder farmers in India achieved yield gains of 30-60 per cent and pesticide reductions of 50 per cent compared to conventional cotton. This contributed to higher net returns and lower risks associated with pest outbreaks. However, the success of *Bt* cotton also brought new challenges. Over time, the overuse of the same *Bt* gene led to the emergence of resistant insect populations. Reports from India and China showed cases of pink bollworm developing tolerance to *Bt* toxins (Tabashnik and Carrière, 2017). This highlighted the need for integrated pest management (IPM) strategies and gene-stacking approaches, where multiple *Bt* genes are combined to delay resistance evolution. The environmental impact of *Bt* cotton has been generally positive in reducing pesticide contamination of soil and water, and in preserving beneficial insect populations. Yet, concerns persist regarding secondary pest outbreaks and biodiversity effects. Ethical debates have also emerged over seed patenting, with multinational corporations control-ling *Bt* technology through intellectual property rights. Farmers' dependence on costly *Bt* seeds and limited access to non-GM alternatives have been central to discussions about equity and sustainability. *Bt* cotton thus remains both a success story and a cautionary example in the history of GM crops. It demonstrates the potential of genetic engineering to enhance agricultural productivity while also underscoring the need for scientific monitoring, regulatory oversight, and ethical safeguards to ensure long-term sustainability and social justice.

The Benefits of GM Crops: One of the most prominent advantages of GM crops is the potential for increased agricultural productivity. By introducing specific genes into plants, crops can be made more resistant to pests, diseases, and environmental stressors like drought and extreme temperatures. For instance, genetically modified drought-resistant maize can thrive in areas prone to water scarcity, potentially improving food security in vulnerable regions. In addition to boosting yields,

GM crops can contribute to environmental sustainability. By developing crops that require fewer chemical inputs, such as pesticides and fertilisers, GM technology can reduce the ecological footprint of agriculture. Herbicide-tolerant crops like glyphosate-resistant soybeans enable farmers to use less toxic chemicals, reducing the overall burden on the environment. The reduction of pesticide use also helps protect non-target organisms, such as beneficial insects and soil microbes. Economic benefits are another significant advantage of GM crops. Farmers who adopt GM technology often experience higher profits due to lower input costs and better yields. This has been particularly beneficial in countries with large-scale commercial agriculture, such as the United States and Argentina. Additionally, GM crops can help reduce the need for arable land, enabling more efficient food production and decreasing pressure on ecosystems.

Ethical Issues Surrounding GM Crops: Despite the clear benefits, there are several ethical concerns associated with GM crops. One of the primary concerns is the potential health risks posed by consuming GM foods. Although scientific consensus holds that GM foods are safe to eat, some argue that long-term health effects are still not fully understood. Critics point to the lack of long-term human studies as evidence that GM crops should be more rigorously tested before widespread adoption.

Environmental risks are also a significant ethical concern. One issue is the potential for GM crops to crossbreed with wild relatives, leading to the unintentional spread of modified genes into the ecosystem. This gene flow could threaten biodiversity by creating hybrids that could outcompete native species or disrupt local ecosystems. Additionally, the overuse of herbicide-tolerant crops has led to the emergence of herbicide-resistant "superweeds," creating new challenges for farmers. The socio-economic implications of GM crop technology are also significant. In many parts of the world, access to GM technology is limited by cost and availability, leaving smallholder farmers and rural communities at a disadvantage. Furthermore, the dominance of large biotech corporations in the GM crop market raises concerns about the monopolisation of global food systems. The high cost of patented GM seeds can place financial strain on farmers, leading to dependency on multinational corporations for their crop production.

Regulatory Framework and Governance of GM Crops: The regulation of GM crops is essential for ensuring that they are safe for human consumption and the environment. In the U.S., the FDA evaluates GM foods for safety, while the USDA regulates their cultivation, and the EPA oversees their environmental impact. Internationally, organisations like the World Health Organisation and the Food and Agriculture Organisation provide guidelines for GM crop safety, ensuring that GM crops meet stringent standards before being introduced into the market. However, the regulatory landscape varies significantly across countries. In the European Union, for example, regulations are much stricter, with only a

handful of GM crops approved for cultivation. In contrast, countries like Brazil and Argentina have embraced GM crops more enthusiastically, driven by the potential economic benefits. Public perception also plays a significant role in shaping regulatory decisions, as seen in the EU, where consumer concerns about GM crops have influenced policy decisions. The governance of GM crops involves balancing innovation with precaution. Many experts argue that more transparent and inclusive regulatory processes, as well as continued research on the long-term effects of GM crops, are necessary to ensure that technological advancements do not come at the cost of public health or environmental sustainability.

Ethical Framework for the Future: Moving forward, it is crucial to develop an ethical framework that guides the responsible development and deployment of GM crops. This framework should prioritise environmental sustainability and biodiversity conservation, ensuring that GM crops do not harm ecosystems or disrupt the balance of nature. Additionally, there must be greater efforts to ensure that smallholder farmers and developing nations can access GM technologies fairly and equitably. Partnerships with international organisations and government subsidies could help make GM crops more accessible to underserved populations. Public engagement and transparency will also be key in the future of GM crops. As biotechnology continues to evolve, it is essential to foster open dialogue between scientists, policymakers, and the public. Ensuring that ethical considerations are taken into account at every stage of GM crop development will help build trust and create a more responsible and sustainable food system.

Conclusion

Genetically modified crops have the potential to address some of the most pressing challenges in global agriculture, including food security, climate change, and resource efficiency. However, their development and deployment raise important ethical questions that must be carefully considered. From potential health risks to environmental impact and socio-economic consequences, the moral challenges of GM crops require a balanced approach. A comprehensive regulatory framework, transparency, and public engagement will be essential to ensuring that the benefits of GM crops are realised without compromising environmental or social values. By advancing responsible innovation, we can ensure that GM crops contribute to a sustainable and equitable future for global agriculture.

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Effective Weed Control Methods for Sustainable Farming

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Abstract

Weeds cause substantial yield losses and increase production costs in agriculture. Sustainable weed control requires balancing efficacy, environmental safety, and long-term resilience. This article reviews cultural, mechanical, biological, chemical, and precision-based weed management strategies. The analysis includes crop rotations, stale seed beds, mulching, and intercropping for reducing weed pressure. Mechanical weeding, tillage, and robotic spot spraying are evaluated. Biological agents, cover crops, and allelopathy are assessed for their effectiveness. Selective herbicides, reduced-dose mixtures, and herbicide resistance management are compared. Precision methods, including computer vision, uncrewed aerial vehicles (UAVs), and autonomous weeders, are examined through case studies. The article assesses trade-offs, costs, and limitations, and concludes with recommendations for integrating multiple tactics within an Integrated Weed Management (IWM) framework for sustainable agriculture.

Introduction: The Challenge of Weeds in Sustainable Farming

Weeds compete with crops for water, nutrients, light, and space. In many cropping systems, unmanaged weed pressure can reduce yield by 20-50 % (Paul *et al*., 2024; Parven *et al.*, 2025) Modern agriculture often relies heavily on herbic-ides, but that approach has drawbacks: resistance evolution, environmental contamination, harm to non-target species, and public concern (Monteiro *et al.*, 2022; Parven *et al*., 2025). Sustain-able farming demands weed control that lowers chemical input, preserves soil health, and avoids harmful residues. Integrated Weed Management (IWM) offers a strategy. IWM combines multiple tactics to maintain weed pressure below damaging thresholds while

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reducing reliance on any one method (Monteiro *et al.*, 2022). Recent advancements in sensing, robotics, and data analytics have expanded the potential for effective weed management (Vasileiou *et al.*, 2024). Despite these developments, adoption rates remain inconsistent, particularly among smallholder farmers. The following sections review effective weed control methods, supporting evidence, and limitations, and propose practical approaches for integrating multiple tactics.

Cultural and agronomic strategies

Agronomic strategies are implemented prior to weed emergence or during early developmental stages. These approaches decrease the probability of weed establishment within cropping systems.

Crop rotation and intercropping: Crop rotation involving species with varying growth periods and competitive abilities suppresses weed populations adapted to monocultures. Alternating cereal and broadleaf crops disrupts weed ecological adaptation. Intercropping with shade-producing or rapidly growing companion species further limits light availability for weeds.

Stale seedbed (false seedbed): In the stale seed bed technique, fields are prepared early, allowed to germinate weeds, and then weeds are removed before planting the main crop (via light tillage, flaming, or shallow cultivation) (Wikipedia, stale seed bed). This reduces the weed seed bank without profound soil disturbance.

Mulching and living mulches: Applying organic or synthetic mulch on soil suppresses weed germination by blocking light and physically impeding seedlings. Mulches also conserve moisture and moderate soil temperature. In horticultural systems, black plastic mulch or infrared-transmitting films have shown good weed suppression (Monteiro *et al.*, 2022). A living mulch is a cover crop grown simultaneously with the main crop (e.g. undersown legumes), which competes with weeds and can fix nitrogen. However, living mulches may compete with the crop for water or nutrients, especially under stress (Wikipedia, living mulch).

Crop density, row spacing, and planting timing: Increasing crop density or reducing row spacing accelerates canopy closure, thereby suppressing weed growth through shading. Modifying planting dates can also help avoid periods of peak weed emergence. In direct-seeded rice, for instance, weed pressure rises; narrow row spacing and timely weeding are critical (Wikipedia, direct-seeded rice).

Summary of strengths and constraints: These preventive strategies minimise chemical inputs. However, their effectiveness is influenced by site-specific conditions. Weed suppression is typically partial, and additional control methods are often necessary. Implementation requires increased management expertise and monitoring.

Mechanical and physical approaches

Mechanical and physical methods eliminate weeds using force, heat, or light, and are generally applied after weed emergence.

Tillage, hoeing and hand weeding: Tillage and hoeing uproot or bury weeds. Early post-emergence

cultivation (shallow) is often effective. Hand weeding remains indispensable in many low-input systems, especially for smallholder farms. Manual weeding may achieve 72-99 % weed removal but has low field capacity (0.001 to 0.033 $hm^2\ h^{-1}$) (Gatkal *et al.*, 2025). Regular mechanical weeding prevents weed seed production and gradually depletes the soil seed bank.

Mowing, cutting and flaming: Mowing reduces aboveground biomass, slows weed growth, and prevents seed set. Flaming (thermal weeding) can kill small weeds using heat. Mowing is more feasible in forage, vineyards, or orchards (Paul *et al*.). Perennial weeds frequently regenerate after initial control and typically require repeated interventions for effective management.

Soil steaming: In high-value or greenhouse settings, soil steaming (applying steam to heat the soil) can sterilise weed seeds, pests and pathogens (Wikipedia, soil steam sterilisation). Steaming is energy-intensive and less feasible for large fields, but it is a chemical-free alternative.

Automated mechanical weeding and robotics: Robotic weeders combine mechanical removal with sensors to distinguish weeds from crops. A robot for narrow row spacing was developed with autonomous navigation and recharge capability, and is low-cost (< US$400) (Du *et al.*, 2021). It demonstrates that automation is feasible even for tight interrow conditions. In sugarcane fields, robotic spot spraying using computer vision reduced herbicide use by 35% while achieving 97% of broadcast efficacy; in some low-weed zones, the reduction reached 65% (Rahimi Azghadi *et al.*, 2024).

Strengths and constraints: Mechanical methods do not leave chemical residues and can improve soil aeration while reducing compaction. However, intensive tillage increases the risk of soil erosion and structural degradation. High labour or machinery costs, along with the need for frequent operations, limit their practicality.

Biological control and ecologically based tactics

Biological and ecological methods utilise natural interactions to suppress weed populations, aiming to minimise external inputs and promote long-term system stability.

Classical and augmentative biological control: Classical biocontrol uses pathogens, insects, or fungi specific to a weed species. Introduced agents attack weeds in a species-specific way. This approach is more common in non-cropped ecosystems or pastures, rather than arable cropping, due to the risk of non-target effects.

Living mulches and cover crops: As described earlier, living mulches compete against weeds and support beneficial organisms. Some cover crop species have allelopathic properties, releasing compounds that inhibit weed germination. For example, allelopathic legumes under cocoa or other crops have reduced weed pressure (Monteiro *et al.*, 2022).

Targeted grazing: Using animals (goats, sheep, cattle) to graze weed-infested areas helps control weeds in pastures or agroforestry. Grazing must be timed to prevent crop damage and manage weed

regrowth. Grazing is more suited for integrated systems where animals are already present (Monteiro *et al.*, 2022).

Directed energy / nonchemical autonomous systems: An emerging prototype uses directed energy (e.g. thermal or light) with computer vision to kill weeds without chemicals or soil disturbance (Cao *et al*., 2024). In a soybean/corn system, the system classified weeds with up to 98 % accuracy. Such systems may remain expensive in the near term.

Strengths and constraints: Biological and ecological approaches decrease reliance on chemical inputs and frequently enhance biodiversity. Weed suppression is generally slower and highly context-dependent. These methods require precise ecological matching and ongoing monitoring, and may be insufficient during periods of high weed pressure.

Chemical control of herbicides continues to play a significant role in many agricultural systems because of their cost-effectiveness and operational simplicity. The primary challenge is integrating chemical control without compromising sustainability objectives.

Selective and dose reduction strategies: Use selective herbicides that target weeds without crop damage. Lower doses, split applications, or tank mixtures can reduce total chemical load. Rotate modes of action to delay resistance.

Spot spraying and banding: Instead of broadcasting, apply herbicide only to weed patches or narrow bands. Robotic spot sprayers (Rahimi Azghadi *et al.*, 2024) are an example of precision application. Banding herbicide over crop rows while leaving interrows untreated also reduces pesticide use.

Herbicide resistance management: Continuous use of the same herbicide mode of action drives resistance. Integrate herbicide use with other tactics to reduce selection pressure. Use mixtures of modes of action and rotate herbicide families (Monteiro *et al.*, 2022).

Risk mitigation and environmental control: Buffer zones, drift control measures, and timing applications under favourable weather reduce off-target effects. Monitor residues and soil health. In modern sustainable agriculture, broad-spectrum herbicide use is declining; more targeted chemistries are being developed (Parven *et al*., 2025).

Strengths and constraints: Herbicides provide rapid and efficient weed control. However, improper use results in resistance development, environmental contamination, and negative public perception. Sustainable chemical control requires strategic and minimised application.

Precision and emerging technologies

New tools in sensing, computing and automation enable more intelligent weed control with reduced inputs.

Remote sensing and mapping: Use satellite, drone, or multispectral imaging to map weed patches and dynamics (Kontogiorgakis *et al.*, 2025). Machine learning models classify management methods in orchards from imagery.

Computer vision and AI: Deep learning models can

distinguish between weeds and crops in images. Combined with robotics, they guide spot applications or mechanical weeding (Vasileiou *et al*., 2024). Directed energy weed control uses AI to target weeds (Cao *et al*., 2024).

Autonomous robots and UAVs: Robots navigate fields, detect weeds, and apply control (spray or mechanical). The Du *et al*. (2021) robot autonomously recharges. UAVs can spray from above, reducing soil compaction. In the sugarcane case study, herbicide use decreased by 35 % without yield loss (Rahimi Azghadi *et al.*, 2024).

Decision support and sensor networks: Sensors for soil moisture, nutrient levels, microclimate, and weed emergence help optimise timing and intensity of control. Decision support is Hindered by High initial investment, ongoing maintenance requirements, technical skill demands and data infrastructure limitations, which restrict adoption, particularly among smallholder farmers. Successful implementation depends on integration with local agricultural practices. Long smallholders. Integration with local. No individual method provides comprehensive weed control. Effective sustainable weed management relies on the intelligent combination of multiple tactics within an Integrated Weed Management (IWM) framework.

Principles for integration

- ✓ Use cultural strategies to reduce weed pressure baseline
- ✓ Monitor weed emergence and weed seed bank
- ✓ Apply mechanical removal early and frequently
- ✓ Use biological tools where suited
- ✓ Use herbicides as a last resort, in targeted ways
- ✓ Incorporate precision tools gradually, suited to scale and resources

Example workflow for a cropping season

- ✓ At season end, apply stale seedbed: prepare and germinate weeds, then remove (cultural).
- ✓ Before planting, sow a living mulch or cover crop (ecological).
- ✓ Use narrow row spacing and optimal sowing timing (design).
- ✓ After emergence, monitor weeds via scouting or imaging.
- ✓ Apply mechanical weeding (hoeing or robot) to germinated weeds.
- ✓ For remaining patches, use spot herbicide or directed energy (chemical or precise).
- ✓ Between seasons, rotate crops and rotate herbicide modes of action (resistance management).

Cost-benefit and decision factors: Farmers must evaluate labour, equipment, input costs, risk, and potential yield benefits. Certain precision technologies require a substantial initial investment but can reduce ongoing input costs. Biological and ecological methods often necessitate additional knowledge and monitoring. Adoption rates increase when extension services and training are accessible. For smallholder farmers, combining low-technology mechanical removal with cultural practices remains a practical approach.

Scaling to regions: In developed agricultural systems, robotics and artificial intelligence techno-

logies are likely to scale more rapidly. For smallholder systems, integrating hand weeding, mulching, and limited herbicide application is initially more feasible. Policy interventions and subsidies can promote the adoption of sustainable practices.

Conclusion

Weed control in sustainable farming requires a shift from relying on singular tactics to adopting integrated and adaptive systems. Cultural and agronomic strategies reduce initial weed pressure. Mechanical and physical methods target emerging weeds without causing chemical side effects. Biological control and ecological tactics harness ecosystem services. Chemical control retains a role, but must be used judiciously in spots, in rotated modes, and with low doses. Precision technologies robotics, sensing, AI promise to reduce labour and chemical inputs while preserving efficacy. Empirical results, such as the sugarcane robotic spot spraying trial, demonstrate that herbicide use can be reduced by 35% with negligible yield impacts. Successful weed management requires farmers to integrate tactics tailored to their specific resources, scale, climate, and weed species. Ongoing monitoring, method rotation, and incremental investment in new technologies are essential. Support from extension services, subsidies, and research institutions is critical for reducing adoption barriers. Over time, integrated strategies can stabilise yields, minimise environmental impact and enhance system resilience. Sustainable weed control is achieved through dynamic, adaptive management rather than reliance on a single method. A single method it is a dynamic system.

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India's Hidden Crisis: The Devastating Impact of Soil Erosion and Land Degradation

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Abstract

Soil erosion and land degradation are a pressing environmental issue in India, with far-reaching consequences for agricultural productivity, rural livelihoods, biodiversity, and food security. The problem is widespread, with a significant portion of the country's land area affected by desertification and degradation. The main drivers of this issue are a combination of natural factors, such as climate variability and intense rainfall, and human activities like deforestation, unsustainable farming practices, and mining. If left unchecked, land degradation can lead to severe consequences, including reduced crop yields, increased flood risk, loss of soil health and biodiversity, and socioeconomic distress for millions of smallholder farmers. To mitigate this crisis, India needs to adopt a comprehensive approach that includes sustainable land management practices, such as conservation agriculture, agroforestry, and watershed development. This requires informed planning, long-term financing, farmer engagement, and robust monitoring to ensure the effectiveness of restoration efforts and achieve sustainable food systems and climate resilience.

Introduction

Soils are the foundation of terrestrial life: they store and cycle water and nutrients, support crop production and biodiversity, and act as a major terrestrial carbon reservoir. When soils are degraded by erosion, organic matter loss, salinization, compaction or contamination their capacity to deliver these services falls. In India, where agriculture directly supports the livelihoods of hundreds of millions and national food security depends on relatively limited arable land, soil degradation is therefore both an environmental and a socioeconomic emergency. The problem is not hypothetical: national remote-sensing assessments indicate extensive and growing areas affected by desertification and land degradation (Space Applications Centre / ISRO, 2016). International assessments likewise show that soil degradation is a major global challenge with consequences for nutrition, climate mitigation and ecosystem resilience (FAO and ITPS, 2015; Lal, 2009).

Definitions and scope

- ✓ Soil erosion refers to detachment and transport of soil particles by water, wind, or tillage. It reduces topsoil depth and fertility and can proceed at rates far exceeding soil formation.
- ✓ Land degradation is a broader concept capturing long-term loss of ecosystem function and productivity due to physical, chemical or biological deterioration (including erosion, salinization,

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nutrient depletion, and loss of organic matter).

- ✓ Desertification is land degradation in drylands (but the term is often used in policy discourse more broadly). The Desertification and Land Degradation Atlas of India (SAC/ISRO, 2016) provides spatially explicit estimates that help quantify and target interventions.

Soil Erosion and Land Degradation extent and patterns in India

National mapping using remote sensing and field inputs has documented substantial areas undergoing degradation. The Desertification and Land Degradation Atlas of India (Space Applications Centre / ISRO, 2016) reported that during 2011-13 nearly 96.4 million hectares roughly 29.3% of India's total geographical area were undergoing processes of land degradation. Water-driven erosion, wind erosion and loss of vegetation cover are spatially heterogeneous: arid and semiarid regions (northwest, parts of central India), steep hill slopes in the Himalaya and the Western Ghats with deforested catchments, and intensively cultivated plains subject to continuous cultivation and inadequate residue management are among the worst affected. Regional studies and successive atlas updates indicate some increases in degraded area in most decades, signifying that degradation remains a dynamic and continuing problem (Space Applications Centre / ISRO, 2016).

Drivers of soil erosion and land degradation in India

Multiple, interacting drivers operate at different scales:

Agricultural intensification and inappropriate tillage: Continuous cultivation without adequate residue return, deep tillage that disrupts soil structure, mono-cropping and insufficient organic inputs reduce aggregate stability and organic carbon, making soils more susceptible to detachment by raindrop impact and runoff.

Deforestation and land-cover change: Conversion of forests, shrublands and grasslands to cropland or settlements removes protective canopy and root systems, increasing surface runoff and slope instability.

Overgrazing and pastoral pressures: Concentrated grazing removes protective vegetation, compacts soil surfaces and increases susceptibility to wind and water erosion.

Unsustainable irrigation and secondary salinization: Poor drainage, over-irrigation and use of saline/alkaline water can raise water tables and cause salinization and sodication that render soils unproductive.

Mining, infrastructure and urban expansion: Large-scale mining, road construction and unplanned urban sprawl strip topsoil and change hydrology, leading to enhanced erosion and permanent land take.

Extreme weather and climate variability: Monsoon intensification, high-intensity rainfall events and drought cycles (exacerbated by climate change) increase erosion pulses and reduce vegetation recovery periods.

Institutional and socio-economic factors: Perverse incentives (e.g., subsidies favouring certain crops or fertilizer use without emphasis on soil organic matter), insecure land tenure, limited access to extension services and credit, and migration pressures all influence land-use decisions that can exacerbate degradation.

These proximate drivers are consistent with global syntheses pointing to unsustainable agriculture and land-use change as key agents of accelerated soil loss (Montgomery, 2007; FAO & ITPS, 2015).

Biophysical and socio-economic impacts

Loss of productive topsoil and yield decline: Erosion removes the most fertile horizon, lowering water-holding capacity and nutrient stocks; long-term studies show declines in yield potential when soil depth and organic matter fall below thresholds. This is particularly acute for smallholder plots with limited capacity for reclamation.

Nutritional quality and hidden hunger: Soil degradation can reduce concentrations of micronutrients (Zn, Fe, Se and others) in staple crops through loss of soil micronutrient pools and changes in soil chemistry, thereby contributing to hidden hunger even where caloric production appears adequate (Lal, 2009).

Carbon loss and climate feedbacks: Erosion and reduced soil organic matter release soil carbon to the atmosphere and decrease soils' capacity to sequester carbon, undermining mitigation potential. This is a global concern and has implications for India's land-based mitigation strategies (FAO & ITPS, 2015).

Water quality, sedimentation and flood risk: Sediment from eroded fields increases siltation in reservoirs and waterways, reducing storage capacity and degrading aquatic habitats. Concentrated runoff from degraded catchments can raise flood peaks downstream.

Biodiversity loss and landscape fragmentation: Soil degradation alters habitats and reduces below- and above-ground biodiversity, affecting ecosystem resilience and services such as pollination and pest regulation.

Livelihood insecurity and migration: Loss of land productivity raises production costs, reduces incomes and can trigger distress migration and social dislocation in rural areas dependent on agriculture.

These impacts are cumulative and often disproportionally affect landless and smallholder households with limited assets for adaptation or restoration.

Measurement, monitoring and knowledge gaps

Accurate mapping of degradation, identification of causal processes and monitoring of intervention outcomes are prerequisites for effective action. Remote sensing (multispectral time-series, radar for soil moisture and topography, and high-resolution imagery) combined with systematic field sampling provides the basis for the ISRO/SAC atlas and for sub-national targeting. However, important gaps remain:

- ✓ Longitudinal field data on soil formation vs. loss rates across diverse Indian agroecology are

sparse.

- ✓ Linking remote-sensing indicators to functional soil health metrics (available water capacity, aggregate stability, microbial activity, micro-nutrient stocks) needs more ground calibration.
- ✓ Socioeconomic monitoring that tracks adoption, cost-effectiveness and livelihood impacts of soil conservation measures is patchy.

Addressing these gaps would improve targeting of restoration finance and increase evidence-based scaling of promising interventions.

Possible technical interventions

A range of technical measures many locally adapted and cost-effective can reduce erosion and restore productivity. Evidence from India and other regions demonstrates measurable benefits when measures are well designed and maintained:

Soil and water conservation in agricultural landscapes: Contour bunds, terraces, graded bunds, check dams and gully plugs reduce runoff velocity and capture sediments. Watershed development programs that combine structural measures with vegetative stabilization have improved soil moisture and productivity in many Indian catchments.

Conservation agriculture (CA): CA principles minimal soil disturbance, permanent soil cover (mulch/cover crops), and crop rotation improve aggregate stability, increase infiltration and reduce erosion. CA also builds soil organic matter over the medium term.

Agroforestry and perennials: Boundary planting, alley cropping and incorporation of trees/shrubs on farms stabilize slopes, provide biomass and diversify incomes, while increasing root-derived carbon inputs.

Organic matter restoration: Compost, farmyard manure, biochar and crop residues enhance soil structure, increase water retention and reduce susceptibility to detachment.

Improved grazing management: Rotational grazing, stocking rate adjustments and re-establishment of degraded pastures reduce soil exposure and wind erosion.

Targeted reclamation for salinized soils: Leaching with good drainage, gypsum application (for sodic soils), and selection of salt-tolerant crops constitute established reclamation practices.

Policy instruments and governance for scaling restoration

Technically feasible options need enabling policy and finance. Key policy directions include:

Spatial targeting and payment for ecosystem services (PES): Prioritize the most degraded and high-risk catchments for investments and offer payments/incentives for stewardship.

Integration of soil health in agricultural subsidies and extension: Incentivize practices that build soil organic matter rather than only input-heavy intensification. (India's Soil Health Card initiative a national program to inform farmers about soil nutrient status represents one national effort to bring soil testing and recommendations to scale.)

Watershed and landscape approaches: Multi-stakeholder watershed programs that combine struc-

tural works, afforestation, and livelihood measures are essential for landscape-level stabilization.

Long-term financing and public-private partnerships: Restoration requires sustained investments beyond short project cycles; blended finance and public support can de-risk adoption.

Monitoring, reporting and verification (MRV): Rigorous outcome monitoring (soil depth, organic carbon, yields, livelihoods) should accompany investments to ensure accountability and learning.

Policy must also address land tenure, gendered access to inputs and extension, and local institutional capacity, all of which influence adoption.

Research priorities and innovation needs

To underpin effective action in India, a focused research agenda should include:

- ✓ High-resolution, time-series mapping of erosion and soil health integrated with socioeconomics to prioritize interventions.
- ✓ Long-term experimental sites across agro-ecologies to quantify erosion rates, SOC dynamics and threshold responses to management.
- ✓ Development of low-cost soil health indicators and rapid field tests for use at scale.
- ✓ Economic studies on cost-effectiveness and livelihood impacts of restoration packages to inform incentive design.
- ✓ Social science research on adoption barriers, gender dynamics, and collective action for communal land restoration.

Interdisciplinary research that couples bio-physical and socioeconomic analysis will yield the most policy-relevant insights.

Integrated recommendations

Adopt a landscape approach: Combine site-level soil conservation with upstream catchment measures, agroforestry and watershed management to achieve synergies and avoid piecemeal efforts.

Target investments using spatial data: Use national and state-level maps (e.g., ISRO atlas and subsequent updates) to identify high-priority zones for restoration and monitor change.

Promote soil-building agronomy: Scale conservation agriculture, residue retention, rotations and manure/compost application through extension, subsidies for conservation equipment and market linkages for diversified crops.

Finance long-term restoration: Create funding windows for multi-year landscape rehabilitation (public funds, PES, climate finance) and support community institutions that manage common resources.

Strengthen monitoring and learning: Develop MRV systems for soil health that integrate remote sensing with systematic ground-truthing and livelihood indicators.

Build farmer incentives and capacity: Tailor incentive mechanisms and extension services to smallholders, prioritize women farmers, and use participatory models to ensure local ownership.

Mainstream soil health into national planning: Recognize soil conservation as central to climate,

food and health policy and ensure cross-sector coordination (agriculture, water, forest, mining and urban planning).

Conclusion

India's soils are a vital but vulnerable national asset. The combination of empirical mapping (Space Applications Centre / ISRO, 2016), international assessments of soil status (FAO & ITPS, 2015) and process-level research (Montgomery, 2007; Lal, 2009) converge on the conclusion that soil erosion and land degradation are significant, multidimensional threats to agrifood systems, climate mitigation and rural prosperity. The technical solutions are known and often low-cost, but large-scale impact requires integrated landscape planning, durable finance, farmer engagement and robust monitoring. Without decisive scaling of restoration and conservation, India risks continuing erosion of its productive base a trajectory that imperils food security, rural livelihoods and environmental resilience for generations.

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Unlocking Socioeconomic Potential: The Role of Digital Ecosystems in Agriculture

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Abstract

Digital ecosystems networked combinations of connectivity infrastructure, data platforms, devices, services, and actors are reshaping agriculture and rural livelihoods by linking farms to information, markets, finance, and services. When properly designed, they have the potential to enhance productivity and incomes, minimize post-harvest losses, improve risk management, and foster greater inclusion of smallholders. Achieving these benefits requires strong investments in digital connectivity, sound data governance, interoperable platforms, digital literacy, and supportive policy and business models. Failure to address these critical enablers can reinforce existing inequalities and create dependency on proprietary systems. This review synthesizes conceptual frameworks, technological foundations such as the Internet of Things (IoT), remote sensing, artificial intelligence, mobile platforms, and blockchain; it further examines evidence of socioeconomic impacts, barriers, governance and policy implications, business models, environmental and resilience dimensions, as well as key research gaps and practical recommendations for policymakers and practitioners. The analysis draws upon a wide range of scholarly studies and institutional assessments on the digital transformation of agriculture.

Introduction

Agriculture is increasingly influenced by digital technologies that collect, process and deliver data-driven insights across the food system. The term digital ecosystem highlights that benefits accrue not from isolated tools but from interacting elements: infrastructure (connectivity, sensors), platforms (marketplaces, advisory services), analytics (AI/ML, big data), financial services, extension and the human actors who use and govern them. This review examines how digital ecosystems can unlock socioeconomic potential for different agricultural stakeholders smallholders, cooperatives, agribusinesses, extension agents and policymakers while identifying the constraints and governance requirements necessary to translate technological potential into equitable outcomes. Key reference syntheses informing this review show both the promise and the governance/business-model obstacles facing digital agriculture.

Conceptual framework: What is a digital agricultural ecosystem?

A digital agricultural ecosystem is an interconnected system made up of:

Physical infrastructure: broadband/ mobile networks, edge devices, IoT sensors, satellites and

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drones.

Data layer: telemetry, imagery, farm records, market prices and weather datasets.

Platforms and middleware: APIs, cloud services, data marketplaces and interoperable standards that enable data exchange.

Service layer: advisory systems (decision support), e-commerce/marketplace platforms, digital financial services (payments, credit, insurance), logistics and traceability systems.

Actors and governance: farmers, service providers, telecoms, aggregators, cooperatives, researchers and public regulators who set rules on data access, privacy and competition.

This layered view highlights that socio-economic outcomes depend not only on single technologies but also on how layers interoperate and how actors govern data and services. Recent FAO and World Bank syntheses emphasize that planning (e.g., a Digital Agriculture Roadmap) must align these layers with national priorities to avoid fragmentation.

Core technologies and functionalities

Connectivity and sensing: Mobile broadband and low-power wide-area networks connect sensors and edge devices to back-end services. Sensors measure soil moisture, nutrient status, microclimate and machine performance; remote sensing (satellite and drone imagery) provides field-level and regional monitoring for crop health and area estimates.

Data, analytics and AI: Large volumes of heterogeneous agricultural data time series from sensors, imagery, market transactions, and farmer records can be analyzed using machine learning and statistical methods to generate yield predictions, pest/disease alerts, fertilizer recommendations and price forecasts. Reviews of "big data" in farming emphasize that analytics can improve decision quality at multiple scales, from plot-level precision to supply-chain optimization.

Platforms and marketplaces: Digital platforms aggregate producers and buyers, enable price discovery, coordinate logistics and integrate financial products (e.g., input-on-credit tied to sales). Interoperable platform architectures and open APIs are crucial to avoid fragmentation and vendor lock-in.

Digital financial services and verifiable records: Mobile payments, digital IDs, credit scoring from alternative data and index-insurance products enable better access to finance and risk management especially when combined with verifiable supply-chain records (traceability) made possible by ledger technologies.

Socioeconomic benefits (how digital ecosystems unlock potential)

The literature and recent policy guides identify several channels through which digital ecosystems generate socioeconomic gains:

Productivity and input efficiency: Site-specific recommendations (fertilizer, irrigation scheduling) delivered via decision-support tools raise input-use efficiency and yields, reducing costs for farmers. Big-data and AI systems can optimize resource

allocation at scale.

Market access, price realization and reduced transaction costs: Digital marketplaces and phone-based buyer–seller matching reduce search costs, expand buyer choice for producers, and can increase farmers' share of the final price by shortening value chains. Digital aggregation (via cooperatives or e-platforms) enables smallholders to meet quality/ quantity requirements of larger buyers.

Financial inclusion and resilience: Digital payments, mobile wallets and alternative-credit scoring based on digital footprints expand access to savings, credit and digital insurance helping households smooth consumption and invest in productivity-enhancing inputs. Roadmaps by development agencies stress integrating finance into platform ecosystems for scalability.

Reduced post-harvest loss and improved logistics: Real-time supply-chain data and demand signals enable better storage and routing decisions; traceability systems can reduce spoilage and open higher-value export markets.

Knowledge transfer and advisory services: Digital advisory (SMS, voice, chatbots, apps) extends extension capacity, especially where human extension is scarce; multimedia content can be localized to context and literacy levels, increasing uptake of improved practices. FAO synthesis underscores this role while cautioning about digital literacy gaps.

Inclusive employment and new business opportunities: Digital ecosystems create non-farm jobs (data services, input delivery, platform agents) and new revenue streams (value-added services, precision ag contractors), although outcomes depend on local capacity and market structure.

Evidence and limits: what the literature shows

The literature on digital agriculture reveals a mixed picture, with promising potential but inconsistent real-world impacts. While trials have shown productivity and efficiency gains, particularly for medium-to-large farms, benefits for smallholders are more pronounced when platforms are specifically designed for them and integrated with extension and logistics services. However, persistent barriers such as connectivity gaps, high costs, limited digital skills, poor data governance, and unsuitable business models hinder scalability and equitable diffusion. Moreover, research tends to focus on early adopters and pilot projects, with rigorous impact evaluations at scale being relatively scarce. To achieve sustainable digital agriculture systems, it's essential to prioritize governance, interoperability, and viable business models.

Barriers, risks, and unintended consequences

The adoption of digital agriculture is accompanied by several barriers, risks, and unintended consequences that need to be addressed. These include the digital divide and inequality, where lack of access to affordable connectivity, gendered access barriers, and low digital literacy can exclude the poorest and reinforce existing inequalities. Data governance and privacy are also significant concerns, as proprietary platforms can limit farmers'

control over their data, exposing them to unfair pricing or exclusion. Vendor lock-in and fragmentation can occur when platforms are not interoperable, reducing choice and increasing costs. Furthermore, technical reliability and contextual fit are crucial, as algorithms may not generalize across different agroecological zones, highlighting the need for local calibration and inclusive co-design. Additionally, automation could lead to employment displacement and skill mismatches, requiring compl-ementary training and reallocation to determine net welfare effects. Finally, cybersecurity and systemic risks, such as platform outages, cyberattacks, or erroneous automated recommendations, could disrupt production and markets, emphasizing the need for resilience planning and mitigation strategies to address these challenges.

Governance, policy and institutional enablers

Governance, policy and institutional enablers play a crucial role in fostering equitable digital ecosystems in agriculture. Effective policy frameworks and public investments can enable the development of sustainable and inclusive digital agriculture systems. National digital agriculture strategies and roadmaps can coordinate investments in key areas such as connectivity, standards, capacity building, and public data infrastructures, helping to avoid fragmented and uncoordinated pilot projects. Additionally, infrastructure and affordability are critical, requiring public-private investments in broadband and electricity, targeted subsidies for last-mile connectivity, and spectrum policies for IoT networks. Data governance and rights are also essential, with policies needed to specify data ownership, consent, portability, anonymization standards, and fair sharing of commercial benefits, striking a balance between innovation and protecting farmer rights. Furthermore, standards and interoperability are vital, with open data standards, common taxonomies for agronomic data, and APIs helping to reduce vendor lock-in and enable modular ecosystems. Capacity building and extension reform are also necessary, with investments in digital literacy, gender-sensitive outreach, and blended extension services accelerating adoption and promoting equitable benefit sharing. Finally, market regulation and competition policy are important to prevent anti-competitive behavior on large platforms, protecting the interests of smallholder farmers and promoting a level playing field. By addressing these areas, governments can create an enabling environment for digital agriculture to flourish, promoting sustainable and equitable development in the sector.

Business models and sustainability

Sustainable digital ecosystems in agriculture require viable business models that align incentives across stakeholders. Potential models include freemium and subscription-based advisory services, transaction fees on marketplace platforms, and bundling finance and inputs to increase retention. Public-private partnerships can also be effective, where public goods like weather data and cadastral maps are provided by the state, and private actors

innovate downstream services. To achieve scalability, it's crucial to focus on unit economics, farmers' willingness to pay, and the cost of last-mile service delivery, ensuring that the business models are financially sustainable and beneficial to all stakeholders.

Environmental and resilience co-benefits

Digital ecosystems can support sustainability goals by optimizing inputs (reducing fertilizer and water overuse), enabling precision application, and improving monitoring for climate-smart practices. Real-time weather and pest alerts enhance adaptive capacity. However, environmental benefits are context-dependent and hinge on adoption at scale and incentives that reward sustainable practices (e.g., premium markets for low-input or traceable produce).

Research gaps and priority areas

To build evidence and guide policy in digital agriculture, several priority research areas have been identified. These include conducting large-scale impact evaluations of digital ecosystem interventions to assess their effects on farmer incomes, nutritional outcomes and environmental indicators. Additionally, value-chain analyses are needed to understand how platformization affects bargaining power and price transmission among stakeholders. Research is also required to design interoperable architectures and standards that balance competition with data portability. Furthermore, governance experiments should be conducted to test innovative models, such as data trusts and farmer cooperatives as data stewards and alternative benefit-sharing arrangements. Lastly, socioeconomic studies focusing on gender, youth, and marginalized groups can inform the design of inclusive products and services that cater to the needs of diverse stakeholders.

Practical recommendations

Effective action against land degradation requires accurate mapping, identification of causal processes, and monitoring of intervention outcomes. While remote sensing and field sampling have enabled the creation of detailed atlases and sub-national targeting, significant gaps persist. These include the need for longitudinal field data on soil formation and loss rates across diverse agro-ecologies, better linkage between remote-sensing indicators and functional soil health metrics, and more comprehensive socioeconomic monitoring to track adoption, cost-effectiveness, and livelihood impacts of soil conservation measures. Addressing these gaps is crucial for targeted restoration finance and evidence-based scaling of promising interventions, ultimately enhancing the effectiveness of efforts to combat land degradation and promote sustainable land management.

Conclusion

Digital ecosystems hold transformational promise for agriculture: improving productivity, connecting farmers to markets and finance, and strengthening resilience. Realizing socioeconomic potential requires moving beyond technology pilots to system-level design integrating infrastructure investment, governance, capacity development and

sustainable business models. International organizations and academic reviews converge on this message: technology is necessary but not sufficient policy, institutions and inclusive design determine whether digital ecosystems become engines of equitable rural development or new pathways for exclusion.

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Future of Agricultural Extension: Towards Data-Driven and AI-Powered Advisory Systems

N. Krishna Priya, Rita Fredericks and Anil Kumar

Abstract

Agricultural extension is entering a new era driven by digital transformation, data analytics, and artificial intelligence (AI). Traditional models of knowledge transfer are being replaced by technology-enabled systems that deliver real-time, location-specific, and personalized advisories to farmers. This article explores how data-driven and AI-powered extension services are reshaping agricultural decision-making, enhancing productivity, and promoting sustainability. It also discusses challenges and the way forward for integrating modern technologies into extension frameworks to empower farmers in the digital age.

Introduction

Agricultural extension plays a vital role in disseminating scientific knowledge, innovations, and best practices to farmers. Traditionally, extension relied on person-to-person contact, field demonstrations, and printed materials. However, the increasing complexity of farming systems, climate change challenges, and the need for precision agriculture demand a shift toward data-driven and AI-enabled solutions. With the rapid expansion of mobile connectivity, remote sensing technologies, and big data analytics, extension services are undergoing a paradigm shift. The integration of data science and AI allows real-time monitoring of crop health, weather conditions, and market trends transforming advisory services from reactive to proactive systems. This evolution not only enhances decision-making but also ensures sustainability, resilience, and profitability in modern agriculture.

https://www.sciencedirect.com/science/article

The Role of Data in Modern Agricultural Extension

Data serves as the backbone of modern agricultural extension. Through digital tools, massive amounts of data are collected from various

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Sources satellite imagery, sensors, drones, and farmer apps. These data sets help in creating precise, localized advisories for farmers.

Weather and Climate Data: Real-time weather forecasts help in advising farmers on the best times for sowing, irrigation, and pest control.

Soil and Crop Data: Soil sensors and geospatial mapping generate valuable insights about nutrient status, pH, and moisture content, enabling targeted fertilizer use.

Market Data: Market intelligence platforms track price trends, helping farmers plan harvest and sales effectively.

Artificial Intelligence in Agricultural Advisory Systems

AI has become a transformative force in agricultural extension, enabling intelligent decision-support systems that go beyond traditional advisory methods.

AI Chatbots and Virtual Assistants: Tools like "Kisan GPT," "Plantix," or "AgroAI" provide 24/7 multilingual support to farmers, answering queries related to crop management, pest diagnosis, and input use.

Predictive Analytics: Machine learning algorithms analyze past and real-time data to forecast pest outbreaks, disease incidence, and yield potential.

Image Recognition and Diagnostics: AI-based image recognition helps in early detection of crop diseases, nutrient deficiencies and weed identification through smartphone apps.

Voice and Text-Based Advisory: AI-powered voice assistants reach even semi-literate farmers, making information more inclusive and accessible.

Integration with IoT, Drones, and Remote Sensing

The integration of AI with Internet of Things (IoT) devices, drones, and remote sensing technologies adds a new dimension to agricultural extension.

IoT Sensors: Installed in fields continuously record vital parameters such as soil moisture, temperature, nutrient levels, and humidity. This real-time data helps in optimizing irrigation schedules, fertilizer applications, and crop monitoring, leading to water and resource conservation.

Drones: Play a crucial role in precision farming by capturing high-resolution images of large agricultural areas. These aerial insights help identify crop stress, pest infestations, weed growth, and nutrient deficiencies, allowing timely and targeted interventions.

Remote Sensing: Technology, through satellite imagery and spectral analysis, provides extensive monitoring of vegetation indices like NDVI (Normalized Difference Vegetation Index). This data supports region-specific advisories related to nutrient management, crop health assessment, and pest or disease prediction. When integrated with AI algorithms, these technologies enable predictive modeling and generate actionable recommendations for farmers. Consequently, agricultural extension services become more proactive, data-supported, and location-specific, improving productivity, sustain-

ability, and resilience against climate change. This smart integration marks a major step toward digital and intelligent farming systems in modern agriculture.

Benefits of Data-Driven and AI-Powered Advisory Systems

Precision Decision-Making: AI provides farmers with precise, evidence-based recommendations.

Timely Interventions: Real-time data alerts help prevent crop losses due to pest attacks or weather extremes.

Resource Optimization: Efficient use of water, fertilizers, and pesticides enhances sustainability.

Inclusivity: Digital platforms reach small and marginal farmers in remote areas through mobile connectivity.

Climate Resilience: AI models help farmers adapt to changing climatic conditions by forecasting risks.

Overall, these systems increase productivity, reduce input costs, and strengthen the socio-economic status of farmers.

Challenges and Limitations

Despite the vast potential of AI in agricultural extension, several challenges hinder its full adoption. The digital divide remains a major issue, as many small and marginal farmers lack access to smartphones, internet, and digital literacy. Data privacy and security concerns also arise, requiring strict measures to protect farmer information. Additionally, the localization of content is essential to ensure that AI-generated advisories are region-specific and culturally relevant. Capacity building is another key challenge, as extension professionals need training to effectively use AI and data analytics tools. Furthermore, infrastructure gaps, including poor rural connectivity and unreliable electricity, limit large-scale implementation.

Future Prospects and Way Forward

The future of agricultural extension lies in integrating human expertise with digital intelligence. Hybrid models combining human extension agents with AI-based systems can offer the best of both worlds personal trust and technological efficiency. Government and private sectors should invest in digital infrastructure, AI research, and capacity-building programs for extension workers. Collaboration among universities, research institutes, agri-tech startups, and farmer organizations will ensure that AI solutions are scalable, farmer-centric, and sustainable. AI-powered extension systems will also align with global goals such as the United Nations Sustainable Development Goals (SDGs), particularly those targeting zero hunger, climate action, and sustainable agriculture.

Conclusion

The transition towards data-driven and AI-powered agricultural extension marks a revolutionary step in global farming systems. By combining big data analytics, AI models, and digital communication, these systems enable personalized, real-time, and predictive advisory services. However, successful implementation requires inclusive policies, ethical governance, and continuous skill development of extension professionals. Empower-

ing farmers with intelligent tools and reliable data will ensure a more sustainable, resilient, and productive agricultural future bridging the gap between technology and the field, science and practice, and knowledge and action.

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Water Use Efficiency in Agriculture: Insights from e-Crop Data

Rita Fredericks

Abstract

Water use efficiency (WUE) is also essential for sustainable agriculture, especially with expanding water scarcity and climate volatility. e-Crop systems, as digital agriculture platforms, offer real-time information on soil water, crop development, weather, and irrigation regimes, making water management possible in an accurate and precise manner. Through IoT sensors, remote sensing, GIS, and AI-based analytics, e-Crop facilitates evidence-based irrigation planning, drought observation, and water productivity mapping. These technologies increase water productivity per unit of crop production, minimize wastage, save groundwater, and enhance climate resilience. By utilizing e-Crop data, farmers and policy-makers are able to manage water resources with maximum efficiency, supporting productive, climate-resilient, and sustainable agricultural systems.

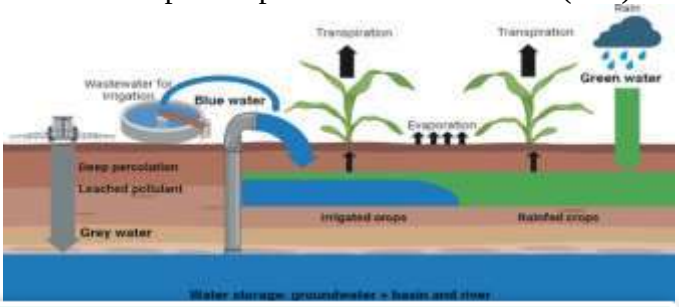
Introduction

Water is the very lifeblood of agriculture and is responsible for almost 70% of the world's freshwater use. With increasing climate change, one of the most pressing threats to international food security has been water scarcity. Unpredictable rainfalls, over-extraction of groundwater, and inefficient irrigation techniques have necessitated sustainable water management as a pressing requirement. The challenge here is not only to grow more food using less water but to utilize available resources in a more efficient manner. The onset of digital agriculture and specifically e-Crop systems has transformed the way water use efficiency (WUE) is quantified, tracked, and enhanced. These digital systems compile field-level information like soil moisture, weather, growth stages of crops, and irrigation history to inform evidence-based water management choices. This paper examines how e-Crop information supports analyzing, enhancing, and optimizing water use efficiency in agriculture, promoting a shift towards climate-resilient and sustainable agriculture systems.

Concept of Water Use Efficiency (WUE)

Definition: Water Use Efficiency (WUE) is a measure of the ratio of crop yield (biomass or grain) to the quantity of water consumed. It describes the efficiency with which a plant or cropping system transforms available water into economic produce.

$$WUE = \frac{\text{Crop Yield (kg ha}^{-1}\text{)}}{\text{Evapotranspiration or Water Used (mm)}}$$



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Significance of WUE

Enhancing WUE guarantees:

- ✓ Greater productivity per unit of water
- ✓ Less pressure on groundwater resources
- ✓ Greater drought resilience
- ✓ Lower energy expenditure on irrigation
- ✓ Sustainable balance of ecosystems

In contemporary agriculture, where water resources are scarce, optimal utilization of every drop has become pivotal to economic sustainability as well as climate resilience.

Role of e-Crop Systems in Improving Water Use Efficiency

What is an e-Crop System?

An e-Crop system is an internet-based platform that combines remote sensing, IoT-based sensors, GIS, and artificial intelligence to gather and analyze real-time agricultural data. Under collaborative efforts of ICAR, state government departments, and research institutions, the e-Crop system acts as a centralized decision-support tool for policymakers and farmers.

Major Functions of e-Crop Pertaining to Water Management

Data Collection: Collects real-time weather, irrigation, and soil moisture information using sensors and satellites.

Data Integration: Merges field-level data with hydrological and climatic information.

Analysis and Prediction: Applies algorithms to forecast irrigation requirements and water stress.

Decision Support: Offers localized advisories for drought relief and irrigation scheduling.

By performing these operations, e-Crop data enables accurate and adaptive water management in different agro-climatic zones.

e-Crop Data Analytics for Water Use Optimization

Soil Moisture Monitoring: e-Crop takes into account information from IoT-based soil moisture sensors that are deployed in farms. Soil water content is continuously monitored by these sensors, allowing the system to:

- ✓ Determine the best irrigation time.
- ✓ Prevent over-irrigation and deep percolation losses.
- ✓ Save groundwater through optimal soil moisture levels.
- ✓ Farmers get real-time alerts from mobile apps, and irrigation will be applied only when needed.

Remote Sensing for Detection of Crop Water Stress: Satellite imagery and NDVI (Normalized Difference Vegetation Index) are employed by e-Crop systems for the detection of crop water stress. Any change in NDVI reflects drought or excess conditions. Spatial information enables:

- ✓ Zone-by-zone irrigation management.
- ✓ Early identification of water-based crop stress.
- ✓ Effective distribution of scarce water resources.

Weather Forecasting Integration: e-Crop systems interface with meteorological information to predict rainfall and evapotranspiration. Farmers are instructed to postpone irrigation prior to rainfall or reschedule in heatwaves, with the least amount of

wastage.

Irrigation Scheduling Models: The system makes use of crop growth models and water balance equations based on real-time input to ascertain:

- ✓ Optimal irrigation intervals.
- ✓ Water demand based on crop type and stage of growth.
- ✓ Yield-water potential relationships.

Data-based models greatly improve decision-making at the field level and promote sustainable water use.

Water Productivity Mapping: With the help of GIS software, e-Crop creates spatial water productivity maps showing where and how water is being used efficiently, and where there is over- or under-irrigation. These maps inform farmers as well as policymakers in decisions on resource distribution and infrastructure development.

Climate-Smart Insights from e-Crop Data

Drought Early Warning Systems: With satellite data, rainfall trends, and soil moisture indices analyzed together, e-Crop forecasts drought risk months or even years ahead. This enables:

- ✓ Farmers to change cropping patterns.
- ✓ Governments to plan water allocation and relief measures.
- ✓ Agricultural departments to initiate drought-resilient interventions.

Real-Time Decision Support: The integration of AI-based algorithms in e-Crop systems provides farmers with real-time irrigation advisories. These advisories consider both weather forecasts and crop requirements, reducing water losses by up to 25-40%.

Groundwater Management: Through real-time tracking, e-Crop locates groundwater depletion areas and assists in controlling borewell use. It also aids in planning artificial recharge structures and rainwater harvesting locations.

Integrating with Climate-Resilient Practices: e-Crop facilitates climate-smart interventions including:

- ✓ Mulching and conservation tillage to minimize evaporation.
- ✓ Drip and sprinkler irrigation systems for targeted application.
- ✓ Crop diversification based on trends of local water availability.

Case Studies and Examples

Andhra Pradesh e-Crop Initiative: The Andhra Pradesh e-Crop portal, linked with IoT and GIS information, enhanced irrigation planning for paddy fields. The farmers conserved 20-30% irrigation water without any yield reduction by sensing soil moisture and precipitation.

ICAR-CRIDA Pilot Studies: Central Research Institute for Dryland Agriculture (CRIDA) utilized e-Crop-assisted sensors to assess WUE in rainfed crops. It enabled the design of contingency irrigation plans that enhanced productivity under drought conditions.

International Example: In Israel's precision irrigation system, comparable data-based models like e-Crop employ satellite images and soil sensors

to realize the highest WUE in the world, a model for water-scarce countries.

Advantages of Utilizing e-Crop Data for WUE

Lower Water Losses: Precision irrigation using real-time information reduces evaporation and percolation losses.

Increased Productivity: Equitable water application promotes plant growth and yield.

Energy Conservation: Lower frequency of pumping saves electricity.

Policy Efficiency: Governments are able to plan water-saving plans based on data-driven insights.

Sustainability: Facilitates climate-smart agriculture by minimizing waste of resources and enhancing resilience.

Challenges and Limitations

However, there are various challenges in achieving e-Crop systems in water management:

- ✓ High Sensor and Infrastructure Cost for smallholder farmers.
- ✓ Data Accuracy Problems due to faulty sensors or weak connectivity.
- ✓ Low Digital Literacy among the farming community.
- ✓ Absence of Inter-Regional Database Integration with national platforms.
- ✓ Policy Gaps in real-time data utilization for water management.

Future Directions

The future generation of e-Crop systems will have to integrate:

- ✓ Machine learning and AI for smart irrigation control.
- ✓ Blockchain to ensure transparent use of water and tracking of subsidies.
- ✓ 5G connectivity to provide real-time high-resolution monitoring.
- ✓ Satellite-Sensor Integration for national water accounting.

Conclusion

Efficiency in water use is a pillar of sustainable farming in a time of climatic uncertainty. By combining field-level and climatic information, the e-Crop system offers on-the-ground insights for water saving and irrigation optimization. With soil moisture measurements, satellite-based stress identification, and advisory using AI, e-Crop turns raw data into actionable decisions that improve productivity and sustainability.

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Impacts of Improved Rural Connectivity (5G, Broadband) on Agricultural Tech Adoption

Anil Kumar, Subhas Verma, Manjul Jain and Rita Fredericks

Abstract

Improved rural connectivity through 5G, broadband, and IoT is revolutionizing agriculture by enabling faster technology adoption and precision farming. Enhanced connectivity boosts productivity, supports data-driven decisions, and promotes sustainability. However, challenges like limited digital literacy, affordability, and infrastructure gaps remain. Overall, rural connectivity is vital for resilient, modern, and efficient agricultural systems.

Introduction

Agriculture, the backbone of rural economies, is undergoing a digital transformation powered by innovations such as precision farming, drones, artificial intelligence (AI), and smart sensors. However, these technologies rely heavily on reliable and high-speed internet connectivity. The deployment of 5G and broadband networks in rural areas bridges the digital divide, enabling farmers to access real-time data, automated machinery, and market intelligence. In India and many developing countries, where over 60% of the population depends on agriculture, digital connectivity is vital to modernize farming practices. Rural connectivity does not merely provide access to the internet; it creates a digital ecosystem where farmers, agribusinesses, extension services, and policymakers interact in real time. Improved connectivity transforms rural landscapes into hubs of innovation, efficiency, and inclusivity.

The Role of Connectivity in Agricultural Transformation

Agricultural technologies depend on data flow, real-time monitoring, and machine-to-machine communication. Improved rural connectivity supports this by linking every component of the agricultural value chain. Key areas where enhanced connectivity drives change include:

Precision Agriculture: Precision farming relies on accurate and timely data collection from sensors, drones, and satellites.

Source: https://www.sciencedirect.com/science/article/abs/pii

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High-speed broadband and 5G allow for instant transmission of large datasets, facilitating decisions on irrigation, fertilizer application, and pest control. Farmers can optimize inputs, enhance yields, and minimize environmental footprints.

Internet of Things (IoT) in Agriculture: IoT devices, such as soil moisture sensors, weather stations, and livestock trackers, require constant connectivity to send and receive data. With 5G, these devices function seamlessly, offering farmers real-time insights into field conditions and enabling automated responses like irrigation scheduling and nutrient application.

Digital Advisory and Extension Services: Broadband and mobile networks expand the reach of digital advisory platforms that deliver crop-specific guidance, pest alerts, and market prices. Farmers receive localized, data-backed recommendations, improving decision-making and reducing dependency on traditional guesswork or middlemen.

Market Linkages and Financial Inclusion: Connectivity connects farmers directly to online marketplaces and e-agriculture platforms, allowing them to access fair pricing, insurance, and credit. Digital transactions enhance transparency, traceability, and income security, contributing to rural economic growth.

5G Technology: A Catalyst for Smart Agriculture

The rollout of 5G technology represents a major leap forward in agricultural innovation. Unlike 4G, 5G offers ultra-low latency, massive connectivity and faster data speeds. These features enable real-time operations of autonomous machinery and precision applications.

Enhanced Machine Communication: 5G allows autonomous tractors, drones, and harvesters to communicate and operate efficiently, even in remote fields. This machine-to-machine communication enhances productivity and reduces labor dependency.

Remote Monitoring and Control: Farmers can remotely monitor their farms through connected sensors and video systems. For instance, real-time weather alerts and pest surveillance systems provide timely warnings, enabling preventive rather than reactive measures.

Smart Supply Chain Management: Connectivity-driven logistics platforms enhance traceability and reduce post-harvest losses. Sensors track produce quality during storage and transport, helping maintain freshness and market value.

Economic and Social Impacts of Improved Rural Connectivity

Productivity Enhancement: With better access to digital tools and analytics, farmers can optimize inputs and maximize output. Studies have shown that connected farms achieve up to 20-30% higher productivity compared to those without digital infrastructure.

Empowerment and Inclusion: Connectivity enables women and smallholder farmers to access knowledge platforms, training programs, and digital financial tools. This inclusivity fosters gender equity and youth engagement in agriculture.

Rural Entrepreneurship: Improved connectivity opens opportunities for rural startups offering agri-tech solutions, e-commerce services, and equipment sharing platforms. This promotes local innovation and job creation, strengthening rural economies.

Data-Driven Governance and Policy Support: Governments and agricultural institutions benefit from digital connectivity by accessing accurate, real-time data on crop conditions and market trends. This data supports better policy formulation, disaster management, and subsidy implementation.

Challenges in Implementing Rural Connectivity

While the potential of rural connectivity is immense, several challenges hinder its widespread adoption:

Infrastructure Gaps: Many rural regions lack fiber-optic infrastructure or reliable power supply, restricting broadband deployment.

Digital Literacy: Farmers need training to use digital platforms effectively. Without adequate digital education, the benefits remain underutilized.

Affordability: High device costs and data charges deter small and marginal farmers from using digital tools.

Policy and Institutional Barriers: Coordination between telecom providers, local governments, and agricultural agencies is often weak, slowing progress.

Addressing these challenges requires a multi-stakeholder approach, involving public-private partnerships, rural digital literacy programs, and policy harmonization.

Future Prospects and Recommendations

Future prospects for rural connectivity in agriculture focus on fostering public-private partnerships to expand broadband access and empowering farmers through continuous digital literacy training. Ensuring affordable internet and smart devices will promote inclusivity among smallholders. Encouraging region-specific innovations for soil health, crop management, and pest monitoring will enhance sustainability. Furthermore, implementing strong data governance frameworks is essential to safeguard privacy, ensure ethical data use, and build farmers' trust, paving the way for smarter, more resilient agriculture.

Conclusion

Improved rural connectivity through 5G and broadband is transforming agriculture by enabling precision, sustainable, and resilient practices. It empowers small farmers with data-driven insights, enhances productivity, and promotes inclusion in the digital economy. Overcoming infrastructure and policy challenges will ensure a smart, efficient, and sustainable agricultural future for rural communities.

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Climate-Smart Precision Agriculture Tools for e-Crop Systems

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Abstract

Climate-smart precision agriculture combines cutting-edge digital technologies with environmentally friendly farming practices to improve productivity, resource utilization, and climate resilience. e-Crop systems are digital platforms that harvest and interpret real-time information from IoT sensors, remote sensing, and AI models to enable data-driven decision-making in agriculture. These systems support precise use of inputs, early warning for climate threats, and enhanced yield forecasting. Through the integration of technologies like drones, GIS, big data analytics, and block chain, e-Crop systems encourage adaptive and sustainable farming. The synergistic approach ensures sustainable food production, minimizes green gas emissions, and enhances climate change impact resilience.

Introduction

Agriculture today confronts two major challenges meeting the rising global food demand and addressing the severe impacts of climate change. Climate-Smart Precision Agriculture (CSPA) provides an innovative approach that leverages digital technologies to optimize resource use, enhance productivity, and reduce environmental degradation. At the core of this approach is e-Crop systems integrated digital platforms that collect, analyze, and interpret real-time crop data to support informed decision-making. These systems combine sensors, satellite imagery, and predictive analytics to guide farmers, researchers, and policymakers in adapting to changing climatic conditions. The integration of CSPA and e-Crop technologies marks a paradigm shift from conventional, input-intensive farming to a knowledge-driven, adaptive model emphasizing efficiency, sustainability, and long-term resilience in global agriculture.

Definition of Climate-Smart Precision Agriculture

Climate-Smart Agriculture (CSA): Climate-smart agriculture, according to the FAO, is to:

- ✓ Increase agricultural productivity and income sustainably.
- ✓ Build adaptation and resilience to climate change.
- ✓ Mitigate and/or avoid greenhouse gas emissions where possible.

CSA encourages practices such as conservation tillage, crop diversification, integrated nutrient management, and efficient irrigation.

Precision Agriculture (PA): Precision agriculture is site-specific crop management through digital technologies such as:

- ✓ Global Positioning Systems (GPS)
- ✓ Geographic Information Systems (GIS)

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- ✓ Remote sensing and drones
- ✓ Internet of Things (IoT) sensors
- ✓ Big data and artificial intelligence (AI)

By targeting inputs (water, fertilizers, pesticides) where and when they are required, PA increases efficiency, reduces waste, and saves resources.

Source:https://cacm.acm.org/latin-america-regional-special-section/scalable-technological-architecture-empowers-small-scale-smart-farming-solutions/

Integration: Climate-Smart Precision Agriculture

When CSA principles are integrated with PA technologies, Climate-Smart Precision Agriculture comes into being a system that not only increases efficiency and productivity but also enhances resilience to climatic stress through data-driven real-time decision-making.

e-Crop Systems: The Digital Backbone

Definition and Purpose: e-Crop systems are computerized platforms that have been created to gather, dissect, and portray agro-data at the farm, regional, and national levels. They act as focal points where data on crop type, area, growth stage, pest occurrence, soil parameters, and climatic conditions can be kept.

Elements of e-Crop Systems: Tools for data gathering: IoT sensors, drones, and satellite imaging for recording soil moisture, crop condition, and weather.

- ✓ **Cloud-Based Databases:** Safe storage and integration of spatial and temporal data.
- ✓ **Decision Support Systems (DSS):** Give farmers and extension workers real-time advisories.
- ✓ **AI-Driven Analytics:** Predict yield, pest risk, and water needs through machine learning algorithms.
- ✓ **Mobile Applications:** Enable two-way dialogue between farmers and experts for adaptive management.

Policy and Institutional Relevance

The Indian Council of Agricultural Research (ICAR) and various state governments are implementing e-Crop platforms to help digital agriculture endeavors. These technologies facilitate precise crop acreage estimation, yield prediction, and evidence-based policy-making, thereby ensuring transparency and optimal resource usage.

Source: https://link.springer.com/article

Climate-Smart Precision Agriculture Tools in e-Crop Systems

Remote Sensing and GIS: Remote sensing through satellites and UAVs offers real-time observations of vegetation indices (NDVI), soil moisture, and crop

stress. GIS spatially maps this information for zone-wise management for fertilizer application and irrigation planning. These devices enable tracking of climate-driven crop heterogeneity and adaptive strategy planning.

Internet of Things (IoT) Sensors: Soil and weather sensors based on IoT capture real-time data for:

- ✓ Soil water content, pH, and nutrient levels
- ✓ Air temperature and relative humidity
- ✓ Rainfall and wind speed

This information is sent to e-Crop databases, where it activates automated irrigation or prompts pest alerts for outbreaks, minimizing wastage of water and inputs and maximizing climate resilience.

Unmanned Aerial Vehicles (Drones): Multi-spectral camera-equipped drones cover vast expanses of land in a short time, detecting nutrient deficiencies, weed infestations, and pest damage. In climate-stressed areas, drones help evaluate drought intensity, flood loss, and crop recovery, allowing rapid decision-making.

Artificial Intelligence (AI) and Machine Learning (ML): AI and ML models in e-Crop systems process big data to forecast crop growth trends, yield performance, and weather-related hazards. For example:

- ✓ Pest prediction models using AI foresee outbreaks from temperature and humidity information.
- ✓ Machine learning algorithms adjust irrigation timing and input application schedules.
- ✓ These predictive abilities play a critical role in climate adaptation and disaster risk reduction.

Decision Support and Advisory Systems: Integrated DSS in e-Crop platforms deliver localized advisories to farmers via mobile apps and SMS services. These advisories are weather forecasts, irrigation timing, pest management, and nutrient management, facilitating informed and timely decision-making.

Blockchain Technology: Blockchain guarantees transparency, traceability, and trust throughout the agricultural supply chain. Blockchain in e-Crop systems can account for transactions involving input supply, crop certification, and carbon credits facilitating climate-smart markets and incentives for farmers.

Big Data Analytics: Combining large datasets from satellites, sensors, and weather stations, big data analytics enables evidence-based decision-making. Predictive yield mapping, climate trend analysis, and drought or flood early warning systems are all examples that improve preparedness and resilience.

Advantages of Climate-Smart Precision Agriculture Technologies

Improved Productivity and Efficiency: Precision technologies guarantee inputs such as water, fertilizers, and pesticides are utilized efficiently, boosting yield and saving costs.

Climate Resilience: Real-time monitoring and predictive models facilitate timely response to climatic hazards like drought, heat stress, and floods.

Environmental Sustainability: Optimized resource utilization reduces greenhouse gas emissions, pollut-

ion, and water and soil health.

Data-Driven Decision Making: Immediate data enables farmers, researchers, and policymakers to make adaptive, evidence-based decisions for sustainable agriculture.

Improved Policy Implementation: e-Crop data may be utilized by government agencies for improved targeting of subsidies, crop insurance, and management of disaster relief.

Market Transparency: With blockchain and digital traceability, producers are able to reach premium markets and climate-sensitive certification schemes.

Implementation Challenges

Albeit the tremendous potential, a number of challenges limit the far-reaching implementation of climate-smart precision tools:

High Upfront Cost: The price of drones, sensors, and digital infrastructure might be out of reach for smallholders.

Data Management Challenges: Maintaining data quality, interoperability, and privacy is still challenging.

Technical Skill Shortfalls: Field officers and farmers do not receive proper training to use and read digital tools.

Limited Connectivity: Internet penetration in rural areas is poor, preventing real-time data transfer.

Policy Harmonization: Inadequate digital agriculture policies and incentives hinder adoption.

These challenges can be overcome through capacity-building initiatives, public-private collaborations and government support for digital agriculture inclusion.

Future Opportunities

The way forward for climate-smart e-Crop systems is to combine upcoming technologies with policy templates and farmer engagement. A few trends that are optimistic include:

- ✓ AI-driven predictive analytics for weather-resistant cropping patterns.
- ✓ 5G connectivity to stream real-time data from far-flung fields.
- ✓ Autonomous robots for precision sowing, weeding, and harvesting.
- ✓ Digital twins of farms for scenario simulation and planning.
- ✓ Maturation in carbon credit markets to incentivize sustainable practices.

Conclusion

The intersection of climate-smart agriculture and precision technologies through e-Crop systems is a revolutionary pathway towards sustainable and resilient food production. With the use of tools like remote sensing, IoT, AI, and big data analytics, farmers can make adaptive, informed decisions that maximize resource efficiency, minimize environmental impacts, and avoid climate risks. For true potential of climate-smart precision agriculture to be achieved, focus should be directed towards digital infrastructure, farmer capacity building, and policy mainstreaming. In the right hands, e-Crop systems can be the backbone of agriculture in the future guaranteeing productivity, profitability and environmental responsibility under conditions of climate

unpredictability.

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Crop Diversification: Turning Farm Risks into Resilience

Saniya Meena, Ratansingh Vaskel, Neeraj Kumar Meena and Vijay Shankar Gurjar

Introduction

Agriculture is the lifeline of humanity. It provides food, fiber, fodder, fuel, and raw materials for industries. Beyond this economic role, it also anchors the cultural, social, and ecological fabric of rural societies. For countries like India, where nearly half of the population depends directly or indirectly on farming, agriculture is not merely a source of income but a way of life and survival. Despite its importance, agriculture is one of the most risk-prone sectors. Farmers are constantly exposed to unpredictable weather conditions, erratic rainfall, floods, droughts, hailstorms, cyclones, pest infestations, and fluctuating market prices. These uncertainties reduce farming from a potentially profitable occupation into one fraught with risks and insecurity.

One of the major reasons why agriculture becomes so vulnerable is its overdependence on monocropping. Modern farming systems, particularly since the Green Revolution, have been dominated by monoculture of staple crops like rice, wheat, or maize. While these systems initially delivered food security, they also exposed farmers to high risks. A single unfavorable event be it a drought, pest outbreak, or market crash can wipe out the entire harvest. Moreover, continuous monocropping drains soils of nutrients, depletes groundwater, and increases dependency on synthetic fertilizers and pesticides, leading to environmental degradation.

In this backdrop, crop diversification is emerging as a time-tested yet modern solution. Crop diversification is not a new concept it has deep roots in traditional farming practices, where farmers naturally grew a mix of cereals, pulses, vegetables, fruits, and spices to meet household needs. However, in the modern era, it is regaining importance as a strategy for risk management, ecological balance, and nutritional security. By cultivating multiple crops either simultaneously, sequentially, or in combination, farmers can reduce dependence on a single crop, spread risks and maximize the use of land, water, and nutrients. Thus, crop diversification has become a cornerstone of sustainable farming and resilient livelihoods.

Understanding Crop Diversification

Crop diversification refers to the systematic shift from growing a narrow range of crops to cultivating a wider variety of cereals, pulses, oilseeds, vegetables, fruits, fodder, spices, and even medicinal plants. It can take different forms depend-

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ing on farmers' goals, resources, and agro-ecological conditions:

Horizontal Diversification: Introduction of new crops alongside traditional crops. For example, adding pulses and oilseeds to a rice-wheat cropping system.

Vertical Diversification: Moving beyond primary production by linking crops with processing, value addition, and marketing. For example, growing sugarcane and producing jaggery or bio-ethanol.

Spatial Diversification: Cultivating multiple crops in the same field through intercropping, mixed cropping, or strip cropping. This ensures better land use and ecological stability.

Temporal Diversification: Rotating crops across different seasons or years. For instance, alternating wheat with legumes or vegetables improves soil fertility and reduces pest cycles.

This multidimensional approach is not only about growing more crops but about designing a farming system that balances economic, ecological, and nutritional needs.

Why Crop Diversification is Crucial

Mitigating Climatic Risks: Climate change is no longer a distant threat it is already reshaping agriculture. Delayed or weak monsoons, unseasonal rains, extended droughts, and rising temperatures are disrupting traditional farming calendars. For example, wheat yields decline significantly with a mere 1-2°C rise in temperature during grain filling. Rice cultivation, too, is threatened by water scarcity. Farmers dependent on a single crop may lose their entire investment during such events. Diversified farms, however, act as a form of natural insurance. Different crops respond differently to stress while heat-sensitive wheat may suffer, a drought-tolerant millet or pulse crop may still yield reasonably well. This ensures at least partial recovery of income and food supply.

Coping with Market Volatility: Agricultural markets are notoriously unstable. Global trade policies, supply-demand imbalances, and local gluts often cause wild swings in crop prices. For instance, tomato farmers in India frequently face "boom and bust" cycles earning handsome profits one season and suffering losses the next when prices crash. Farmers who grow only tomatoes or only cotton remain at the mercy of the market. But those cultivating a combination of cereals, pulses, vegetables, and fruits spread their risks. If one crop fetches a poor price, income from others compensates. Thus, diversification stabilizes household incomes and shields farmers from financial distress.

Enhancing Soil Fertility: Soils are living systems. Continuous monocropping without replenishing nutrients leads to nutrient exhaustion, declining organic matter, and soil degradation. For example, rice–wheat systems in northern India have caused imbalances of nitrogen, phosphorus, and potassium. Diversification helps restore balance. Legume crops like chickpea, pigeon pea, and groundnut fix atmospheric nitrogen, enriching soil naturally. Crop rotations improve soil organic matter, enhance microbial activity & promote healthier root systems.

Over time, this reduces dependency on costly chemical fertilizers and builds long-term soil fertility.

Pest and Disease Management: Pests and pathogens thrive when the same crop is grown repeatedly on the same land. This creates an ideal environment for pest multiplication and disease persistence. Crop diversification disrupts these cycles. Intercropping marigold with tomato suppresses nematodes, while alternating cereals with legumes breaks pest life cycles. By reducing pest buildup, diversified systems lower pesticide requirements, cutting costs and minimizing environmental hazards.

Improving Nutrition and Food Security: A monocropped farm may produce abundant calories but cannot meet household nutritional needs. A rice-based system, for instance, lacks proteins, vitamins, and minerals. Crop diversification bridges this gap. A farm that produces cereals, pulses, vegetables, and fruits ensures a balanced diet rich in carbohydrates, proteins, vitamins, and micronutrients. At the community level, it enhances food security and reduces dependence on external markets for diverse foods. This is particularly important in rural areas, where malnutrition and hidden hunger remain widespread.

Benefits of Crop Diversification

Economic Stability: Diversified income streams protect farmers from complete financial collapse during crop failures or price drops.

Climate Resilience: Systems with multiple crops withstand droughts, floods, and temperature fluctuations better than monocropping systems.

Sustainability: By conserving soil fertility, enhancing biodiversity, and reducing input dependence, crop diversification contributes to ecological balance.

Employment Generation: High-value crops like fruits, vegetables, flowers, and spices demand more labor and create rural jobs.

Women Empowerment: Home gardens and small diversified plots are often managed by women, providing household nutrition and supplementary income.

Real-World Examples

Crop diversification is not a theoretical concept it is being practiced successfully across regions:

The Green Revolution Belt of Punjab and Haryana: Decades of rice-wheat monoculture have depleted groundwater and degraded soils. Introduction of maize, pulses, oilseeds, and horticultural crops has improved water-use efficiency and restored balance.

Millet Revival in Rajasthan and Karnataka: Farmers in semi-arid regions are reviving pearl millet, sorghum, and minor millets. These hardy crops withstand drought, provide nutritious food, and support livestock fodder needs.

Horticulture Integration in Maharashtra: Mango and pomegranate orchards intercropped with vegetables, legumes, and spices generate year-round income and improve land-use efficiency.

Agroforestry Models in Southern India: Farmers planting timber trees like teak and neem alongside crops like turmeric and ginger enjoy short-term cash flow and long-term timber returns, while improving biodiversity and carbon sequestration.

International Example

Kenya: Smallholder farmers intercropping maize with beans and cassava have improved household food security and reduced vulnerability to drought.

Latin America: Coffee farmers diversifying with fruit trees and spices have stabilized incomes during coffee price crashes.

Challenges in Adopting Crop Diversification

Despite its many benefits, farmers face several challenges:

Market Constraints: Alternative crops often lack assured procurement, leading to poor market realization.

Policy Bias: Government subsidies and MSP policies are disproportionately focused on rice and wheat.

Knowledge Gaps: Many farmers are unaware of optimal intercropping or rotation systems for their region.

Infrastructure Limitations: Fruits, vegetables, and flowers require cold chains, processing units, and better transport facilities.

Seed Availability: Region-specific, high-yielding seeds for pulses, oilseeds, and vegetables are not always accessible.

Risk Aversion: Farmers accustomed to staple crops may hesitate to adopt new crops without strong institutional support.

Strategies to Promote Crop Diversification

Policy Reforms

- ✓ Extend MSP and procurement systems to pulses, millets, and oilseeds.
- ✓ Offer subsidies and crop insurance support for diversified systems.

Research and Innovation

- ✓ Develop stress-tolerant, short-duration, and high-yielding varieties for diverse crops.
- ✓ Promote region-specific integrated cropping models.

Market and Infrastructure Development

- ✓ Establish cold chains, processing facilities, and efficient transportation.
- ✓ Encourage Farmer Producer Organizations (FPOs) to strengthen collective bargaining and market access.

Capacity Building

- ✓ Train farmers through extension programs, field demonstrations, and ICT tools.
- ✓ Disseminate successful models of diversified farming.

Climate-Smart Practices

- ✓ Promote conservation agriculture, organic farming, and agroforestry.
- ✓ Integrate livestock, fisheries, and poultry with cropping systems to maximize resilience.

Future Prospects

With increasing demand for nutritious food, bioenergy and eco-friendly farming, crop diversification will shape the future of agriculture.

The global push to revive millets and traditional crops demonstrates a shift toward resilient, nutrition-rich farming systems. India's leadership during the International Year of Millets (2023) shows how diversification aligns with both farmers' livelihoods and global food security agendas.

Diversification is also crucial for achieving the Sustainable Development Goals (SDGs) from zero hunger and good health to climate action and biodiversity conservation. With proper support, diversified farming can transform agriculture into a sustainable, climate-resilient, and nutrition-sensitive enterprise.

Conclusion

Crop diversification is much more than a traditional practice; it is a strategic pathway to sustainable agriculture. It reduces risks, improves resilience, enhances soil and ecosystem health, and ensures nutritional and economic security. However, for its full potential to be realized, farmers need enabling policies, market access, training, and infrastructure support.

The timeless wisdom "Do not put all your seeds in one basket" remains highly relevant. In today's uncertain agricultural scenario, crop diversification provides farmers with the much-needed insurance against risks while opening new opportunities for income and sustainability. It is not just a survival strategy but a transformative approach to turn farm risks into resilience and long-term prosperity.

Protected Cultivation: A Profitable Future for Vegetables and Flowers

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Introduction

Protected cultivation growing plants under some form of shelter such as greenhouses, polyhouses, shade nets, tunnels or low-cost structures has moved from being a niche, high-investment option to a mainstream, high-return enterprise for smallholders and commercial growers alike. By controlling the crop environment (temperature, humidity, light, water, and pests), protected cultivation reduces risk, extends growing seasons, boosts yields and quality, and opens access to premium markets for off-season vegetables, cut-flowers and ornamentals. This article explains the what, why and how of protected cultivation, focusing on vegetables and flowers. It's written as a popular-style, practical guide for farmers, entrepreneurs, extension workers, agri-students and anyone curious about profitable, climate-smart horticulture.

Why protected cultivation matters now

Higher and more stable incomes: Protected systems provide higher yields per unit area and better product quality (appearance, size, shelf life), allowing farmers to command better prices especially for off-season produce and premium flowers.

Reduced climate risk: Shelters buffer crops from erratic rainfall, hail, heat waves and cold snaps conditions that are increasingly common with climate change.

Efficient resource use: Drip irrigation, fertigation and controlled microclimates improve water and nutrient use efficiency, lowering input costs per kg of produce.

Reduced pest and disease losses: When well managed, physical barriers and integrated pest management (IPM) reduce pesticide reliance and crop losses.

Year-round production and diversification: Growers can cultivate high-value crops out of season and diversify into floriculture, seedling nurseries, and value-added production (e.g., ready-to-eat salads, potted ornamentals).

Types of protected structures

Protected structures range from low-cost to high-tech. Choice depends on budget, crop, climate and market targets.

Low tunnels / Polytunnels: Simple semi-circular frames covered with polythene; low cost, suitable for small-scale vegetable production and season extens-

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ion.

Shade nets / Net houses: Frames covered with nets (30-90% shade) used for shade-loving ornamentals and to reduce heat/light intensity.

Polyhouses: Rigid steel/Aluminium framed houses covered with UV-stabilized polyethylene film; good microclimate control for vegetables and cut-flowers.

Greenhouses (glass or multi-layer films): More durable and often equipped with ventilation, cooling, heating and automation used for high-value floriculture and seedlings.

Venlo/single/double span glasshouses: High investment but excellent control for premium flowers (roses, gerberas, chrysanthemums) and export-grade vegetables.

Crops suited to protected cultivation

Vegetables

Tomato (indeterminate varieties): Highly profitable when grown in protected systems long harvest window, high value.

Capsicum (bell peppers / sweet peppers): Premium prices for good-sized, blemish-free fruit.

Cucumber (slicing / pickling): High productivity; greenhouse cucumbers are premium.

Leafy greens and salad mixes: Fast turnaround, high turnover, suitable for hydroponics and vertical setups.

Eggplant (brinjal), beans, peas: Can be profitable with good management.

Herbs (basil, coriander, mint): High-value niche markets fresh herbs for restaurants and retail.

Flowers and ornamentals

Roses: Classic high-value cut flower under greenhouse management.

Gerbera, carnation, chrysanthemum: Demand in domestic and export markets.

Orchids and potted ornamentals: Require shade-controlled environments; high per-plant value.

Marigold, zinnia, tuberose: Good for local markets and ceremonies.

Economic case: why it can be profitable

Protected cultivation increases the value per square meter through:

- ✓ Higher yields (2-10× depending on crop & baseline)
- ✓ Off-season pricing (2-4× price premium)
- ✓ Reduced grading losses and higher quality grades
- ✓ Possibility to sell directly to high-value buyers (supermarkets, hotels, florists, exporters)
- ✓ Multiple crops per year (short-cycle crops allow continuous turnover)

Design and critical components

A well-designed protected structure integrates these core elements:

Orientation and Site Selection

- ✓ Choose well-drained sites with good solar access.
- ✓ Orient ridges to maximize winter sun (usually north-south orientation for single span) and minimize shading.
- ✓ Ensure accessibility to markets, electricity and water.

Structure and Covering Material

- ✓ Frame: galvanized steel or aluminum for durability.

- ✓ Cover: UV-stabilized polyethylene film (multi-wall), polycarbonate or glass depending on budget and crop.
- ✓ Ensure adequate height for crop growth and ventilation.

Ventilation and Climate Control

- ✓ Natural ventilation (side and roof vents) is basic; forced ventilation, exhaust fans and evaporative cooling provide precise control in hot climates.
- ✓ Heating (if required) for temperate high-value flowers during colder months.

Irrigation and Fertigation

- ✓ Drip irrigation for vegetables; ebb-and-flow or nutrient film technique (NFT) for hydroponics.
- ✓ Fertigation enables precise nutrient delivery, reducing fertilizer losses and improving growth.

Soilless Media and Hydroponics

- ✓ Cocopeat, perlite, rockwool and other soilless mixes allow cleaner production and better root control.
- ✓ Hydroponic systems (NFT, Dutch buckets) are widely used for tomato, cucumber, and leafy greens.

Pest and Disease Management

- ✓ Use physical exclusion (screens), sanitation (footbaths, netting), biocontrols (predatory insects), and minimal-risk pesticides if needed.
- ✓ Regular monitoring and early detection are essential.

Lighting

- ✓ Natural light is primary; supplemental LED lighting extends production, improves flowering and can shift crop cycles.

Automation and Sensors

- ✓ Temperature, humidity, CO_2 and soil moisture sensors coupled with automated vents and irrigation reduce labor and improve consistency particularly useful for larger commercial units.

Crop management practices (practical tips)

Seedlings / Planting material: Use healthy, virus-free seedlings consider nursery under protected conditions.

Plant spacing and trellising: Optimize light distribution and airflow; trellis indeterminate tomatoes and peppers.

Pruning and training: Regular pruning improves fruit quality and reduces disease risk.

Pollination: For crops like cucumber, provide pollinators (bees) or use hand pollination / parthenocarpic varieties.

Sanitation: Remove old plant debris, disinfect tools, and maintain strict hygiene to prevent disease carryover.

Nutrient monitoring: Conduct periodic tissue and substrate tests to adjust fertigation recipes.

Marketing: capturing higher value

Protected cultivation opens multiple marketing channels:

Local high-end markets: Supermarkets and hotels demand consistent quality and presentation.

Direct-to-consumer: Farmers markets, farm-gate sales and subscription box models.

Restaurants and catering: Fresh herbs and salad mixes are in demand year-round.

Cut-flower auctions / florists / exporters: Require uniform stems, precise grading and reliable supply.

Processed and value-added: Packaged salads, pre-washed herbs, cut-flowers in retail packaging.

Key to capturing premium prices: consistent supply, standardized packing, food-safety certification, and reliable delivery.

Financial snapshot (example table)

Item	Low-cost polytunnel (1000 m²)	Mid-range polyhouse (1000 m²)
Initial investment (structure + basic equip.)	₹250,000-400,000	₹700,000-1,200,000
Annual operating cost (seeds, fert, labor, utilities)	₹150,000-300,000	₹300,000-600,000
Annual gross income (vegetables/flowers)	₹400,000-800,000	₹900,000-2,000,000
Estimated payback	1-3 years	2-4 years

Case examples (typical farm stories)

Smallholder salad greens micro-enterprise: A 200 m² tunnel producing mixed baby greens sold to cafés by subscription can generate steady weekly cashflow and high per-square-meter returns.

Commercial tomato in polyhouse: A 1000 m² polyhouse with drip fertigation, trellising and integrated pest management producing grafted tomatoes can harvest for 8-10 months and supply urban wholesale markets.

Flower entrepreneur: A 500 m² greenhouse producing gerbera and roses primarily for city florists achieves premium prices through quality and year-round supply.

Challenges and solutions

High initial capital

Solutions: Phased investment, loans, group investments through FPOs, government subsidy programs.

Technical know-how

Solutions: Extension services, training programs, mentorship from experienced growers, digital advisory tools.

Pest/disease outbreaks in closed systems

Solutions: Strict sanitation, crop rotation, biological controls, quarantine of new plants.

Market access

Solutions: Aggregation through FPOs, contract farming with buyers, online marketplaces, value addition.

Water and energy costs

Solutions: Rainwater harvesting, solar-powered irrigation and fans, energy-efficient designs, shading to reduce cooling costs.

Scaling and business models

Small-scale entrepreneurship: Home gardens, micro-tunnels for herbs and greens, backyard flower production.

Medium-scale commercial: Multiple polyhouses with standardized production for city markets and processors.

Integrated models: Combining protected cultivation with post-harvest processing (cold storage, grading), agritourism, and training centers.

Service providers: Nursery production of high-quality seedlings, contract production for brands, installation and maintenance of protected structures.

Policy, finance and institutional support (what growers should seek)

Subsidies and grants: Many governments provide partial subsidies for greenhouse construction and micro-irrigation check local schemes.

Credit and insurance products: Crop and asset insurance tailored for greenhouse crops reduce financial risk.

Quality and food-safety certifications: GHP (Good Horticultural Practices), GlobalGAP for exports help secure high-value buyers.

Capacity building: Support from agricultural universities, Krishi Vigyan Kendras, and extension services.

Environmental and social considerations

Resource efficiency: Protected systems can reduce water use and chemical runoff if properly managed.

Waste management: Proper disposal/ recycling of plastic films and substrates is essential to avoid pollution.

Labor implications: Protected cultivation can create skilled jobs; ensure fair wages and safe working conditions.

Equity and smallholders: Design affordable, low-cost models so smallholders and women farmers can participate.

Step-by-step starter guide (for a new grower)

Market validation: Identify buyers and price expectations for your intended crop.

Site visit and feasibility: Assess land, water, electricity, and microclimate.

Choose crop and scale: Start with 100-500 m^2 for learning; choose crops with quick turnover (leafy greens, herbs) to build cashflow.

Select structure and supplier: Get quotes, check warranties and after-sales support.

Invest in quality seedlings / varieties: Consider grafted seedlings for disease tolerance in tomatoes.

Install irrigation system & fertigation controller

Train staff: On hygiene, IPM, pruning, harvesting and post-harvest handling.

Set up packhouse and cold chain: Simple shade, sorting table and basic cooling prolong shelf life.

Start small, monitor and adapt: Keep records of yields, inputs and sales to refine the enterprise.

Scale up: Once profitable, expand and diversify crops.

Emerging trends to watch

Hydroponics and vertical farming: Higher space-use efficiency and urban production close to consumers.

LED lighting and climate automation: Lower operating costs and precision growing.

Digital ag-tech: Sensors, data analytics and remote monitoring to optimize resource use.

Circular systems: Reusing nutrient solutions and substrates, integrating with aquaponics.

Conclusion

Protected cultivation transforms horticulture from seasonal, weather-dependent farming into a predictable, high-value enterprise. For vegetables and flowers, the advantages in yield, quality and market access are compelling. While initial costs and technical complexity are real, practical solutions affordable structures, shared investments, training and market linkages make protected cultivation accessible to many growers.

For farmers willing to adopt best practices and learn, protected cultivation is not just a way to

get higher profits it's a pathway to resilience in the face of climate change, market uncertainty and the increasing demand for safe, high-quality produce.

Biosensors for Plant Pathogen Detection: Fundamentals, Technological Innovations and Future Prospects

Ashish Singh Bisht, Sonam Bhatt, Monalisha Guru, Bijender Kumar and Rashmi Tewari

Introduction

Plant pathogens, including fungi, bacteria, and viruses, pose a significant threat to global food security and agriculture, causing an estimated 20% to 40% of annual crop production losses and financial costs exceeding $290 billion USD. Factors like climate change and global trade are accelerating the spread of these pathogens, necessitating a paradigm shift in plant pathology towards a new "mantra" of "early detection" in conjunction with "fast, accurate, and cheap" diagnostics. This is not just an economic issue; severe outbreaks can threaten human and animal health through poisonous mycotoxins and even lead to the extinction of plant species, making advanced diagnostic tools a public health and environmental imperative.

For years, conventional methods like Polymerase Chain Reaction (PCR) and Enzyme-Linked Immunosorbent Assay (ELISA) have been the standard for plant disease diagnosis, offering high accuracy and specificity. However, these traditional techniques are fraught with limitations that render them unsuitable for modern, large-scale surveillance. They are inherently time-consuming and labor-intensive, often requiring samples to be sent to a central laboratory for analysis, which can take days or weeks. This delay is catastrophic for rapidly spreading diseases, as it provides a crucial window for pathogens to multiply before intervention can be implemented. The complex and expensive equipment required for methods like PCR also makes them impractical for on-site use by farmers or non-specialists.

This trade-off between diagnostic accuracy and real-world applicability creates a significant diagnostic gap, particularly for small-scale farmers in resource-constrained settings where the costs and logistical complexities of traditional methods are prohibitive. Bridging this gap requires a new class of diagnostic tools that are rapid, accurate, and affordable, suitable for on-site, point-of-care (POC) use. Biosensor technology is uniquely positioned to address this critical need, driving the search for innovative solutions that enable real-time, on-site monitoring of crop health.

Core Principles of Biosensor Technology

Foundational Components: Bioreceptor, Transducer and Signal Processing: A biosensor is a device that converts a biological or chemical reaction into a measurable signal by using three main components: a bioreceptor, a transducer, and an electronic system. The bioreceptor, such as an antibody or nucleic acid, is the biological element that specifically interacts with the target substance (the analyte).

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The transducer then converts this bio-recognition event into a quantifiable signal, which can be electrical or optical. Finally, the electronic system processes this raw signal, making it interpretable for the user.

Key Performance Metrics in Biosensing: The performance of a biosensor is measured by three key metrics: selectivity, sensitivity, and the limit of detection (LOD). Selectivity is the device's ability to accurately identify a specific analyte within a complex sample, preventing false-positive results. Sensitivity and LOD are related to the biosensor's quantitative capabilities; sensitivity is the smallest change in concentration that can be measured, while LOD is the lowest concentration that can be detected. A low LOD is crucial for the early detection of plant pathogens, as it allows for diagnosis before the pathogen concentration becomes high enough to cause visible symptoms. A significant challenge in real-world application is that complex plant extracts can interfere with a biosensor's performance, reducing its accuracy and reliability.

Classification of Biosensors for Plant Pathogen Detection

Biosensors for plant pathogen detection can be broadly categorized based on the type of biorecognition element or the transduction mechanism they employ. This classification system provides a useful framework for understanding the diverse approaches being developed to address the diagnostic needs of agriculture.

Biorecognition-Based Systems

Nucleic Acid-Based Biosensors: Nucleic acid-based biosensors utilize DNA or RNA as the bioreceptor to detect the genetic material of the target pathogen. This approach offers exceptional specificity and sensitivity, particularly when integrated with nucleic acid amplification techniques. For example, DNA-based biosensors have been established as powerful tools for the rapid and sensitive identification of plant pathogens, often by coupling probe-functionalized electrodes with redox-active indicators to convert a recognition event into a quantifiable electrochemical signal. An innovative electrochemical nanobiosensor was developed for the detection of *Leifsonia xyli* subsp. *xyli* (*Lxx*) DNA in sugarcane sap, achieving an exceptional detection limit of 10 cells/µL. This method demonstrated high reproducibility and strong correlation with known disease resistance ratings in field trials, offering a cost-effective, equipment-free, and scalable solution for on-site deployment. Recent advancements in this area have been propelled by the adaptation of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)-Cas systems for diagnostics. Platforms like SHERLOCK and DETECTR leverage the collateral cleavage activity of Cas enzymes to detect nucleic acids without the need for thermal cycling, offering high specificity and femtomolar-level sensitivity in a rapid (15-45 minute) and low-cost format. These systems represent a significant leap forward, as they address many of the practical limitations of conventional PCR while retaining high performance. The shift from traditional bioreceptors

to programmable and more stable elements like aptamers and CRISPR systems reflects a broader trend in the field. The desire for greater durability, broader applicability, and ease of manufacturing for portable devices is driving researchers towards these more advanced biorecognition elements, whose robust nature is better suited for the harsh and complex conditions of field use.

Immunobiosensors: Immunobiosensors are based on the highly specific and selective binding affinity between an antigen and its corresponding antibody. In this system, antibodies are immobilized on the transducer surface, and the subsequent binding of the target pathogen's antigen produces a measurable signal. This technology is particularly well-suited for the on-site, large-scale detection of plant pathogens, as demonstrated by their use in tissue print ELISA and lateral flow devices. However, the performance of immunobiosensors is fundamentally limited by the quality and storage conditions of the antibodies employed, as their stability can be affected over time and by environmental factors.

Phage and Aptamer-Based Biosensors: Beyond traditional bioreceptors, a number of emerging technologies are being explored. Phage-based biosensors utilize bacteriophages, which are viruses that specifically infect bacteria, as the recognition element. Aptamer-based biosensors, on the other hand, employ synthetic single-stranded DNA or RNA molecules that can be engineered to bind to a specific target with high affinity. These emerging bioreceptors are being developed to overcome some of the limitations of antibody-based systems, offering enhanced stability and specificity.

Transduction-Based Systems

Electrochemical Biosensors: Electrochemical biosensors are a highly promising class of diagnostic tools that measure changes in electrical properties caused by a bio-recognition event. They are characterized by their simple instrumentation, high specificity, and cost-effectiveness, making them particularly attractive for point-of-care applications. The core mechanisms of these sensors include:

- ✓ **Current-based (Amperometric) sensors:** These systems directly detect targets through redox reactions that cause a measurable change in current. An example is a sensor that detects oxalic acid secreted by pathogenic bacteria, where the intensity of the generated current signal is positively correlated with the acid's concentration.
- ✓ **Impedance-based sensors:** These monitor the change in charge transfer resistance at the electrode interface and are suitable for the quantitative analysis of molecules like DNA or proteins.
- ✓ **Potentiometric sensors:** These capture the target, causing a shift in the electrode potential, which is then measured. An immunosensor using a polyclonal antibody attached to gold electrodes was developed for the in-field detection of plant pathogens, demonstrating high specificity and rapid response.

Optical Biosensors

Optical biosensors leverage the properties of light to detect the presence of specific molecules. They operate by measuring changes in light characteristics such as absorption, reflection, and fluorescence.

Fluorescence Resonance Energy Biosensors (FREBs): These systems use a fluorescent bioreceptor that emits a signal in the presence of an analyte. Green fluorescent proteins (GFPs) have been successfully employed in fluorescent biosensors to detect fungal pathogens such as *Phytophthora palmivora* and *Aspergillus nidulans*.

Chemiluminescence (CL) sensors: These devices are based on the emission of light from a chemical reaction and are valued for their high sensitivity, broad dynamic range, and low cost. A DNA-based chemiluminescent optical fiber biosensor has been designed for the rapid diagnosis of *Brettanomyces bruxellensis*.

Surface Plasmon Resonance (SPR) biosensors: This powerful optical technique measures a change in the refractive index that occurs when molecules bind to a metal surface, typically a thin film of gold. An SPR-based immunosensor was developed for the early detection of Asian rust in soybean leaf extracts, demonstrating a linear response by immobilizing an antibody on a gold plate.

Optical biosensors offer enhanced sensitivity and label-free detection, but they can be complicated, expensive, and less amenable to miniaturization compared to other methods. This suggests a clear trade-off: while optical methods can achieve superior performance in controlled settings, the practicality of on-site deployment often favors simpler, more economical transduction methods, such as electro-chemical ones.

Mass-Based Biosensors: Mass-based biosensors detect analytes by measuring a change in mass. This principle is often applied using micro- or nano-scale oscillators, such as cantilever beams. When a target analyte, such as a bacterial cell, binds to the surface of the cantilever, it increases the overall mass of the structure, causing a measurable shift in its resonant frequency. This technique has shown significant potential for ultrasensitive detection, with the ability to detect bacteria at the single-cell level. By immobilizing specific antibodies on the cantilever, researchers have demonstrated the selective capture of bacterial cells, further enhancing the specificity of the system.

The Convergence of Enabling Technologies

The next generation of plant pathogen biosensors is defined not by a single technological breakthrough but by the convergence of several complementary fields. The integration of nanotech-nology, microfluidics, and artificial intelligence is creating a new class of diagnostic tools that address the limitations of their predecessors and pave the way for a more intelligent and sustainable agricultural future.

The Role of Nanotechnology, Microfluidics, and AI in Biosensors

Nanotechnology has transformed biosensors by using materials like metallic nanoparticles and

carbon nanotubes to boost sensitivity and catalytic activity. Their high surface-area-to-volume ratio allows for more bioreceptors, leading to a lower limit of detection. For example, gold nanoparticles enhance the signals in optical and electrochemical biosensors, making them more accurate and sensitive. Microfluidics and "lab-on-a-chip" systems are crucial for on-site diagnostics. These portable devices automate complex steps like sample preparation, eliminating the need for bulky lab equipment. One example is a microfluidic device that detects plant spores by measuring changes in electrical impedance, offering a selective and real-time solution for field-based analysis.

The full potential of biosensors is realized through the integration of Artificial Intelligence (AI) and Machine Learning (ML). These technologies act as "analytical engines," turning raw sensor data into actionable insights. AI models can detect subtle signs of disease from images (image-based diagnostics), analyze complex genetic data (omics data analysis), and integrate information from multiple sensors into a comprehensive monitoring system (IoT).

Challenges and Future Directions

Despite their promise, several challenges hinder the widespread adoption of biosensors. Technical hurdles include interference from complex plant and environmental samples and the instability of biological components. Economic and regulatory barriers include high manufacturing costs and a lack of standardized regulations for agricultural diagnostics. The future of biosensing for plant pathogens is focused on technological convergence. This includes developing multi-pathogen detection platforms, using nanobiosensors for unparalleled sensitivity, and integrating these systems with IoT and drone technology. This will create an automated, data-driven ecosystem for precision agriculture, enabling farmers to make targeted, sustainable decisions.

Conclusion

The development of biosensors for plant pathogen detection represents a critical and transformative leap forward in modern agriculture. By offering a rapid, sensitive, and on-site alternative to traditional laboratory-based methods, these devices are poised to fundamentally change how plant diseases are managed. The core principles of biosensing, which rely on the synergistic integration of highly specific bioreceptors and versatile transducers, have given rise to a diverse array of innovative platforms, including electrochemical, optical, and mass-based systems. These platforms, in turn, are being propelled by the convergence of enabling technologies. Nanotechnology enhances biosensor performance by improving sensitivity and catalytic activity, while microfluidics enables the miniaturization and automation necessary for point-of-care diagnostics. Ultimately, the integration of these devices with AI and IoT systems promises to create a comprehensive data ecosystem that transforms raw data into actionable intelligence, facilitating proactive disease surveillance and management. However, the field is not without its challenges. Issues related to sample matrix interfer-

ence, reagent stability, and the economic and regulatory hurdles associated with commercialization must be addressed. Despite these limitations, the trajectory of research is clear: the future of plant disease diagnostics lies in the continued development of integrated, high-performance, and secure biosensing systems. By harnessing the power of these technologies, agricultural professionals can move beyond reactive disease control to a new era of precision agriculture, safeguarding crop yields, ensuring a stable food supply, and promoting a more sustainable agricultural legacy for generations to come.

Soil Health and Management: The Key to Sustainable Agriculture

Neha Yadav

Soil is more than just the ground beneath our feet, it is the foundation of life and the bedrock of global food security. For agriculture students, understanding soil health and its effective management is not only part of the curriculum but also essential knowledge for shaping a sustainable future. Healthy soil supports plant growth, regulates water, stores nutrients, and hosts countless microorganisms that are vital for ecological balance. However, with increasing pressure from modern agricultural practices and environmental degradation, the issue of soil health has become more critical than ever. As future agronomists, scientists, and policymakers, agriculture students must grasp the intricate dynamics of soil and adopt practices that preserve and enhance its vitality.

What is soil health?

Soil health, often referred to as soil quality, encompasses the biological, chemical, and physical properties that allow soil to function effectively as a living ecosystem. It includes parameters such as nutrient availability, soil structure, organic matter content, water retention capacity, and microbial activity. A healthy soil is loose, well-aerated, rich in organic matter, and teeming with beneficial organisms. It should provide a stable environment for roots, facilitate water infiltration, and allow for balanced nutrient exchange. Moreover, it acts as a natural buffer against droughts, floods, and climate extremes. When soil health deteriorates, these functions are compromised, resulting in lower crop yields, increased susceptibility to pests and diseases, and long-term land degradation.

Causes of Soil Degradation

In many agricultural regions, soil health is declining at an alarming rate. Unsustainable farming practices such as continuous mono-cropping, excessive tillage, overuse of chemical fertilizers and pesticides, deforestation, and improper irrigation are leading to soil erosion, nutrient depletion, salinization, and loss of organic matter. One of the most damaging effects is the reduction of soil microbial diversity, which plays a crucial role in nutrient cycling and disease suppression. Additionally, compacted soils with poor structure inhibit root growth and water absorption, further stressing crops and reducing productivity. As the global population grows and the demand for food increases, it becomes essential to reverse these trends through effective soil management strategies.

Soil Testing and Analysis: The first step in managing soil health is understanding its current status. Soil testing is an essential practice that allows farmers and researchers to assess key indicators such as pH levels, macronutrient concentrations (nitrogen, phosphorus, potassium), organic carbon content, and

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texture. By conducting regular soil tests, agriculture professi-onals can make informed decisions about fertilizer application, crop selection, and soil amendments. Correcting soil pH through liming or acidifying agents, for instance, can significantly improve nutrient availability and microbial activity. Such data-driven approaches reduce unnecessary input costs and prevent environmental pollution caused by excessive fertilizer runoff.

Organic Matter and Soil Fertility: One of the most effective strategies for improving soil health is the integration of organic matter into the soil. Organic inputs like farmyard manure, compost, crop residues, and green manure enrich the soil with nutrients and improve its structure. They also serve as food for beneficial soil microbes, which in turn help release nutrients in plant-available forms. Incorporating legumes into crop rotations is another proven technique, as legumes fix atmospheric nitrogen and naturally enhance soil fertility. In addition, using biofertilizers containing beneficial bacteria and fungi (such as *Rhizobium*, *Azotobacter*, and mycorrhizae) can further strengthen the biological health of the soil and reduce dependency on synthetic inputs.

Conservation Tillage and Cover Cropping: Conservation tillage practices such as zero tillage or reduced tillage also play a vital role in maintaining soil integrity. These methods minimize soil disturbance, reduce erosion, and help retain moisture and organic matter. Tillage disrupts soil structure and microbial habitats; hence, adopting minimal tillage conserves soil biota and improves water infiltration. Cover cropping, another essential practice, involves growing specific crops like clover, mustard, or rye during fallow periods. These crops prevent erosion, suppress weeds, and when incorporated into the soil, contribute to organic matter and nutrient enrichment.

Water Management for Soil Health: Water management is another cornerstone of soil health. Poor irrigation practices can lead to salinization, compaction, or waterlogging, all of which harm soil quality. Efficient systems like drip or sprinkler irrigation ensure precise water delivery and reduce wastage. In rain-fed areas, constructing farm bunds, contour trenches, and check dams helps conserve moisture and reduce runoff. Mulching covering the soil with crop residues, straw, or plastic helps retain soil moisture, regulate temperature, and control weed growth, thus supporting overall soil health.

Integrated Nutrient Management (INM): Integr-ated nutrient management (INM) promotes the balanced use of chemical fertilizers along with organic and biological sources. Relying solely on synthetic fertilizers may result in short-term yield gains but long-term soil exhaustion. INM ensures the efficient use of nutrients, enhances soil fertility, and improves crop productivity without compromising ecological balance. For example, applying a calculated dose of urea along with compost and biofertilizers ensures nutrient availability while maintaining microbial diversity and organic content. This method is both economic-ally viable and environmentally sustainable.

Promoting Soil Biodiversity: In addition to physical

and chemical management, promoting biodiversity within the soil is crucial. A diverse community of organisms such as bacteria, fungi, earthworms, nematodes, and arthropods contributes to nutrient cycling, pest control and organic matter decomposition. Encouraging agroecological practices that support this diversity leads to resilient, self-sustaining farming systems. Crop diversification, agroforestry, intercropping, and reduced pesticide use are effective ways to nurture soil biodiversity and enhance long-term sustainability. Soil health management is not a one-time activity but a continuous, adaptive process. It requires careful observation, regular testing, and a willingness to integrate traditional knowledge with modern scientific methods. Agriculture students must approach soil as a living resource that needs to be nurtured and protected. By adopting sustainable soil management practices early in their careers, they not only improve farm productivity but also contribute to environmental conservation, climate change mitigation, and food security. In conclusion, soil health is a vital component of agricultural success and environmental sustainability. As the global agricultural landscape faces increasing challenges rising population, climate change, and land degradation investing in soil health becomes more important than ever. For agriculture students, this knowledge forms the foundation for responsible farming and innovative research. By understanding the principles of soil health and implementing sound management practices, they can play a key role in transforming agriculture into a more sustainable and resilient sector for generations to come.

Impact of Acid Soils in Agriculture

B. Nookanna Naidu

Abstract

Soil is the source of agricultural productivity, and its chemical, physical, and biological properties govern crop performance. Out of the several soil-related problems, soil acidity is one of the greatest challenges facing sustainable agriculture. Acid soils with a pH level of less than 5.5 cover almost 30% of the earth's ice-free land surface, predominantly in subtropical and tropical areas. They limit nutrient supply, enhance the solubility of toxic metals like aluminum and manganese, and negatively affect soil microbial processes.

Introduction

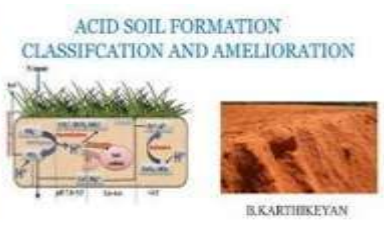
Soil is a multifaceted medium that offers necessary nutrients, water, and support to crops. Its quality has direct implications on farm productivity and food security. Soil acidity ranks as one of the key constraints in world agriculture as it adversely affects crop yield and places livelihood at risk for farmers. Acid soils are widespread in regions of high rainfall where leaching depletes basic cations such as calcium, magnesium, potassium, and sodium. These soils are widespread in tropical Africa, South America, Southeast Asia, and much of India. Acid soils are not only chemically degraded, but also have less microbial activity and organic matter decomposition, with impaired nutrient cycling. For nations such as India, where much of the agricultural land is acidic (approximately 49 million hectares), soil acidity must be addressed in order to enhance crop production, alleviate rural poverty, and promote food security. This essay delves into the causes, magnitude, and effects of acid soils in agriculture and subsequently, management techniques and sustainable methods that can be used to counteract their negative impacts.

Causes of Soil Acidity

Soil acidity arises as a result of both natural processes and anthropogenic actions. The key causes are:

Leaching of Basic Cations: The removal of these leaves behind cations like H^+ and Al^{3+} which are acidic in nature, leading to a low soil pH.

Parent Material: Soils developed from acidic parent rocks (like granite) naturally have acidic nature. Weathering of these rocks yields fewer base cations.



Characteristics of Acid Soils

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Low pH (< 5.5)

Nutrient Deficiencies: Calcium, magnesium, phosphorus, molybdenum and potassium deficiencies are frequent.

Poor Microbial Activity: Acid soils inhibit helpful microbes such as nitrogen-fixing bacteria, making the soil less fertile.

Decreased Cation Exchange Capacity (CEC): Resulting in poor nutrient holding and availability.

Africa: Central Africa and Southern Africa.

Asia: Northeast India, Southeast Asia, Chinese regions, and Indonesia.

Europe: Scandinavian nations and hilly regions.

In India, acid soils are primarily located in Assam, West Bengal, Odisha, Jharkhand, Chhattisgarh, Kerala, Karnataka, Meghalaya, and Tripura.

Effect of Acid Soils on Agriculture

Nutrient Imbalance

- ✓ Acid soils result in low levels of vital nutrients such as phosphorus, calcium, magnesium, and molybdenum.
- ✓ Toxic substances like aluminum and manganese become very soluble and suppress root growth.

Inhibited Root Growth and Function

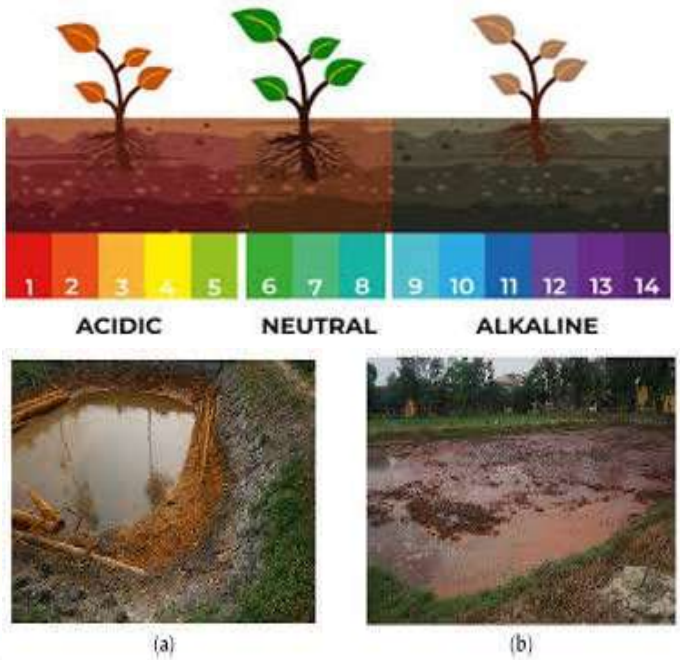
- ✓ Aluminum toxicity limits the root elongation, which in turn reduces the plant's ability to uptake water and nutrients.
- ✓ Shallow roots enhance susceptibility to drought.

Low Crop Yields

- ✓ Acid soils lower the yield of major crops like maize, wheat, rice, barley, pulses, and oilseeds.
- ✓ Nodulation in legumes is drastically lowered by poor conditions for Rhizobium bacteria.

Microbial Suppression

- ✓ Beneficial microbes like Rhizobium, Azotobacter, and phosphate-solubilizing bacteria are inhibited in acidic environments.



Management of Acid Soils

Selection of Acid-Tolerant Crops

- ✓ Tea, potato, sweet potato, pineapple, oats, and rye are more tolerant of acidity.
- ✓ Introduction of acid-tolerant rice, maize, and wheat varieties can guarantee productivity.

Enhanced Soil Management

- ✓ Implementation of conservation practices like mulching, cover cropping, and reduced tillage minimizes erosion and leaching.

Case Studies

India: Institutions like the Indian Council of Agricultural Research (ICAR) have encouraged lime application and acid-tolerant varieties to increase

production.

Brazil: Brazil's Cerrado region possesses enormous acidic soils. Through liming, phosphate fertilizer applications, and production of acid-tolerant soybean and maize varieties, Brazil converted the region into one of the world's major agricultural centers.

Conclusion

Soils with acid pH pose a critical problem to world agriculture, particularly in the tropics and subtropics. Their low pH, poisonous aluminum and manganese content and nutrient deficiency massively lower crop yields, compromise soil biology, and impact farmer livelihoods. Yet, with effective management practices like liming, organic amendments, balanced fertilizers, and cultivation of acid-tolerant plants, agricultural productivity in acidic soils can be improved. Case studies from Brazil and India illustrate that sustainable interventions and policy support can turn acid soil areas into productive agricultural spaces.

Pre-Monsoon Management of Coffee

Alfiya A. S. and Amrita M. R.

Abstract

Coffee (*Coffea* sp.) is an important beverage crop of export importance. Coffee originated in India because of the Sufi monk who took some coffee beans along with him as he returned to India from Yemen. Karnataka ranks first in production followed by Kerala and Tamil nadu. There are certain specific practices we need to focus on during the pre-monsoon season while cultivating coffee. This article covers the agronomic practices, irrigation methods and timings for a better yield. Irrigation during flowering flushing season is to be carefully carried out. Sprinkler systems and nutrient solutions are being employed to enhance drought resistance and check fruit drop. Fertilizer applications vary according to coffee type, age and soil conditions, is crucial during the emergence of new shoots post-harvest. Phosphorus plays a key role in flowering. Shade management has to be carried out strategically during May. It is vital that disease and pest control is achieved sustainably by incorporating both organic and chemical methods. Integrating these practices during the pre-monsoon period enhance plant vigor, mitigates monsoon-related disease outbreaks, and supports long-term productivity and farmer income.

Introduction

When we drink a good cup of coffee, an indescribable sensation seeks us out. It is said that the world became acquainted with coffee and its influence through a shepherd who, after his goats consumed coffee cherries, leapt about in ecstasy. In A.D. 1600, a Sufi monk named Baba Budan smuggled 7 coffee beans from Yemen and planted them on the hills of Chikmagalur, believed to be the first coffee in the country. Kerala, which stands second in coffee cultivation in India, grows 72 MT of coffee primarily in the regions of Wayanad and Nelliyampathi. The main varieties of coffee grown are Arabica and Robusta, with 80% of coffee in Kerala being Robusta. The primary intercropping activities in coffee plantations, such as fertilization and irrigation, should be carried out carefully during the pre-monsoon season. As pest and disease outbreaks during the rainy season can affect coffee yields, plant protection and coffee care during the pre-monsoon period are essential.

Fig. 1: A morning coffee brewed from roasted beans https://coffeefactz.com/wp-content/uploads/2024/07/typica-coffee-seeds-yemen-to-india.jpeg.avif

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Irrigation: Robusta coffee requires 2-4 cm of rain during the flowering months of February-March and 5-7.5 cm of rain during the sprouting period of April-May. In areas with limited rainfall, water availability must be ensured. In places where water is available, sprinkler irrigation can be employed. Applying the following nutrient solution at a rate of 1L per plant can enhance the drought resistance of Robusta coffee. The quantities of nutrients needed to prepare 200 L of the solution are: 1kg of urea, 750 g of muriate of potash, 1 kg of super phosphate, and 1 kg of zinc phosphate.

Application method: It can be applied once after the last rain (in the second half of January) and subsequently applied approximately every 30-45 days. Additionally, mixing a chemical like Ralli Dhan 110 at 200 ml in 200 L of water can help reduce sweating and assist in preventing drought.

Fruit drop: During the developmental stage of berry, 10 to 50 per cent premature fruit drop occurs due to insufficient carbohydrate, auxin-carbohydrate imbalance, nutritional disorders and waterlogging. Following growth regulators could increase the yield when they are given as foliar application 10-15 days after blossom (first spray) and during last week of May before the onset of southwest monsoon (second spray).

Fertilizer Application: After the coffee harvest, the coffee plants may weaken and become feeble. It is extremely essential to provide fertilizer at the time when new shoots appear after receiving pre-monsoon rains. The ratio of chemical fertilizer varies according to the type of coffee, its age, production, growth stages, and soil. Fertilizer application should be done in 3 stages. One stage needs to be during the pre-monsoon season. Phosphorus is a very important nutrient to be provided during the flowering period and post flowering period. After removing the soil cover, the soil at this place needs to be well loosened and the fertilizer mixture should be applied. Then, it should be well mixed and covered with soil cover. While applying fertilizer, care must be taken to never exceed the ratio of 100:75:100 kg NPK ha^{-1}.

Shade management: Proper shade management during pre-monsoon season is very critical for protecting coffee plants from harsh sunlight and preparing the plantation for the upcoming rains. During this period, we should maintain temporary and permanent shade to ensure adequate light, prevent heat stress, and support healthy plant growth.

Important practices for shade management

May is the best time for shade management. After receiving 4-5 inches of rainfall, the hanging branches at a height of 9-12 meters from the plant should be pruned. Doing this when the soil is dry will adversely affect the growth of new shoots. The pruned branches can be used to create a protective soil cover around the plant. Plant temporary shade trees like *Erythrina lithosperma* and permanent shade trees like silver oak. Coat the stems of young shade trees with lime or wrap them with polythene sheets. For newly planted shade trees, apply a small

dose of superphosphate fertilizer for better rooting. Ensure that the permanent shade trees are properly spaced to provide filtered light. After the first monsoon showers, go for lopping or pruning the shade trees for better canopy management and light penetration.

Precautions: Don't go for heavy pruning during dry season as it may expose the coffee plants to sun scorch. Maintain a Two-Tier System by combine lower temporary shade (dadap) with taller permanent shade (silver oak) to create an ideal microclimate for coffee growth and yield. Carry out shade regulation every year to avoid sudden stress from drastic canopy changes. Remove and destroy unwanted or diseased plants during summer to minimize pest and disease incidence.

Disease management

Coffee leaf rust: Small pale-yellow spots appear on the lower leaf surface. Orange-yellow spore masses develop and causes defoliation and die-back of plants.

Management Practices for Coffee Rust:

Cultural Practices: Increase planting space to reduce disease spread. Maintain optimal shade levels.

Biological Practices: Use *Verticillium hemeleia*, which covers rust uredospores and lesions with white mycelial mass, help in control the disease. Use freshly prepared Bordeaux mixture at 0.5% concentration, ensuring thorough coverage on the underside of foliage before the southwest monsoon begins.

Black rot

Symptoms: Blackening and rotting of affected leaves, young twigs and berries. Affected leaves get detached and hang down by means of slimy fungal strands.

Management: Prune and center bushes regularly. Remove infected leaves and berries promptly. Apply 1% Bordeaux mixture on leaves and developing berries before monsoon. Spray 0.03% Carbendazim 45 days after first Bordeaux spray, only after removing infected parts.

Pest management

White stem borer - *Xylotrechus quadripes*: Yellowing and wilting of leaves. Sawdust-like (frass) residues on the ground. Visible exit holes of adults in the stem.

Management: Destroy affected plant parts during March-April and September-October**.** Maintain optimal shade to reduce coffee exposure to sunlight, as adults prefer sunlit plants for egg laying**.** Perform scrubbing in October and April using coir gloves or coconut husk to remove loose scaly bark and eliminate egg-laying sites. Apply *Beauveria bassiana* to young larvae under bark for effective control. Spray or swab lindane 20 EC at 1300 ml per 200 liters of water with 200 ml wetting agent once in April and once in October. Apply chlorpyriphos 20 EC at 600 ml per 200 liters of water with 200 ml wetting agent.

Coffee Shot Hole Borer (*Xylosandrus compactus*): Young plants: main stem may be attacked, showing shot holes. Initial symptom: drooping and drying of

leaves. Withering occurs faster in young branches, slower in older twigs. Premature leaf fall on attacked leaves.

Management: Maintain optimum or thin shade and ensure good drainage. Remove and destroy unwanted or infested suckers during summer to prevent pest breeding. Spray crop with quinalphos (2 ml litre^{-1}) twice at monthly intervals in November-December.

Conclusion

Timely care of coffee during pre-monsoon season is crucial for realising a healthy and productive crop and hence increase the income of the farmers. Negligence of the information regarding fertilizer application, pest and disease management, irrigation, shade etc. will considerably reduce yield. Together, these practices would create a robust and sustainable ecosystem.

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Instructional Design Models and Their Relevance in Agricultural Extension

Vishnu Priya B. and Kavichelvan V.

Introduction

Instructional design (ID) refers to the organized and methodical development of educational and training experiences that are efficient, effective, and learner-centered. Rooted in behavioural and cognitive psychology, instructional design integrates theory and practice to create structured learning environments. The goal of ID is to ensure that learning objectives are clearly defined, instructional materials are appropriately selected, and evaluation mechanisms are properly implemented to track learning outcomes. In contemporary education and training, instructional design plays a central role in tailoring content to the specific needs and capabilities of the learner. In the field of agricultural extension, instructional design has immense potential. Extension education serves as the bridge between scientific research and field-level application, focusing on the dissemination of new agricultural practices, technologies, and policies. The evolution of extension systems toward digital platforms, mobile learning, and farmer-led innovations has further increased the relevance of instructional design. Models like ADDIE, SAM, and Dick and Carey allow for integration of media, iterative feedback, and continuous improvement critical components in today's dynamic agricultural landscape. These models also help ensure that training programs are responsive to policy changes, climate variability, and market demands, making them more sustainable and impactful.

ADDIE Model in Agricultural Extension

The ADDIE model comprising Analysis, Design, Development, Implementation, and Evaluation is one of the most widely applied instructional design frameworks, offering a systematic process well-suited to agricultural extension. In the analysis phase, extension educators assess learners' needs, existing practices, and socio-cultural contexts to identify knowledge gaps—for example, evaluating farmers' readiness for drip irrigation training. The design phase translates this analysis into clear objectives, instructional strategies, and media choices, whether through farmer field schools, demonstration plots, radio, or mobile apps. The development phase produces the actual materials, such as illustrated manuals, videos, or flipcharts, often tailored to local languages and contexts to enhance accessibility.

The implementation phase delivers training

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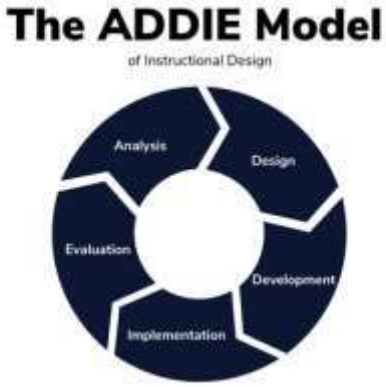
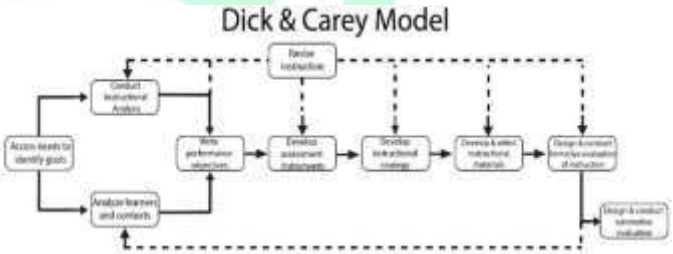
through methods like Training-of-Trainers (ToT), village resource persons, or direct farmer engagement, supported by proper logistical planning. Finally, evaluation ensures accountability and improvement, using formative tools during each stage and summative tools such as pre- and post-tests, feedback or field observations after completion to measure outcomes like knowledge gain or improved yields. In agricultural extension, ADDIE is valued for its clarity, flexibility, and continual improvement orientation, ensuring that training remains practical, context-specific, and actionable. By grounding programs in this structured model, extension educators can improve learning effectiveness, promote adoption of innovations, and strengthen the long-term resilience of farming communities.



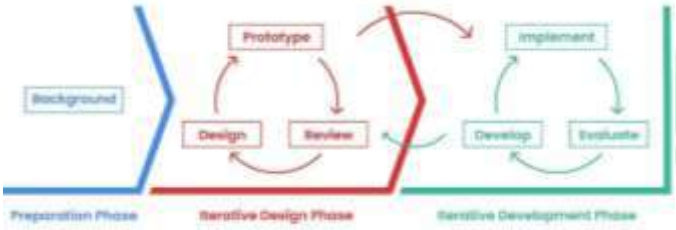
Dick and Carey Model: Systems Approach in Agricultural Extension: The Dick and Carey Model is a comprehensive, systems-oriented instructional design model that treats instruction as a systematic process composed of interrelated components. It emphasizes the alignment between learning objectives, instructional strategies, content delivery, and assessment. This model is particularly well-suited for agricultural extension, where training must be outcome-oriented and adaptable to local needs.

Developed by Walter Dick and Lou Carey, this model identifies nine interrelated steps: (1) Identify Instructional Goals, (2) Conduct Instructional Analysis, (3) Analyze Learners and Contexts, (4) Write Performance Objectives, (5) Develop Assessment Instruments, (6) Develop Instructional Strategy, (7) Develop and Select Instructional Materials, (8) Design and Conduct Formative Evaluation, and (9) Design and Conduct Summative Evaluation. Each component informs and supports the others, creating a cohesive instructional system.



SAM Model (Successive Approximation Model): The Successive Approximation Model (SAM) is an agile, iterative instructional design framework that emphasizes rapid prototyping, collaboration, and continuous feedback. Unlike traditional linear models such as ADDIE or Dick and Carey, SAM is flexible and highly responsive, making it particularly effective in agricultural extension where changing technologies, seasonal cycles, and sudden challenges demand timely solutions. Its iterative design cycles design, prototype, review, and revise allow extension professionals to quickly pilot tools like training videos or mobile tutorials, refine them based on farmer feedback, and scale up only once the content

proves relevant and effective. A central strength of SAM lies in its stakeholder engagement and adaptability. Farmers, NGOs, experts, and extension workers can collaboratively shape learning materials, ensuring cultural appropriateness and practical orientation. Continuous feedback loops further improve clarity and usability by identifying learning gaps early through farmer group reviews. This adaptability is especially valuable in responding to evolving contexts such as pest outbreaks or climate shocks. With the rise of digital platforms apps, podcasts, WhatsApp groups, and e-learning modules SAM's rapid prototyping ensures usability and contextual fit, making technology-enabled extension more farmer-friendly, scalable, and impactful.



ASSURE Model and Its Application in Agricultural Extension: The ASSURE model is an instructional design framework that emphasizes the integration of media and technology into teaching and training. The acronym ASSURE stands for analyze learners, State objectives, select media and materials, utilize media and materials, require learner participation, and evaluate and revise. This model is particularly useful in agricultural extension for planning interactive and technology-enhanced learning experiences tailored to the needs of diverse rural audiences.

In agricultural extension, the ASSURE model provides a systematic approach to designing effective training. It begins with analyzing learners' characteristics such as literacy, cultural background, access to technology, and learning preferences. For instance, farmers with limited literacy benefit more from videos, demonstrations, and flipcharts than from printed manuals. Based on this analysis, extension workers set clear, measurable objectives for example, enabling farmers to identify major pests or demonstrate vermicomposting steps which guide both media selection and evaluation methods. Appropriate instructional media, such as mobile apps, radio programs, or visual aids, are then chosen to suit the learners' context, ensuring cultural relevance, technical functionality, and ease of use. Equally important is encouraging active participation through group discussions, field demonstrations, role-plays and quizzes, which strengthen understanding and build confidence in applying new practices. Finally, evaluation and revision close the cycle by assessing learner outcomes through tests, feedback or observation, allowing extension professionals to refine training materials and methods for continuous improvement. Thus, the ASSURE model

ensures agricultural extension programs remain learner-centered, interactive, and adaptable to local needs, ultimately promoting greater technology adoption and sustainable farming practices.

Conclusion

Instructional design models provide a transformative framework for strengthening agricul-tural extension by making training learner-focused, structured, and outcome-driven. They ensure that content is not only relevant and accessible but also actionable for rural communities. The ADDIE model introduces systematic planning and evaluation, thereby improving the quality and accountability of interventions. Dick and Carey's systems approach emphasizes logical sequencing and mastery-based learning, which suits vocational and skill-based programs. The SAM model, with its iterative prototyping, is well-suited for developing digital and ICT-enabled extension tools, while the ASSURE model prioritizes aligning media and methods with learner characteristics, making it highly effective in low-literacy or mass communic-ation contexts. By integrating these models, extension professionals can better address diverse learning needs, embrace technological advances, and foster active community participation. However, realizing their full potential requires systemic support through capacity building, institutional collaboration, infrastructure investment, and policy alignment. Instructional design is not a rigid formula but a flexible toolkit that, when adapted to local contexts, enhances inclusivity, sustainability, and behavioral change in rural development. Championing its adoption across all levels from grassroots practitioners to policy-makers can transform extension into a process of knowledge co-creation and resilience building in agriculture.

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Sustainable Urban Agriculture: A Path to Food Security and Environmental Resilience

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Abstract

This report examines the increasing significance of sustainable urban agriculture as a critical strategy for enhancing food security and fostering environmental resilience in urbanized areas. It provides a comprehensive overview of key practices, including vertical farming, rooftop gardens, and community-supported agriculture (CSA), and details their benefits in reducing food miles, conserving resources, and creating vital green spaces. The analysis further explores the social and economic dimensions, highlighting how these initiatives build stronger communities and stimulate local economies. The report also addresses the principal challenges, such as land use policy and initial investment costs, and concludes with a forward-looking perspective on how the integration of urban agriculture into city planning can contribute to a more sustainable and equitable future.

Introduction

As global urbanization accelerates, the strain on conventional food supply chains becomes increasingly evident. The concentration of populations in cities intensifies issues related to food security, logistics, and environmental degradation. Urban agriculture (UA) emerges as a viable, forward-thinking strategy to address these challenges by localizing food production. This report provides a detailed examination of sustainable urban agriculture, exploring its various forms, multifaceted benefits, and the obstacles that must be overcome to fully realize its potential. We will discuss its role in creating a more resilient and equitable urban environment, and will conclude with a forward-looking perspective on its integration into future cityscapes.

The Multifaceted Practices of Urban Agriculture

Sustainable urban agriculture is not a monolithic concept but a diverse collection of practices tailored to the unique constraints and opportunities of urban environments. These methods range from simple, low-tech solutions to complex, high-tech systems.

Vertical Farming: This is a cornerstone of modern urban agriculture. By stacking layers of crops in a climate-controlled indoor environment, vertical farms maximize output in a minimal footprint. Using technologies like hydroponics (growing plants in nutrient-rich water) and aeroponics (misting plant roots with nutrients), these farms use up to 95% less water than traditional farming. The controlled environment eliminates the need for pesticides and allows for year-round, consistent production, which

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is crucial for urban food stability.

Rooftop and Container Gardens: Utilizing the vast, often-unused space on building rooftops for cultivation offers multiple benefits. Beyond providing fresh food, rooftop gardens help insulate buildings, reducing energy consumption for heating and cooling. They also absorb stormwater, mitigating urban flooding, and create green spaces that combat the "urban heat island" effect. Similarly, container gardening makes it possible to grow food on balconies, patios, and in small yards, democratizing food production for city dwellers with limited space.

Community and Allotment Gardens: These shared spaces provide a communal approach to food production. They not only yield fresh produce but also serve as vital social hubs, fostering a sense of community, providing educational opportunities, and improving mental and physical health. Community gardens can transform derelict or vacant lots into productive, beautiful green spaces, increasing neighborhood aesthetics and property values.

Aquaponics and Urban Livestock: Aquaponics is a symbiotic system that combines aquaculture (raising aquatic animals like fish) with hydroponics. The waste from the fish provides nutrients for the plants, which in turn filter the water for the fish. This closed-loop system is highly efficient and sustainable. Furthermore, the limited and careful raising of small livestock, such as chickens for eggs or bees for honey, can contribute to a diversified and resilient urban food system.

Environmental, Social, and Economic Impacts

The benefits of sustainable urban agriculture extend far beyond the immediate production of food, creating a ripple effect that touches multiple aspects of urban life.

Environmental Resilience: By producing food locally, urban agriculture dramatically reduces "food miles" the distance food travels from farm to plate. This, in turn, lowers carbon emissions associated with transportation. The practices often incorporate waste recycling, such as composting food scraps to create nutrient-rich soil, which reduces landfill waste. The creation of green spaces improves urban biodiversity, provides habitats for pollinators, and helps to purify the air by absorbing pollutants.

Social Cohesion and Health: Urban farming projects are powerful catalysts for community building. They bring together people from diverse backgrounds, fostering social networks and collective action. They also serve as outdoor classrooms, teaching children and adults about food systems, nutrition, and sustainability. Access to fresh, healthy, and affordable produce, particularly in urban "food deserts," can significantly improve public health outcomes. Gardening has been shown to reduce stress, provide physical exercise, and reconnect people with nature.

Economic Development: Urban agriculture can stimulate local economies by creating jobs from farmers and horticulturists to educators and market managers. It can also provide a stable source of

income for low-income residents. By shortening the supply chain, it empowers local producers to sell directly to consumers, restaurants, and markets, capturing more of the profit and strengthening the local food economy. Furthermore, the aesthetic and communal benefits of these projects can lead to increased property values in surrounding areas.

Challenges and the Path Forward

Despite its immense potential, urban agriculture faces significant challenges that require strategic and collaborative solutions.

Land Use and Zoning: The high cost and scarcity of urban land are major barriers. Many cities have zoning laws that were not designed to accommodate agricultural use, making it difficult to establish and expand urban farms. There is a critical need for urban planning policies that re-zone unused or underutilized land such as rooftops, brownfields, and vacant lots for agricultural purposes.

Policy and Government Support: Without consistent policy support, many urban agriculture initiatives struggle. Government programs can offer financial incentives, grants, and tax breaks to encourage urban farming. They can also create educational and training programs to equip residents with the necessary skills. The integration of urban agriculture into broader city planning and food policy is essential for its long-term success.

Technological and Financial Hurdles: While highly efficient, high-tech methods like vertical farming can have substantial initial setup costs. Ensuring these technologies are accessible to a wide range of communities, not just well-funded enterprises, is a key challenge. Public-private partnerships and innovative funding models are needed to scale up these operations and make them more widespread.

Conclusions and Future Outlook

Sustainable urban agriculture is more than a passing trend; it is a critical component of a resilient and just urban future. By transforming how and where we produce food, it offers solutions to some of the most pressing challenges of our time, from climate change and resource scarcity to food insecurity and social inequality. The future of urban agriculture lies in its seamless integration into the fabric of the city. This will require a concerted effort from policymakers, urban planners, technologists, and community members to overcome existing hurdles and harness the full potential of this powerful movement. As we move forward, the growth of urban agriculture promises not just healthier food, but healthier communities and a healthier planet.

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E-Marketing Platforms for Direct Farmer-to-Consumer Trade: Opportunities and Challenges in Modern Agriculture

Vamshi Reddy Ettadi

Abstract

E-marketing platforms are transforming agricultural trade by directly connecting farmers with consumers, reducing dependency on middlemen, enhancing transparency, and improving farmer profitability. This paper explores the opportunities and challenges associated with farmer-to-consumer e-marketing platforms. Using secondary sources such as government reports, case studies, and published research, the study examines the benefits, limitations, and future potential of digital agriculture in India and globally. Results indicate that while these platforms offer higher price realization, wider market access, and reduced wastage, challenges remain in digital literacy, infrastructure, and trust-building. The paper concludes with recommendations for policy support, technology adoption, and farmer training to strengthen e-marketing adoption in agriculture.

Introduction

Agriculture has traditionally relied on middlemen and local mandis for marketing produce, which often reduces the share of profit earned by farmers. With the advent of digital technology, e-marketing platforms are bridging the gap between farmers and consumers, enabling direct trade. These platforms not only enhance farmer incomes but also provide consumers with fresh produce at competitive prices. However, issues such as lack of internet access in rural areas, low digital literacy, and logistical constraints continue to hinder their widespread adoption.

Literature Review: Several studies have highlighted the potential of ICT and e-marketing in agricultural supply chains. In India, platforms such as e-NAM, Kisan e-Mart, and Ninjacart have demonstrated how digital trade can improve efficiency. Globally, models like Amazon Fresh and Alibaba's agri-trade initiatives serve as examples of integrating farmers into digital supply chains. Past research emphasizes benefits like price transparency and better market linkages, while also noting barriers such as trust deficits, logistics, and financial literacy.

Figure 1: Farmers using mobile apps for selling produce (illustrative)

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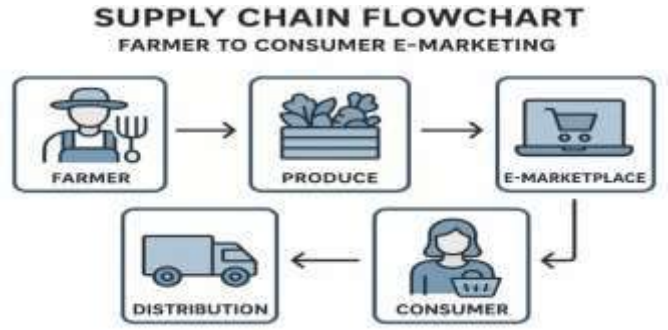

Figure 2: Supply chain flowchart for farmer-to-consumer e-marketing

Methodology: The paper adopts a qualitative approach, relying on secondary data collected from government publications, FAO reports, peer-reviewed journals, and case studies. SWOT analysis is applied to understand the strengths, weaknesses, opportunities, and threats associated with farmer-to-consumer e-marketing platforms.

Results and Discussion: E-marketing platforms present significant opportunities for transforming Indian agriculture. Benefits include direct farmer-to-consumer sales, improved income realization, reduced wastage, and wider consumer reach. However, challenges remain, particularly in logistics, rural internet penetration, and building consumer trust in digital transactions. Case examples like Ninjacart show how strong logistics networks can address these barriers.

Fig. 3: Example of an e-NAM interface for farmers

Conclusion and Recommendations

E-marketing platforms are a promising solution for empowering farmers and enhancing supply chain efficiency. To ensure sustainable adoption, policymakers must focus on improving rural internet infrastructure, digital literacy programs, and farmer-friendly financial services. Public-private partnerships, coupled with innovations like blockchain and smart contracts, can further strengthen transparency and trust in farmer-to-consumer trade.

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Cultivating Success: Inderjeet Singh's Courageous Path as a Progressive Farmer

Mitali Dwibedi and Gurshaminder Singh

Introduction

India is an agriculture country. Here 70-80 percent of the population depends on agricultural directly and indirectly. A farmer's life is incredibly challenging. They are known for their unwavering dedication and hard work, spending extended hours in their fields. Weather conditions don't deter them; whether it's scorching summer, freezing winter, or even during rainfall, they persistently continue their labor. Inderjeet Singh, a seasoned farmer from Punjab' Fatehgarh Sahib district, has dedicated three decades of his life to the art of farming. Prior to this, he served as a teacher in the local village school, where he imparted knowledge and values to the younger generation.

Farmer Profile

Name: Mr. Inderjeet Singh (43 years)

Father's Name: Sh. Jaspal Singh

Religion: Sikh

Family Members: 7 (Joint family)

Farming Experience: Since childhood (inherited traditional knowledge)

Landholding: 17 acres (owned)

Village: Nogawan (Punjab)

Major Crops: Rice, Wheat, Maize, Fodder and Solanaceae crops

Agriculture related Apps used: Kisan kheti, Agri Smart.

The Agricultural Revolution: A Growing Legacy of Change: Now at the age of 43, Inderjeet has become a pioneer in organic farming, advocating its benefits to his fellow villagers. His two brother's have joined him in this agricultural journey, blending traditional wisdom with modern techniques. Together, they've harnessed technology to enhance their organic farming practices. Inderjeet's commitment to sustainable agriculture extends beyond his own fields. He's an active member of the co-operative society (Nogawan), where he shares his expertise and learns from other progressive farmers. Through co-operative society, he collaborates with agricultural experts to introduce innovative methods to his village of land at his disposal, Inderjeet cultivates a diverse range of crops, including various vegetables, rice, wheat, sugarcane, and fodder crops like maize. His ability to diversify and adapt to changing market demands has made him a role model for farmers seeking economic stability.

Inderjeet Singh is an innovative farmer who excels in raising vegetable nurseries, making polybags and producing nutrient-rich vermicompost. He uses advanced irrigation techniques like drip irrigation, sprinklers, and rain guns. As a dedicated member of the PAU Kisan Club.

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He provides valuable support to fellow farmers by nurturing vegetable nurseries and offering labor assistance. His commitment to innovation, sustainability, and community support distinguishes him as a leading figure in modern agriculture.

Advancement and Success: Inderjeet is a progressive farmer who has successfully combined crop cultivation with dairy farming to create a sustainable livelihood. On his fields, he practices scientific farming methods for seasonal crops, ensuring good yields while maintaining soil health. His journey into dairy farming began modestly with just two buffaloes for household needs. Realizing the potential of dairy as steady income, he gradually expanded his herd to 15 cows and 16 buffaloes. With training, better nutrition, and veterinary care, he transformed his dairy into a well-managed enterprise. Seeking a reliable market, Inderjeet approached Verka, the renowned dairy cooperative. After testing the quality of his milk, Verka accepted him as a supplier. Today, his daily supply of fresh, pure milk ensures him fair pricing, transparency, and assured income. What makes Inderjeet stand out is his commitment to humane and ethical cattle care clean housing, balanced feed, and regular health checkups. This not only improves productivity but also builds consumer trust. By diversifying into dairy alongside crops, Inderjeet has created a balanced model of farming. His story shows how innovation, dedication, and the right market linkages can turn small beginnings into long-term success. He is now a role model for other farmers in his community.

Motivation for Everyone: Inderjeet's enthusiasm for farming is infectious. He actively motivates everyone in his village to engage in agriculture, emphasizing the importance of sustainable practices and the coexistence of traditional wisdom with modern technology. He embodies the spirit of a progressive farmer who doesn't just reap the rewards of the land but also sows the seeds of knowledge and progress in the hearts of his community.

A Guiding Light of Optimism: Inderjeet Singh's story continued to resonate, not only in his village but also in the broader agricultural community. His dedication, innovation, and the mantra that "no job is small and big knowledge is everything" remained a powerful driving force behind his success and the inspiration he offered to those who aspired to be progressive farmers like him.

Conclusion

Inderjeet Singh's life is a narrative that transcends the boundaries of traditional farming. It's an enchanting love story between a man and the very soil he tends, a profound journey of a teacher guiding his eager students, a nurturing role of a father to his sons, and a mentor's deep connection with his community. This tale is woven with the threads of emotion, marked by indomitable resilience, and celebrates the timeless beauty of toiling the earth.

Protected Cultivation of Cucumber

Vishal Pal, Neha Kumari Sinha and Mithilesh Kumar Verma

Introduction

Protected cultivation of cucumber involves growing the crop under controlled structures like polyhouses, net houses or low tunnels to ensure optimum temperature, humidity and light conditions. This method safeguards plants from extreme weather, pests and diseases, enabling year-round production and higher yields. It improves fruit quality, reduces chemical pesticide use and ensures efficient water and nutrient management. Protected cultivation also allows off-season cultivation, fetching better market prices and providing consistent supply. It is an advanced, sustainable technique for profitable cucumber farming.

Importance: Protected cultivation of cucumber, using structures like polyhouses or tunnels, allows year-round production, reduces pest and disease incidence, and improves fruit quality and yield. It ensures efficient use of water, nutrients, and space, provides protection from adverse weather, and enables cultivation in non-traditional areas, contributing to higher economic returns for farmers.

Recommended Varieties/Hybrids

European/Greenhouse Types

- ✓ Hilton, Dinamik, Sardius, Malini, Conquistador, Monarch
- ✓ Characteristics: Dark green, thin-skinned, smooth, seedless fruits.

Indian/Commercial Hybrids for Polyhouse

- ✓ Kian, Telstar, Crisper, Indira, Shiela, Hiccu, Neeraja
- ✓ Characteristics: Good shelf life, high yield, suitable for high temperatures.

Mini or Beit Alpha Types

- ✓ Pusa Barkha, Pusa Naveen, Pant Parthenocarpic Cucumber-*2*
- ✓ Characteristics: Small size, tender texture, preferred for salads.

Structure Types

Polyhouse

Description: A framed structure covered with UV-stabilized polyethylene film.

Advantages: Maintains controlled temperature, humidity, and protection from rain and pests.

Benefits for Cucumber: Ensures year-round production, higher yield, uniform fruit quality, and better disease management.

Net House

Description: Covered with insect-proof or shade nets supported by GI/wooden frames.

Advantages: Reduces insect-pest infestation, provides partial shade, allows natural ventilation.

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Benefits for Cucumber: Minimizes viral diseases, lowers pesticide use, and produces clean, market-quality fruits.

Low Tunnel

Description: Small, low-height hoop structures covered with transparent polythene sheets.

Advantages: Protects young cucumber plants from frost, low temperature, and heavy dew.

Benefits for Cucumber: Encourages early crop establishment, extends growing season, and improves germination during winter.

Soil and Climate Requirements: Protected cultivation of cucumber requires well-drained, fertile sandy-loam soil rich in organic matter with pH 6.0-7.0. Solarized or sterilized beds prevent soil-borne diseases. A warm, humid climate is ideal, with day temperature 25-30 °C and night 18-20 °C. Relative humidity of 60-70 % and ample sunlight ensure vigorous growth. Controlled greenhouse or polyhouse conditions with proper ventilation, drip irrigation, and mulching maintain optimum moisture and temperature for year-round production.

Propagation and Nursery Management: Propagation of cucumber involves healthy seed selection, seed treatment, and sowing in sterilized coco-peat or nursery trays. Maintain 25-28 °C temperature and adequate moisture. After 3-4 weeks, transplant sturdy seedlings into protected structures like polyhouse or low tunnels with drip irrigation, ensuring disease-free environment and balanced nutrient management

Planting and Spacing: In protected cultivation, cucumber seedlings are transplanted in well-prepared beds or grow bags with drip irrigation. Maintain spacing of about 1.5-2.0 m between rows and 45-60 cm between plants to ensure proper light, ventilation, and growth. Train vines on trellis or net for better yield, easy harvesting, and to reduce pest and disease incidence.

Nutrient and Irrigation Management: Cucumber under protected cultivation requires balanced nutrient supply through fertigation for optimum growth. Drip irrigation ensures uniform moisture, reduces water loss, and prevents diseases. Regular monitoring of soil and plant nutrient status, along with timely irrigation, improves yield, fruit quality, and resource use efficiency.

Training and Pruning: In protected cucumber cultivation, vines are trained vertically on trellises or strings to optimize space, sunlight, and air circulation. Lateral branches are pruned regularly to focus plant energy on main stems and fruit development. Apical pruning is done to control vine length. Proper training and pruning improve fruit quality, reduce disease incidence, and enhance overall yield.

Pollination Techniques: In protected cultivation of cucumber, effective pollination is crucial for fruit set and quality. Common techniques include hand pollination, where pollen is manually transferred from male to female flowers, and bee-assisted pollination using bumblebees or honeybees inside net houses or tunnels. Controlled pollination ensures uniform fruit development, reduces misshapen fruits,

and improves yield. Timing, flower selection, and gentle handling are essential to maximize pollination efficiency under protected conditions.

Pest and Disease Management: In protected cucumber cultivation, regular monitoring is essential to manage pests like aphids, whiteflies, and spider mites. Use yellow sticky traps and biological controls such as *Trichogramma* and *Beauveria bassiana*. Maintain proper ventilation and avoid waterlogging to prevent diseases like powdery mildew and downy mildew. Apply recommended fungicides and insecticides judiciously, following integrated pest management (IPM) practices for healthy crop growth.

Harvesting and Yield: Cucumbers grown under protected conditions like polyhouses or tunnels can be harvested 45-50 days after sowing. Harvesting is done when fruits reach marketable size, usually every 2-3 days to maintain quality. Protected cultivation enhances yield by 20-30% compared to open field, ensuring uniform, healthy fruits and reducing losses from pests and adverse weather.

Economic Benefits and Profitability: Protected cultivation of cucumber offers significant economic benefits and profitability. By controlling environmental conditions, it ensures higher yields, better fruit quality, and off-season production, leading to premium market prices. Reduced pest and disease incidence lowers input costs, while efficient use of resources like water and fertilizers increases returns per unit area. Overall, this method provides farmers with stable income, faster return on investment, and enhanced market competitiveness.

Challenges and Precautions: Protected cultivation of cucumber faces challenges like high initial investment, temperature and humidity management, pest and disease outbreaks, and nutrient imbalances. To overcome these, proper ventilation, shading, and irrigation systems are essential. Regular monitoring of pests, diseases, and plant health is crucial. Use resistant varieties and maintain proper plant spacing to reduce disease spread. Sanitation of tools and structures prevents contamination. Balanced fertilization and timely pruning ensure healthy growth and higher yields, making cultivation efficient and profitable.

Protected Cultivation of Tomato

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Introduction

Protected cultivation of tomato involves growing the crop under controlled structures like polyhouses, shade nets or greenhouses to protect it from adverse weather, pests and diseases. This method ensures a favourable microclimate, enabling year-round production with higher yields and better fruit quality. It reduces chemical pesticide use and conserves water through drip irrigation. Protected cultivation also allows precise management of temperature, humidity, and nutrients, resulting in uniform growth, extended harvesting period, and improved market value of tomatoes compared to open-field cultivation.

Types of Protected Structures

Playhouse: Protected cultivation of tomato in playhouse involves growing plants under a protected cultivation of tomato under tunnel or low tunnel involves covering plants with polythene sheets, maintaining warmth and humidity, protecting from frost, pests, and rain, ensuring off-season production with higher yield and quality. or net house with controlled temperature, humidity, and light. This system protects crops from pests, diseases, and adverse weather, ensuring higher yield, better quality, and year-round production.

Net house / Shade net house: Protected cultivation of tomato in net or shade net houses provides a controlled micro-climate, reducing pests, diseases, and weather stress. It ensures optimum temperature, humidity, and light, resulting in higher yield, better fruit quality, off-season production, and efficient resource use.

Glasshouse: Protected cultivation of tomato in a glasshouse ensures year-round production by controlling temperature, humidity, and light. It protects plants from pests, diseases, and adverse weather, improving yield, fruit quality, and resource efficiency while reducing chemical pesticide use.

Tunnel / low tunnel: Protected cultivation of tomato under tunnel or low tunnel involves covering plants with polythene sheets, maintaining warmth and humidity, protecting from frost, pests, and rain, ensuring off-season production with higher yield and quality.

Climatic & Soil Requirements: Tomato grows best in warm, frost-free conditions. An optimal temperature range of 20-25 °C during the day and 15-20 °C at night supports flowering, fruit set and quality yield. Excess heat above 35 °C or prolonged cold below 10 °C reduces fruit development. Bright sunshine of at least 6-8 hours daily is essential.

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Tomatoes prefer well-drained, fertile soils rich in organic matter with pH 6.0-7.0. Sandy loam to clay loam with good moisture-holding capacity is ideal. Proper soil aeration and moderate salinity tolerance help maintain root health. Crop rotation and organic amendments improve soil structure, enhance nutrient availability and reduce disease incidence for sustained productivity.

Recommended Hybrids/Varieties (commonly used in India)

Arka Rakshak: Triple disease resistant, firm fruits, good shelf life.

Arka Samrat: Indeterminate, high yield, suitable for polyhouse.

NS 4266, NS 516, NS 6336: Private-sector hybrids with uniform round fruits.

Swarna Vaibhav, Heem Sohna, Naveen: Good for high humidity and off-season production

Nursery Raising and Seedling Management

Nursery raising in tomato ensures healthy seedlings for better yield. Select disease-free seeds and treat with fungicide before sowing. Prepare well-drained, fertile beds enriched with FYM and sand. Sow seeds in rows, cover lightly with fine soil, and irrigate with a fine rose can. Provide partial shade, regular watering, and timely weeding. Apply bio-fungicide to prevent damping-off. Seedlings become ready for transplanting in 25-30 days with 4-5 true leaves.

Soil Preparation and Growing Media: Proper soil preparation ensures healthy tomato growth. Choose well-drained loam or sandy-loam soil rich in organic matter, with pH 6.0-7.0. Plough 2-3 times to achieve fine tilth and remove weeds. Incorporate 20-25 t ha^{-1} well-decomposed farmyard manure or compost during final ploughing. For nursery or protected cultivation, use a sterilized growing media of soil, sand, and well-rotten compost or cocopeat in 1:1:1 ratio. Maintain good aeration, adequate moisture, and add balanced basal fertilizers to support vigorous seedling establishment and high yields.

Planting Techniques and Spacing: Tomato planting requires well-prepared, well-drained soil enriched with compost. Healthy seedlings 20-25 days old are transplanted in moist soil during evening to reduce stress. Maintain rows 75-90 cm apart with 45-60 cm spacing between plants for proper aeration, sunlight, and easy intercultural operations. For staked or indeterminate varieties, spacing can be widened to 90 × 60 cm, while compact determinate types suit 60 × 45 cm. Plant seedlings slightly deeper than nursery level, irrigate immediately, and mulch to conserve moisture and suppress weeds for better growth.

Irrigation and Fertigation Practices: Tomato requires regular irrigation to maintain uniform soil moisture, especially during flowering and fruit set. Drip irrigation is ideal, reducing water loss and disease risk. Fertigation supplies nutrients through the drip system, applying nitrogen, phosphorus, and potassium in split doses. Early growth needs higher nitrogen, while fruiting demands balanced NPK and micronutrients for optimal yield and quality.

Training, Pruning and Trellising: Training, prun-

ing, and trellising guide plant growth for better yield and quality. Training directs vines or shoots along supports to optimize sunlight and air flow. Pruning removes excess, diseased, or non-productive branches to balance vegetative and reproductive growth. Trellising provides a vertical structure, reducing disease, improving fruit exposure, and easing harvest, ensuring healthier, more productive plants.

Integrated Pest and Disease Management: Integrated pest and disease management in protected tomato involves using resistant varieties, healthy seedlings, and proper ventilation to reduce humidity. Regular monitoring, sticky traps, and biological controls like Trichoderma and predatory mites help suppress pests. Timely removal of infected plants, balanced fertilization, and need-based application of safe pesticides maintain plant health and minimize chemical residues.

Harvesting and Post-Harvest Handling: Tomatoes are harvested at the mature green or breaker stage for better shelf life and transport. Careful hand-picking avoids bruising and damage. After harvesting, fruits are sorted based on size, color, and quality. Damaged or diseased fruits are discarded. Tomatoes are then washed, graded, and packed in ventilated crates or boxes. Proper storage at 12-15°C with 85-90% relative humidity reduces spoilage. Timely marketing and gentle handling maintain fruit quality, firmness, and nutritional value.

Challenges & Limitations: Protected cultivation of tomato offers higher yield and quality but faces several challenges and limitations. High initial investment for structures like polyhouses or tunnels is a major constraint for small farmers. Operational costs, including irrigation, fertigation, and labor, are also high. Technical knowledge is required to manage temperature, humidity, and pest control effectively. Disease outbreaks like fungal infections can spread rapidly in enclosed environments. Limited availability of quality planting material and dependence on electricity for fans and pumps further restrict adoption. Additionally, market fluctuations and lack of adequate extension services can reduce profitability, discouraging widespread use of protected cultivation.

Self-Pollination Mechanisms in Plants

Desika, S. Subhashini and K. Cholan

Abstract

Let's be real pollination is basically plants' way of keeping the family line going. Sure, everyone raves about bees doing the heavy lifting, but self-pollination? It's the quiet kid in class who still aces the test. Plants can fertilize themselves literally pollen from anther to stigma on the same flower, or maybe a neighbor flower on the same plant. This piece digs into self-pollination, from how it works, to which plants do it (spoiler: more than you'd think), why it matters for crops, and where it falls short. Once you see how plants handle their own business, you'll never look at your bowl of rice the same way.

Introduction

You ever notice how plants just… keep showing up year after year, even if there aren't bees buzzing everywhere? That's because flowering plants (angiosperms, if you wanna get fancy) don't just rely on wind or bugs. They've got backup plans. Self-pollination is like the insurance policy for plants: when the world lets them down, they make sure reproduction still happens. There are two main ways this goes down: autogamy (same flower, one-stop shop) and geitonogamy (neighboring flowers on the same plant, still pretty close-knit). Sure, it cuts down on genetic remixing, but hey, at least it's reliable. Especially when the weather sucks or pollinators are on strike.

How do Plants Pull off Self-Pollination?

Cleistogamy: So, some flowers just never open. Like, ever. Everything happens inside a closed bud. No visitors allowed. The seeds get made no matter what. Examples: violets, oxalis, a bunch of grasses. Why it rocks: 100% self-pollination, zero risk.

Homogamy: Here, the flower's stigma and anthers mature at the same time perfect timing, like synchronized swimmers. Pollen transfer is basically inevitable. Examples: wheat, rice, peas your pantry essentials. Bonus: More chances for fertilization, less waiting around.

Bud Pollination: Some plants don't even wait for the flower to open. They get pollinated while still in the bud. Examples: rice (again), peanuts. Upside: Zero chance of outsiders sneaking in.

Anther and Stigma Positioning: Sometimes, the flower's design makes it almost impossible for pollen NOT to land on the stigma. They're just…

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right there. Examples: tomato, brinjal (eggplant for the non-Indians).

Mechanical Assistance: Every now and then, a flower's structure or how it moves helps the pollen get where it needs to go. Example: Commelina. Weird little plant, but it gets the job done.

Why do Farmers Care?

Self-pollination is huge in agriculture. Like, you want stable harvests year after year? You better hope your rice, wheat, barley, or oats can pollinate themselves.

- ✓ Stable yields: No pollinators? No problem.
- ✓ Keeping it in the family: Plants make clones of themselves, so farmers get the same quality every season.
- ✓ Plant breeding: Want pure lines for new hybrids? Self-pollinate and you're golden.

Perks of Self-Pollination

- ✓ Seeds happen even when plants are all alone (cue the sad violin).
- ✓ Parental traits stick around no surprises.
- ✓ No need for bees, birds, or the wind.
- ✓ Super handy for making uniform crop varieties.

Downsides

- ✓ Less genetic variety = less adaptability. If the climate changes, these plants might be in trouble.
- ✓ Bad traits can pile up over generations.
- ✓ Plants might get a little… wimpy, eventually.

Wrapping it up: Self-pollination might not be flashy, but it's the backbone of plant survival and modern agriculture. Yeah, it limits diversity, but without it, you'd probably be eating a lot less rice and wheat. Next time you see a tomato or a pea pod, maybe give it a little nod of respect self-pollination keeps the world fed, one closed flower at a time.

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Climate-Smart Agriculture: The Future of Resilient Farming in India

Deep G. Kachot, Rohan V. Patel, Ajay A. Solanki and Ashish K. Pathar

Introduction

The Indian agriculture sector is under severe stress. Erratic rainfall, rising temperatures, droughts, floods and unpredictable weather events are becoming more frequent due to climate change. These climate shocks are disproportionately affecting small and marginal farmers who lack the resources to adapt or recover. Agriculture, both a victim and contributor to climate change, must undergo a transformation to ensure food security, farmer welfare and environmental sustainability. Climate-Smart Agriculture (CSA) - a holistic approach that integrates productivity, adaptation and mitigation. Climate-Smart Agriculture not only prepares farmers to cope with changing weather patterns but also enhances their livelihoods while protecting the environment.

What is Climate-Smart Agriculture?

Climate-smart agriculture (CSA) is an approach that helps guide actions to transform agri-food systems towards green and climate resilient practices. CSA supports reaching internationally agreed goals such as the SDGs and the Paris Agreement. It aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible. Climate Smart Agriculture (CSA) is the core of agricultural systems and adoption of CSA interventions plays a vital role in supporting sustainable agricultural development.

According to the Food and Agriculture Organization (FAO), Climate-Smart Agriculture is an approach that helps guide actions needed to transform and reorient agricultural systems to support development and ensure food security under the new realities of climate change.

Climate-Smart Agriculture has three core objectives:

- ✓ Increase agricultural productivity sustainably
- ✓ Enhance resilience and adaptation to climate change
- ✓ Reduce greenhouse gas (GHG) emissions, where possible

Climate-Smart Agriculture is not a specific technology or practice-it is a framework that guides the selection of context-specific strategies suitable to particular agro-ecological zones and farming systems.

Climate-Smart Agriculture Practices for Indian Farmers

Agroforestry: Integrating trees with crops or livestock enhances biodiversity, improves soil struct-

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ure and offers alternate income sources. Neem, Gliricidia, Subabul and fruit trees are commonly used in Indian agroforestry systems.

System of Rice Intensification (SRI): SRI uses less water and fewer inputs while increasing rice yields. It promotes alternate wetting and drying, younger seedlings and wider spacing.

Zero or Minimum Tillage: Reduces carbon emissions from soil and preserves moisture. Especially suitable for wheat after paddy in north India.

Crop Diversification: Instead of monoculture, farmers are encouraged to grow climate-resilient crops like millets, pulses, oilseeds and short-duration vegetables.

Soil and Water Conservation: Contour bunding, mulching, rainwater harvesting and farm ponds help in managing water efficiently and reduce soil erosion.

Organic and Integrated Nutrient Management: Use of farmyard manure, compost, biofertilizers and minimum chemical inputs to maintain soil health and reduce emissions.

Weather-Based Agro-Advisories: Farmers receive real-time forecasts and advisories to plan sowing, irrigation, fertilizer application and pest control accordingly.

Current Status of Climate-Smart Agriculture in India

India has several national and regional programs that support Climate-Smart Agriculture practices:

- ✓ National Mission for Sustainable Agriculture (NMSA)
- ✓ Soil Health Card Scheme
- ✓ Paramparagat Krishi Vikas Yojana (PKVY) for organic farming
- ✓ PM-KUSUM for solar-powered irrigation
- ✓ Agro-Met Advisory Services (AAS) under IMD and ICAR

Challenges in Climate-Smart Agriculture Implementation

Low Risk Perception: Many farmers do not connect crop loss to climate change. They view it as fate or bad luck, not something that can be mitigated.

Short-Term Needs vs. Long-Term Benefits: Climate-Smart Agriculture practices often show results over time. Poor farmers prioritize short-term income over long-term sustainability.

Lack of Access to Inputs and Finance: Resilient seeds, organic inputs, weather equipment and machinery may be unaffordable or unavailable.

Weak Extension Support: In many areas, extension systems are overburdened, understaffed, or poorly trained in climate-focused extension.

Digital Tools Supporting Climate-Smart Agriculture

Meghdoot App: Provides localized weather-based agro-advisories in 12 languages.

Kisan Suvidha App: Covers weather forecasts, market prices, soil health and pest alerts.

mKisan Poral: SMS-based platform delivering timely information to farmers, used extensively by extension agents.

Crop Weather Watch Group (CWWG): Used by

extension personnel to assess regional crop-weather dynamics and suggest interventions.

Policy Recommendations

Strengthen Climate Extension Services: Include Climate-Smart Agriculture modules in B.Sc. (Agri) and Diploma Extension programs. Recruit climate-literate extension agents.

Incentivize Climate-Smart Agriculture Practices: Offer subsidies for water-saving equipment, composting units, bio-inputs and intercropping systems.

Climate-Smart Agriculture in PMFBY: Reward Climate-Smart Agriculture-adopting farmers with lower insurance premiums due to lower risk exposure.

Climate-Smart Agriculture Index for Districts: Develop a district-level Climate-Smart Agriculture adoption index to track progress and guide investments.

Enhance Public-Private Partnership (PPP): Involve agri-tech companies, NGOs and FPOs in delivering climate information and inputs.

Integration of Climate-Smart Agriculture with Other Missions

Digital India: Use ICTs for weather, pest alerts and advisories.

National Solar Mission: Promote solar-powered irrigation pumps.

Skill India Mission: Train youth in Climate-Smart Agriculture technologies and services.

Rural Livelihood Missions: Diversify income sources with Climate-Smart Agriculture-aligned enterprises like goatery, poultry and composting.

Current status

National Innovations in CRA (NICRA) (2010-2011): Initiated by the Indian Council of Agricultural Research (ICAR) in 2011, NICRA was a comprehensive, interdisciplinary network project aimed at improving the resilience of Indian agriculture to climate change and variability (URL: http://www.nicra-icar.in/). The project mainly focused on improving agricultural adaptability, showcasing customized technology packages and solutions to tackle climate-related challenges in farmers' fields, and enhancing the skills of scientists and stakeholders.

Enhancing adaptive capacity and increasing resilience of small and marginal farmers in Purulia and Bankura district of West Bengal (2015-2019): This project, led by the Development Research Communication and Services Centre (DRCSC), aimed to create climate-resilient and adaptive livelihood systems for small and marginal farmers in West Bengal's Lateritic Zone (URL: http://www.drcsc.org/ and https://www.nabard.org/). This project mainly focused on agriculture and related sectors, achieved through diversification, technology integration, and effective natural resource management. The initiative aims to build the adaptive capacity of vulnerable farming households in the semi-arid areas of Purulia and Bankura districts by implementing strategies to mitigate the adverse impacts of climate change on their food and livelihood security. It is targeted to benefit a significant number households, including

many individuals from vulnerable farming communities and those reliant on natural resources.

Scaling-up CRA towards climate-smart villages (CSVs) in Haryana (2016-2019): This project was designed to empower rural communities in Haryana to adapt to climate change by promoting CRA practices across selected villages (URL: https://www.nabard.org/). This project positively impacted numerous families in several villages across multiple districts, including Yamunanagar, Ambala, Kurukshetra, Karnal, Jind, Kaithal, Panipat, Sonipat, Sirsa, and Fatehabad. The project also operated with a substantial budget and was spearheaded by the Department of Agri culture, Government of Haryana.

Resilient agricultural households through adaptation to climate change in Mahbubnagar district, Telangana (2016-2020): This project was defined to enhance the livelihoods of farming communities in specific villages by implementing science-based and suitable CRA practices (URL: https://www.nabard.org/). The project aimed to promote sustainable farming techniques in the area through soil and water conservation, efficient irrigation methods, establishing climate-resilient cropping systems, and developing forecasting models. Additionally, it sought to share knowledge and experiences with the broader community. The projected impact was to benefit over significant number of farming households in Mahbubnagar district, with 30-50% of the beneficiaries being women. It was also expected that small and marginal farmers would benefit the most from this initiative.

Conclusion

Climate-Smart Agriculture is not a luxury-it is a necessity. As climate risks intensify, India's agricultural extension system must rise to the challenge of educating, equipping and empowering farmers with climate-resilient knowledge and tools. The success of Climate-Smart Agriculture will depend not only on policies or technologies but on the strength of the last-mile connect-the trusted extension worker who guides the farmer in making climate-smart decisions. Climate-Smart Agriculture offers a future where productivity, profitability and sustainability go hand-in-hand. With farmers in the field and extension professionals by their side, Indian agriculture can build a resilient future-crop by crop, village by village.

Mycoviruses: The Secret Weapons against Plant Pathogenic Fungi

Chahat Kaundal and Rajesh Kumar

Discovery and Evolution of Mycoviruses

The first mycovirus was reported in the early 1960s in the cultivated mushroom *Agaricus bisporus*. Subsequent discoveries revealed that fungal viruses are nearly universal among fungal species (Pearson *et al.,* 2009). Mycoviruses likely co-evolved with their fungal hosts over millions of years, maintaining stable intracellular associations. Evolutionary studies suggest they originated from ancient RNA replicons and adapted to exploit fungal cellular machinery for replication (Hillman *et al*., 2018). Over the decades, technological advances particularly next-generation sequencing (NGS) have led to the identification of hundreds of novel mycoviruses across diverse ecological niches (Marzano *et al.,* 2016). These discoveries have shifted scientific perception from viewing mycoviruses as rare curiosities to understanding them as key regulators of fungal populations and ecosystem balance.

Mycoviruses and Hypovirulence

The phenomenon of hypovirulence, first described in *Cryphonectria parasitica*, the chestnut blight fungus, provided a turning point in mycovirus research. Infection by *Cryphonectria hypovirus* 1 (CHV1) was found to drastically reduce the fungus's virulence, leading to natural recovery of chestnut trees in Europe. Since then, several mycovirus-fungus systems showing similar effects have been identified:

- ✓ *Sclerotinia sclerotiorum hypovirus 1* in *Sclerotinia sclerotiorum*, causing reduced pathogenicity on oilseed rape and beans (Xie *et al.*, 2011).
- ✓ *Botrytis cinerea mitovirus 1* in *Botrytis cinerea*, the gray mold pathogen of grapes and strawberries (Wu *et al*., 2022).
- ✓ *Rosellinia necatrix mycoreovirus 3*, responsible for attenuated virulence in white root rot fungus of fruit trees (Kanematsu *et al*., 2014).

These examples highlight how mycoviruses act as biological attenuators, turning aggressive pathogens into weaker, less harmful forms a natural phenomenon that could be harnessed in agriculture.

Mechanism of Action

Mycoviruses alter fungal physiology through multiple mechanisms. They can:

- ✓ Disrupt fungal gene expression related to pathogenicity and toxin production.
- ✓ Interfere with signaling pathways involved in host infection.
- ✓ Induce RNA silencing responses within the

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fungus (Ghabrial *et al*., 2015).

In *C. parasitica*, CHV1 downregulates genes linked to fungal cell wall degradation and oxidative stress, leading to slower growth and reduced lesion formation (Dawe and Nuss, 2013). Some mycoviruses also affect sporulation and reproduction, limiting the spread of the fungal pathogen.

Mycoviruses as Biological Control Agents

The idea of using mycoviruses as biocontrol tools stems from their natural ability to weaken fungal pathogens without harming plants or other organisms. Compared to chemical fungicides, mycovirus-based control is:

- ✓ Environmentally safe, leaving no toxic residues.
- ✓ Highly specific, targeting only the pathogenic fungus.
- ✓ Self-sustaining, capable of persisting and spreading within fungal populations.

The success of CHV1 in controlling chestnut blight in Europe remains a landmark case of natural mycovirus-based control (Milgroom and Cortesi, 2004). Similar approaches are being explored for other major plant diseases such as:

- ✓ White mold (*Sclerotinia sclerotiorum*)
- ✓ Fusarium wilt (*Fusarium oxysporum*)
- ✓ Rice sheath blight (*Rhizoctonia solani*)

Modern molecular tools like reverse genetics and viral genome editing are enabling researchers to manipulate mycoviruses for enhanced biocontrol potential (Kwon *et al.*, 2023).

Recent Advances and Applications

Between 2010 and 2025, research on mycoviruses has expanded rapidly due to advances in metagenomics, transcriptomics and bioinformatics. Studies have revealed that mycoviruses are not limited to pathogenic fungi but also exist in endophytes and mycorrhizal fungi, influencing plant-fungus symbioses (Marzano *et al*., 2016).

Some promising areas of research include:

Mycovirus Engineering: Synthetic biology allows scientists to modify mycoviruses to enhance hypovirulence or improve host range (Kwon *et al*., 2023).

Viral Transmission Improvement: Overcoming natural transmission barriers (such as vegetative incompatibility) can increase biocontrol effectiveness (Xie and Jiang, 2014).

Integration with Other Biocontrol Methods: Combining mycoviruses with microbial antagonists like *Trichoderma* or *Bacillus subtilis* can provide synergistic disease suppression (Wu *et al*., 2022).

Mycoviruses in Non-Pathogenic Fungi: Certain mycoviruses enhance the growth or stress tolerance of beneficial fungi, indirectly supporting plant health (Hammond *et al*., 2020).

Challenges in Practical Application

Despite their potential, several challenges limit the large-scale application of mycoviruses in agriculture:

- ✓ Transmission barriers due to fungal vegetative incompatibility restrict virus spread.
- ✓ Host specificity can limit use across multiple fungal species.
- ✓ Environmental factors may influence viral stabi-

lity and persistence.

- ✓ Regulatory and biosafety concerns require careful evaluation before field release (Pearson *et al.*, 2009).

However, continuous research, coupled with policy frameworks for microbial biocontrol agents, is paving the way for safe deployment.

Future Perspectives

The future of mycovirus research lies in integrative disease management systems. Combining mycoviruses with genomics-based pathogen surveillance, resistant crop varieties, and precision agriculture tools can provide a holistic solution for sustainable farming. With climate change and global trade introducing new plant diseases, biological approaches like mycovirus-based control offer resilience and ecological harmony. As sequencing technologies become cheaper, the discovery of novel mycoviruses from unexplored ecosystems could open new doors for crop protection.

Conclusion

Mycoviruses represent one of nature's most ingenious systems viruses that heal instead of harm. They blur the lines between pathogens and allies, turning fungal foes into weakened forms that protect plants. For farmers and agricultural scientists, harnessing these natural viral allies means moving one step closer to chemical-free, sustainable plant disease management. As ongoing research continues to unravel their mysteries, mycoviruses stand out as silent, microscopic heroes the secret weapons against some of the most devastating plant fungal pathogens.

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The Rise of Digital Farming: Where Agriculture Meets Innovation

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Agriculture has always been a story of innovation. From the domestication of plants thousands of years ago to the mechanization of farms during the Industrial Revolution, humans have continually sought ways to grow food more efficiently. Today, we are witnessing a new agricultural revolution digital farming. Here, technology, data, and smart tools meet the fields, giving farmers unprecedented control over crop growth, resource use, and productivity.

Digital farming is not just about machines or gadgets; it's about smarter decision-making. Farmers can now see what their crops "need" in real-time, address problems before they escalate, and optimize every aspect of production from planting to harvesting.

What is Digital Farming?

At its core, digital farming or smart agriculture uses information technology, sensors, robotics, and analytics to guide farm management. This allows farmers to monitor soil health, track weather conditions, detect pests early, and determine the precise amount of water or fertilizer required for crops. Imagine a farmer receiving real-time notifications on a smartphone that certain areas of the field are too dry, or that a pest outbreak is starting in a specific patch. That's the power of digital farming: it transforms intuition-based farming into data-driven, predictive, and proactive management.

Technologies Driving Digital Agriculture

Internet of Things (IoT) and Smart Sensors: IoT devices such as soil moisture sensors, weather stations, and nutrient monitors continuously collect field data. Farmers can remotely track soil pH, temperature, and moisture levels through apps, ensuring precise irrigation and fertilization. This reduces water and fertilizer wastage, improves crop health, and helps adapt to climate variability.

Drones and Aerial Imaging: Drones equipped with cameras and multispectral sensors provide a bird's-eye view of farmland. They detect crop stress, nutrient deficiencies, pest infestations, and uneven growth patterns long before these issues become visible to the naked eye. With this information,

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farmers can target interventions precisely, saving time, resources, and crop losses.

Artificial Intelligence (AI) and Machine Learning : AI algorithms analyze data from IoT devices, drones, and satellites to predict yields, identify diseases, and optimize input usage. For instance, AI can forecast which areas of a field are most likely to suffer from drought or pest attacks, allowing farmers to act proactively rather than reactively.

Robotics and Automation: Robotics are transforming labor-intensive farming tasks. Automated planters, harvesters, and weeding robots work round-the-clock, reducing human effort while improving precision and consistency. This is particularly valuable in regions facing labor shortages or high labor costs.

Big Data and Decision Support Systems: Modern farms generate vast amounts of data, from satellite imagery to sensor readings. Decision support systems process this data to provide actionable insights, helping farmers choose the best planting dates, crop varieties, and treatment schedules. This ensures optimal resource use and maximizes productivity.

Benefits of Digital Farming

Digital farming offers a host of benefits:

Increased Productivity: Optimized water, nutrient, and pesticide application improves crop yields.

Sustainability: Precision interventions reduce environmental impact by conserving water, reducing chemical use, and maintaining soil health.

Cost Efficiency: Automation and data-driven decisions lower labor and input costs.

Risk Reduction: Predictive analytics help farmers anticipate weather events, pest outbreaks, and disease risks.

Market Competitiveness: Real-time monitoring and accurate yield forecasting allow better planning, pricing, and market access.

Challenges and Opportunities

Despite its potential, digital farming faces several challenges:

High Initial Costs: IoT devices, drones, and AI systems can be expensive, especially for smallholder farmers.

Connectivity Issues: Rural areas often lack reliable internet, limiting the effectiveness of connected devices.

Skill Gap: Farmers need training to interpret complex data and operate advanced technologies.

Data Security: Protecting farm data from cyber threats is essential as agriculture becomes more connected.

However, these challenges also present opportunities. Governments, NGOs, and private startups are developing affordable solutions, farmer training programs, and rural connectivity initiatives to make digital farming accessible to all.

The Future of Agriculture

Digital farming is transforming fields into high-tech landscapes, where technology guides every decision. Emerging innovations such as blockchain for supply chain transparency, AI-driven crop breeding, and autonomous farm machinery are

poised to make agriculture more efficient, transparent and resilient.

Farmers of the future will rely on data-driven insights, predictive analytics, and automation to optimize every step of production. By combining traditional agricultural knowledge with cutting-edge technology, digital farming promises to feed a growing global population sustainably, conserve natural resources, and enhance the livelihoods of farmers worldwide.

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Use of Bijamrut and Jeevamrut against Pest and Diseases of *Kharif* Crops

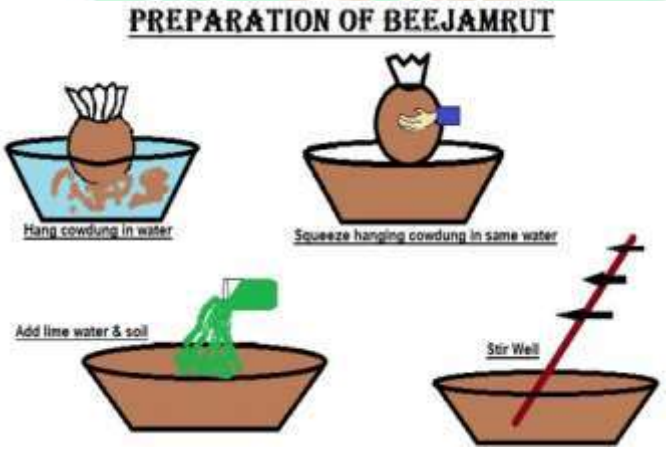
Shubham Mishra, Priyanka Gurjar, A. K. Bhardwaj and Smita Rajan

Introduction

Sustainable agriculture practices have gained significant momentum in recent years, with farmers increasingly turning to organic solutions for crop protection. Among these eco-friendly alternatives, bijamrut and jeevamrut have emerged as powerful biological formulations that effectively combat pests and diseases in *kharif* crops while maintaining soil health and environmental balance.

Understanding Bijamrut and Jeevamrut

Bijamrut is an organic seed treatment solution prepared by fermenting cow dung, cow urine, lime, and soil for 5-7 days. This bio-formulation serves as a seed coating agent that protects seeds from soil-borne pathogens and enhances germination rates.



Jeevamrut is a liquid organic manure created through the fermentation of cow dung, cow urine, jaggery, pulse flour, and soil. This nutrient-rich solution acts as both a growth promoter and a natural pesticide when applied to crops.

Mechanism of Action

Both formulations work through multiple mechanisms:

Microbial Enhancement: They introduce beneficial microorganisms that compete with harmful pathogens for space and nutrients

Natural Antimicrobials: Contain compounds that exhibit antifungal and antibacterial properties

Plant Immunity Boost: Strengthen plant defense mechanisms against pest attacks

Soil Health Improvement: Enhance soil fertility and microbial diversity.

Application in *Kharif* Crops

Seed Treatment with Bijamrut

For *kharif* crops like rice, cotton, sugarcane, and pulses, bijamrut application involves:

- ✓ Coating seeds 24 hours before sowing
- ✓ Providing protection against seed rot and damping-off diseases
- ✓ Improving seedling vigor and establishment

Foliar Application of Jeevamrut

Jeevamrut can be applied as:

Soil drench: 200-250 liters ha^{-1} every 15-20 days.

Foliar spray: 10% dilution during early morning or evening hours

Root zone application: Mixed with irrigation water

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Effectiveness against Major Threats

Disease Management

Fungal diseases: Effective against blast, blight, and wilt diseases in rice and other kharif crops

Bacterial infections: Reduces bacterial leaf blight and bacterial wilt incidence

Root rot: Prevents soil-borne fungal infections through beneficial microbial competition

Pest Control

Sucking pests: Deters aphids, thrips, and whiteflies through natural repellent compounds

Chewing insects: Reduces damage from caterpillars and beetles

Soil pests: Controls grub and root-feeding insects through soil application

Advantages over Chemical Alternatives

Environmental Safety: Non-toxic to beneficial insects, birds, and soil organisms

Cost-Effective: Prepared using locally available materials at minimal cost

Residue-Free: No harmful chemical residues in produce

Soil Health: Improves soil structure and fertility over time

Resistance Management: Reduces development of pest and pathogen resistance

Best Practices for Implementation

- ✓ Prepare fresh solutions every 15-20 days for optimal effectiveness
- ✓ Apply during cooler hours to prevent rapid evaporation
- ✓ Combine with other organic practices like crop rotation and intercropping
- ✓ Maintain proper fermentation conditions for consistent quality
- ✓ Store in shade and use within recommended time frames

Conclusion

The integration of bijamrut and jeevamrut in *kharif* crop management represents a sustainable approach to pest and disease control. These bio-formulations not only provide effective protection but also contribute to long-term soil health and ecosystem balance. As farmers increasingly recognize the importance of sustainable agriculture, these traditional yet scientifically validated solutions offer a promising pathway toward chemical-free farming while maintaining productivity and profitability.

Business Opportunity in Commercial Processing of Maize Straw: Unlocking Value from Agri-Residues

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Introduction

Agricultural residues are no longer being seen as agricultural "waste," but rather as valuable raw materials with immense economic and ecological potential. Among these residues, maize straw (also called stover) stands out because of its sheer volume, availability, and diverse applications. As maize cultivation continues to expand across India, the quantity of straw generated annually has risen sharply. India, the fifth-largest producer of maize in the world, produces around 33-35 million tonnes (MMT) of maize grain each year, which translates into 80-90 MMT of maize stover and straw (ICAR-IIMR, 2022).

However, despite this massive output, the utilization of maize straw remains limited. A significant proportion is either left in the fields to decompose slowly or burned openly. This open burning of maize residues contributes to serious environmental concerns, including:

Air pollution: Release of particulate matter (PM 2.5/PM10), carbon monoxide, and nitrogen oxides.

Soil degradation: Loss of valuable organic matter and nutrients that could otherwise enrich soil health.

Greenhouse gas emissions: Contribution to methane (CH_4) and nitrous oxide (N_2O) emissions, both potent climate change agents.

At the same time, the demand for sustainable and affordable fodder, bioenergy, paper substitutes, and organic fertilizers is rapidly rising. The dairy and livestock sectors in India, for instance, face a 35-40% deficit of green fodder and 25% deficit of dry fodder (IGFRI, 2021). This fodder crisis directly constrains milk productivity, which has significant implications for rural incomes and national GDP. With recent advancements in fodder processing technologies (silage, hay baling, pelletization), biomass utilization for energy, and biodegradable packaging industries, maize straw has emerged as a new business frontier. Unlike traditional disposal methods, commercial processing of maize straw can convert this agricultural residue into value-added products that address both economic needs and environmental challenges. Some of the most promising applications include:

Fodder and Silage: Processed maize straw, especially when ensiled, provides energy-rich feed for cattle, goats, and sheep, helping bridge India's fodder gap.

Bioenergy and Briquettes: Straw can be converted

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into biomass briquettes and pellets, providing a renewable energy source to replace coal and reduce carbon emissions.

Paper and Packaging: Maize straw pulp offers a sustainable alternative to wood-based pulp, helping reduce deforestation while tapping into India's rapidly growing packaging industry, valued at over ₹2 lakh crore (2023).

Organic Compost and Bio-fertilizers: Decomposed straw improves soil carbon content, enhances nutrient cycling, and promotes sustainable agriculture.

The convergence of entrepreneurial interest, technological readiness, and policy push (such as incentives for biomass utilization and residue management under national clean energy and climate missions) makes maize straw a strategic resource for India. Thus, commercial processing of maize straw represents not only a business opportunity for investors and farmers but also an environmental imperative to reduce pollution, mitigate climate change, and ensure sustainable growth.

Estimated Maize Straw Production in Major States (2022) (ICAR-IIMR, 2022; FAO, 2021)

State	Grain Production (MMT)	Estimated Straw (MMT)	Potential Use
Karnataka	4.5	9.0	Silage, Bioenergy
Bihar	3.8	7.5	Fodder, Paper
Andhra Pradesh	3.0	6.0	Silage
Maharashtra	2.8	5.5	Fodder, Compost
Punjab	1.5	3.0	Fodder, Briquettes
Others	17.0	35.0	Multiple uses
Total	**32.6**	**66.0-80.0**	—

Availability of Maize Straw in India

Production: India produces ~33-35 MMT maize grain annually (FAO, 2021). Straw-to-grain ratio is ~2.0, yielding ~80-90 MMT straw.

Utilization: Only ~25% used as fodder; rest is wasted/burned.

Business potential: Even if 50% is commercially processed, it could create a ₹20,000+ crore industry.

Commercial Applications of Maize Straw

Fodder and Silage

Silage Preparation: Maize straw can be transformed into nutrient-rich silage using mechanical balers and ensiling technologies, preserving its energy and fiber content.

Livestock Preference: Dairy farmers favor maize silage due to its high digestible energy**,** improving milk outputs and animal health.

Market Opportunity: India's estimated silage demand exceeds 150 million tonnes annually, representing a significant market gap waiting to be tapped.

Show a field of baled silage as a practical illustration.

Bioenergy and Briquettes

Eco-Friendly Fuel: Straw briquetting transforms waste into renewable biomass fuel, offering a sustainable alternative to coal.

High Energy Density: Maize straw briquettes yield around 14-16 GJ per tonne, making them an energetic and cleaner fuel source for industries and rural heating applications.

Growing Demand: With power plants moving toward co-firing biomass to reduce their carbon footprint, demand for straw briquettes is increasing rapidly.

Organic Fertilizer and Compost

Soil Enrichment: Decomposed maize straw enhances soil carbon levels, improves structure, and lowers the need for chemical fertilizers.

Circular Farming: Integration of straw-based compost into farm systems supports sustainable nutrient cycling and promotes healthy soil ecosystems.

Business Models for Entrepreneurs

The commercial processing of maize straw offers a spectrum of entrepreneurial opportunities. Different business models can be adopted depending on the scale, resources, and target market:

Public-Private Partnership (PPP) with State Governments

Approach: Entrepreneurs can work with state governments to lease land, establish straw collection centres, and use cooperative networks for fodder cultivation and distribution.

Benefit: Ensures government support, access to large land tracts, and institutional buyers such as dairy federations, gaushalas and farmer cooperatives.

Example: Punjab's PPP model for paddy straw baling (under National Clean Air Programme) can be replicated for maize straw.

Cluster-Based Units

Approach: A cluster of 5,000-10,000 farmers linked to a fodder/silage unit through Farmer Producer Organizations (FPOs).

Benefit: Reduces procurement cost, builds community ownership, and ensures steady supply.

Potential: Each cluster can process 50,000-100,000 tonnes of maize straw annually, generating both fodder and bioenergy products.

Export-Oriented Units

Approach: Process maize straw into silage bales, pellets, and briquettes for export to fodder-deficit countries in the Middle East and Southeast Asia.

Benefit: High-value international markets provide better margins.

Potential: Countries like UAE, Saudi Arabia, and Oman already import fodder worth billions of dollars annually due to water scarcity.

Technology Provider and Service Model

Approach: Entrepreneurs can partner with machinery suppliers (balers, shredders and silage bagging machines) and operate as custom hiring centres.

Benefit: Farmers don't have to bear high upfront machinery costs, while entrepreneurs earn service

fees.

Potential: Custom hiring centres are already successful for tractors/harvesters maize straw machinery services can be the next big frontier.

Conclusion

Maize straw, once regarded as a low-value residue, is now emerging as a strategic agricultural resource with enormous commercial, environmental, and social potential. With annual availability of nearly 80-90 million tonnes in India, its underutilization represents both a challenge and an untapped opportunity. By channeling maize straw into fodder and silage production, India can address its 35-40% green fodder deficit, thereby enhancing livestock productivity and farmer incomes. Similarly, converting straw into bioenergy and briquettes provides an eco-friendly substitute for coal, aligning with India's clean energy targets. Its use in paper and packaging industries offers a sustainable alternative to wood pulp, reducing deforestation and dependence on imports, while organic compost applications help restore soil health and strengthen circular farming systems. The future of maize straw utilization depends on scalable business models such as PPP-based collection and processing, cluster-driven farmer networks, export-oriented enterprises, and technology-driven service hubs. However, bottlenecks such as high collection costs, lack of farmer awareness, and inadequate infrastructure must be addressed through policy incentives, capacity building, and investment in modern machinery and storage facilities.

If these challenges are systematically tackled, maize straw commercialization can evolve into a multi-billion-rupee industry. It will not only generate new revenue streams for farmers but also create rural employment, reduce stubble burning and pollution, and contribute significantly to India's GDP and environmental sustainability goals. In short, maize straw is not a waste it is a hidden asset waiting to be unlocked. With the right partnerships, investments, and policies, it can become a powerful engine of growth in India's green economy.

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Impact of Climate Change on Mango Production

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Abstract

Mango (*Mangifera indica* L.) is one of the world's most important tropical and subtropical fruit crops economically, culturally and nutritionally. Climate change expressed as rising mean temperatures, altered rainfall patterns, increased frequency of extreme events, and shifting pest and disease dynamics is already reshaping mango phenology, productivity, quality and the livelihoods of growers. This article reviews the principal climate drivers affecting mango, summarizes observed and projected impacts on flowering, fruit set, yield and post-harvest quality, discusses pest and disease interactions, and outlines practical adaptation and mitigation strategies for growers, researchers and policymakers. Emphasis is given to actionable recommendations: cultivar choice and breeding, orchard management (water, nutrition, canopy), pest/disease surveillance and control, post-harvest handling, and supportive policies to build resilient mango value chains.

Introduction: why climate matters for mango

Mango is a phenologically sensitive tree: flowering, fruit set, development and ripening occur in narrow climatic windows. Unlike fully temperate fruit trees, mango responds strongly to cues such as cool nights, dry spells before flowering and the timing of monsoon rains or seasonal humidity. Small shifts in temperature or rainfall timing can therefore change the date of flowering, the synchrony of male/female flower viability, pollinator activity and ultimately fruit set and quality. Because many mango-growing regions are smallholder-dominated and rainfed, climate variability directly translates into yield variability and income instability for millions of households worldwide (Liu *et al*., 2023).

Principal climate drivers affecting mango production

Rising average and extreme temperatures: Global warming increases both mean temperatures and the frequency of heat extremes. In mango, higher night or daytime temperatures during floral induction and early fruit development can reduce the proportion of hermaphrodite (perfect) flowers, encourage vegetative growth over reproductive development, and accelerate fruit maturation often reducing size, sugar accumulation and keeping quality. Varietal responses differ: some cultivars require cool nights (11-14 °C) for optimum flowering while others are less sensitive (Rangare *et al*., 2022).

Changes in rainfall timing and intensity: Erratic rainfall shifting onset of monsoon or increased pre-monsoon showers can wash out pollen, lower pollin-

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ator activity, and increase flower/young-fruit mortality. Heavy rains during flowering also favor fungal infections and fruit blackening, while prolonged drought during fruit development causes fruit drop and poor size. Conversely, unexpected rains can trigger off-season flowering in some contexts, disrupting markets (Raju *et al*., 2024).

Increased frequency of extreme events: Storms, hail, unseasonal frosts (in subtropical margins), and heatwaves cause direct mechanical fruit loss, canopy damage and tree mortality. Repeated extremes reduce orchard longevity and raise rehabilitation costs.

Altered pest and disease pressure: Warmer temperatures and higher humidity often expand the geographical range, survival and reproductive rates of pests (fruit flies, mealybugs, stem borers) and pathogens (fungi, bacteria). Some emergent or re-emergent threats for example sudden-decline syndromes or more active fruit-borer populations have been linked to changing climate and associated ecosystem stress (Gonzalez and Hormaza, 2020).

How climate change affects key biological processes

Flowering and floral morphology: Mango flowering is cued by a sequence of dry and cool conditions, which are becoming less predictable. The result is irregular flowering (out-of-phase or asynchronous flowering), fewer hermaphrodite flowers (reducing self-fruitfulness), and shorter flowering windows that compress pollination opportunities. Studies report that mean minimum temperatures outside the 11-14 °C range reduce the production of ideal flowers, especially under Central Indian conditions (Rangare *et al*., 2022).

Pollination and fruit set: Heavy rains during bloom reduce pollinator activity and remove pollen. Heat stress at anthesis can reduce pollen viability and stigma receptivity. Reduced pollination leads to poor fruit set, increased alternate bearing and smaller harvests in subsequent seasons.

Fruit growth, quality and shelf life: Higher temperatures accelerate respiration and sugar metabolism, which can lower sweetness and firmness at harvest and shorten shelf life. Heat and water stress during early fruit development increase the incidence of internal breakdown and physiological disorders, lowering marketable yield (Halder and Hasan, 2020).

Post-harvest losses: Climate-driven deterioration of fruit quality (e.g., skin blackening after rain, greater insect damage) raises post-harvest losses. Added humidity fosters fungal growth in packinghouses and cold-chain gaps compound spoilage problems.

Observed regional impacts selected examples

India (major global mango producer): Reports and studies from India indicate delayed or erratic flowering, increased fruit drop related to heat at marble stage, and rising pest incidence tied to unusual pre-monsoon rains and warmer winters. These changes have reduced yields in vulnerable districts and complicated varietal choice and harvest planning. Farmer perception surveys also link rising temperatures and declining rainfall to increased input use (irrigation, pesticides) and income uncertainty

(Rangare *et al*., 2022).

Mexico, Peru and other tropical producers: In Mexico and parts of Latin America, alternating droughts and heavy rains have shifted flowering windows and caused quality losses, while increased humidity has raised fruit-fly and fungal pressures. Some producing regions reported compressed or delayed harvests that disrupted export schedules.

Global synthesis: Comprehensive reviews and book chapters synthesizing regional case studies show consistent themes: shifting phenology, increased yield variability, heightened pest/disease pressure and rising economic vulnerability of smallholders. Projections suggest that without adaptation, some current growing areas may become marginal for high-quality mango production while new areas (higher elevations or latitudes) might become suitable (Halder and Hasan, 2020).

Pest and disease dynamics under climate change

Changing climate alters host pathogen vector interactions in ways that often favor outbreaks:

Fruit flies and thrips: Warmer temperatures accelerate lifecycles and broaden seasonal activity, increasing infestation windows.

Stem borers and gall-formers: Stress-weakened trees are more susceptible to insects and secondary pathogens.

Fungal diseases: Increased rainfall and humidity promote blackening, anthracnose and post-harvest rots; unpredictable rains during flowering worsen pollination failures.

Bacterial diseases and decline syndromes: Complex declines often involve multiple pathogens and are aggravated by climatic stress and vector activity (Gonzalez and Hormaza, 2020).

Effective response requires strengthened pest surveillance, rapid diagnostics, integrated pest management (IPM) adapted to changing seasonality, and region-specific thresholds for interventions.

Socio-economic impacts

Mango is a high-value but perishable crop. Climate-driven yield and quality losses translate into immediate income loss for growers and ripple effects across labor, transport, agro-processing and export sectors. Smallholders with limited access to irrigation, credit, or cold-chain infrastructure suffer most. At the national level, repeated poor seasons can reduce export volumes, raise domestic prices and harm food systems that depend on stable fruit supplies. Reviews emphasize the importance of combining technical adaptation with social safety nets and market access improvements to protect vulnerable households.

Adaptation strategies practical options for growers

Adaptation must be multi-scale: on-farm practices, research/breeding, value-chain adjustments and enabling policies.

Orchard management and cultural practices

Water management: Expand drip irrigation and fertigation to precisely meet crop needs and reduce drought vulnerability. Mulching and soil organic matter retention improve moisture buffering.

Canopy and pruning management: Maintain

balanced vegetative/reproductive growth, reduce humidity inside canopy to limit disease, and improve spray coverage.

Flowering management: Use regulated deficit irrigation, potassium nitrate sprays or growth regulators (where appropriate and safe) to manage flowering timing and synchrony. Local trials are essential before large-scale adoption.

Microclimate modification: Shade nets, wind-breaks and protective covers can reduce heat stress and protect blossoms from heavy rain or hail in high-value orchards (Naqvi *et al*., 2025).

Pest and disease adaptation

Strengthen IPM: Regular monitoring, pheromone or baited traps, biological control agents, and targeted applications reduce reliance on calendar spraying and lower environmental risks.

Post-harvest hygiene and cooling: Rapid cooling, good packhouse hygiene and improved packaging reduce losses under warmer transport conditions.

Variety and rootstock selection; breeding

Heat- and drought-tolerant cultivars: Screen and promote varieties that maintain flowering, fruit set and quality under warmer/wilder conditions.

Rootstock research: Rootstocks that confer drought tolerance, improved nutrient uptake and disease resistance can buffer trees against climatic stress.

Accelerated breeding and molecular tools: Use marker-assisted selection and genomic tools to speed development of climate-resilient genotypes.

Diversification and value chain resilience

- ✓ Crop diversification and intercropping reduce income variability.
- ✓ Value addition and processing (pulp, dried mango, ready-to-use ingredients) can stabilize prices and extend marketing windows.
- ✓ Market linkages and contract farming help secure better prices and reduce post-harvest risk.

Policy and institutional measures

- ✓ Climate-smart subsidies and credit to invest in micro-irrigation, cold chain and protected structures.
- ✓ Early-warning systems and extension for seasonal forecasts, pest alerts and best practices.
- ✓ Insurance products tailored to horticulture and index-based payouts to protect smallholders against weather shocks.

Research and knowledge gaps

To effectively sustain mango production under changing climates, research should prioritize:

- ✓ Phenology modeling linking local climate variables to flowering and fruit set to develop actionable seasonal advisories.
- ✓ Varietal screening across climates, including multi-location trials for heat/ drought/ pest resilience.
- ✓ Integrated water-nutrient-pest management studies that quantify tradeoffs and synergies under real farm conditions.
- ✓ Post-harvest technology adapted to warm chains, focusing on low-cost, smallholder-appropriate cooling.
- ✓ Socio-economic research on adoption constraints for climate-smart practices and effective policy

instruments.

Practical recommendations (short list for extension agents and growers)

- ✓ Monitor local seasonal forecasts and plan flowering/ harvest interventions accordingly.
- ✓ Invest in or access micro-irrigation (drip/ fertigation) and soil moisture conservation.
- ✓ Adopt IPM: pheromone/fruit-fly traps, sanitation, timely biological control and targeted sprays.
- ✓ Trial tolerant varieties and appropriate rootstocks; prioritize local adaptability.
- ✓ Improve post-harvest handling: rapid sorting, cooling and hygienic packing to reduce climate-driven losses.
- ✓ Engage cooperatives or outgrower schemes to pool resources for cold chain and market access.

Conclusion

Climate change is not a distant threat for mango growers it is already altering phenology, increasing pest and disease pressures, and amplifying yield and quality variability in major producing regions. The response must be proactive, combining immediate on-farm measures (water management, IPM, canopy care), accelerated breeding and varietal selection, improved post-harvest systems, and enabling policies that provide finance, insurance and extension support. With coordinated action across research institutions, extension services, value-chain actors and policymakers, mango cultivation can be adapted to sustain production, secure livelihoods and preserve the cultural and economic value of this iconic fruit.

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Silkworm Rearing: A Sustainable Livelihood Practice in Arunachal Pradesh

Biki Islary, Dora Ponio, Tech Nisham Tara and Sonbeer Chack

Introduction

Silk, known for its luster and elegance, has fascinated humankind for centuries. Sericulture, or silkworm rearing, is one of the oldest agro-based industries, contributing significantly to rural development and sustainable livelihoods. In the context of Arunachal Pradesh, a biodiversity rich region of Northeast India, sericulture holds special importance. With its favorable climate, abundant flora, and traditional practices, the state has great potential to emerge as a hub for silk production. This article presents an overview of silkworm rearing practices with specific reference to Himalayan University, Itanagar, Arunachal Pradesh, where Students and Professors are actively engaged in promoting sustainable sericulture.

Rearing Process at Himalayan University

At Himalayan University, silkworm rearing is not only as part of academic learning but also as an initiative to promote entrepreneurship and sustainable livelihood among students. The process involves:

Eri plant Cultivation: University research field are used for growing healthy Eri plants to ensure a steady supply of nutritious leaves.

Incubation of Egg: Female moth lays more than 100 eggs in a day. Eggs are preserved in controlled environment with optimum temperature and humidity to ensure uniform hatching.

Larval Rearing: (Total duration- 28 days)- Larval rearing are of Two (2) stage:

- ✓ **Chawki Rearing (Early stage):** Here Young Silkworms are delicate and require frequent feeding with tender eri leaves, along with strict hygiene.
- ✓ **Late Age Rearing:** As the larvae grow, they consume larger leaves in greater quantities. Clean rearing houses with adequate ventilation prevent disease outbreak.

Mounting and Cocooning: Larvae mature in 18 days. Mature larvaes stop feeding and transferred to mountage where they spin cocoons in 2-3 days.

Harvesting: After 4-5 days, the cocoons are collected. Unlike other varieties, the pupa inside the cocoon are not waste but are commonly consumed as a nutritious food in Arunachal Pradesh and other parts of Northeast India, while others are processed to extract silk filaments through boiling or steaming.

Importance for Arunachal Pradesh

Silkworm rearing has immense potential in the socio-economic development of Arunachal Pradesh:

Employment Generation: Sericulture provides self-employment opportunities to rural youth and

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women.

Sustainable Practice: It is eco-friendly, requiring investment and relying on renewable resources.

Cultural Value: Handwoven silk garments are an integral part of tribal tradition in the state.

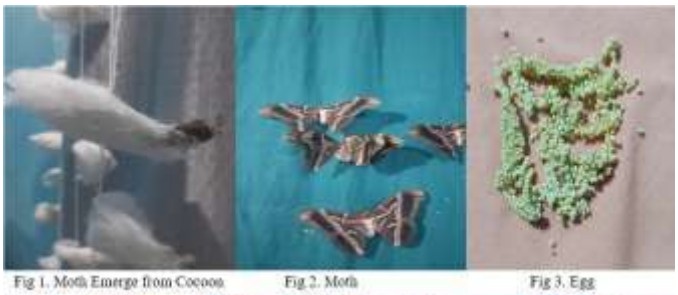

Fig 1. Moth Emerge from Cocoon Fig 2. Moth Fig 3. Egg

Fig 4. Chawki Stage (Newly hatch Silkworm); Fig 5. Late age silkworm Fig 6. Late age Feeding

Fig 7. Mature silkworm Fig 8. Cocoon Harvesting

Life Cycle of Silkworm

Challenges in the Region

Despite its potential, sericulture in Arunachal Pradesh faces several challenges:

- ✓ Climate fluctuation affecting silkworm growth.
- ✓ Limited awareness and training among farmers.
- ✓ Market access and pricing issues for rural producer.

Conclusion

Silkworm rearing at Himalayan University, Itanagar, reflects the institution's commitment to combining academic excellence with rural development. Under the guidance of faculty Dr. Sonbeer Chack, student such as Biki Islary, Dora Ponio and Techi Nisham Tara are contributing to the promotion of sustainable sericulture practices in Arunachal Pradesh.

Smart Dairy Farming: Harnessing AI and Machine Learning

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Introduction

Modern dairy farming is undergoing significant advancements, with emerging technologies such as artificial intelligence (AI) and machine learning (ML) offering substantial benefits in productivity, animal health, and profitability. Contemporary dairy producers can utilize these sophisticated tools for data-driven decision-making, thereby enhancing the precision and efficiency of routine management practices.

Role of AI and Machine Learning

AI and ML are like having a wise assistant on the farm. They help farmers:

- ✓ Optimize milk production by predicting yields more accurately.
- ✓ Detect diseases faster using photos and sensors, allowing early and cost-effective treatment.
- ✓ Design better feeding plans tailored for each animal, keeping cattle healthy and reducing costs.
- ✓ Improve record-keeping and automate repetitive tasks to save time and eliminate errors.

Keeping Animals Healthier

AI-powered apps and systems can analyze images of cattle to detect diseases and suggest early remedies. For instance, farmers may utilize a smartphone to photograph an ill animal and receive a diagnostic assessment with suggested treatments. Advanced wearable sensors and collars track cattle movements and monitor health signals, providing warnings for issues like lameness, stress, or abnormal grazing behavior. These tools help contain disease outbreaks, prevent losses, and improve animal welfare.

Smart Feeding: Machine learning models can advise farmers on the best diets for their cattle, considering age, breed, milk yield, and even weather conditions. Automated feeders and weighing systems ensure animals get the right amount of food at the right time, reducing waste and costs. Smart systems can also forecast monthly feed needs and adjust recipes for optimal nutrition.

Boosting Milk Production: Predictive tools analyze farm records, feed data, and environmental parameters to estimate milk yields and interpret fluctuations in production levels. Decision support systems track costs and profits, suggesting practical ways to improve margins, such as smart feed sourcing or better herd management. Early warning systems, tied to sensors and milk collection equipment, help avoid spoilage or production interruptions.

Financial Management and Planning: Smart farm management apps help track expenses, income, feed costs, and labour. AI can analyze these numbers and suggest where to save money or invest for better

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returns. Automated records and forecasts make budgeting and planning much easier, promoting profitability and long-term success.

Easy Steps to Start Using AI

Start with digital record-keeping: Use farm management apps to log animal health, feed, and production data.

Add sensors or smart collars: Simple devices can monitor vital animal behaviours and health indicators.

Use automated feeders or weighing systems: These can save time and ensure consistency.

Join agricultural programs or cooperatives focused on smart farming to access training and shared technologies.

Conclusion

Introducing new technology may require initial investment and learning. However, many tools are user-friendly and supported by agricultural organizations. With the right approach, even small farms can benefit from automation, data analysis, and remote monitoring. By adopting AI and ML in daily operations, dairy farmers can build healthier herds, boost productivity, and secure a more profitable future.

Women in Agriculture: Role of Women in Development of Agriculture

Varsha Upadhyay and Sonam Upadhyay

Introduction

Agriculture has always been the backbone of rural economies, and women form its invisible yet indispensable foundation. Across the world, particularly in developing countries, women contribute significantly to farming, livestock rearing, post-harvest operations, and household food security. From sowing seeds and managing crops to processing food and conserving natural resources, their role spans every stage of agricultural activity. Despite contributing nearly 60-80% of agricultural labor in many regions, women's efforts often remain undervalued due to limited land ownership, restricted access to resources, and socio-cultural barriers. Recognizing and empowering women in agriculture is not only essential for ensuring food security and rural development but also for achieving inclusive and sustainable agricultural growth.

Role of Women in Agriculture

Women play diverse roles in agriculture that extend beyond farming activities:

Crop Production: Sowing, transplanting, weeding, irrigation, fertilizer application, plant protection, harvesting, threshing, and post-harvest operations. In some regions, women are the main seed preservers and custodians of indigenous knowledge.

Livestock Management: Feeding, cleaning, and milking animals. Poultry, goat rearing, piggery, and dairy farming are often women-led enterprises.

Post-Harvest and Processing: Drying, cleaning, grading, storing, and processing of crops. Value addition such as pickle-making, grain processing, or food preservation.

Household Food Security: Ensuring availability and nutritional quality of food for the family. Managing kitchen gardens and small-scale horticulture.

Natural Resource Management: Collecting water, firewood, fodder, and fuel. Conserving biodiversity through traditional practices like seed selection and crop rotation.

Challenges Faced by Women in Agriculture

Limited Land Ownership: Most women do not have legal rights over land, even though they are the primary cultivators. Inheritance laws and social norms often favor men, leaving women dependent.

Limited Access to Technology and Training: Agricultural training, extension services, and modern technology are often male-oriented. Women depend on traditional tools, which increase drudgery and reduce efficiency.

Heavy Workload and Dual Responsibilities:

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Women juggle farm work with household duties like cooking, childcare, and water/fuel collection. This creates time poverty and reduces their productivity.

Wage Discrimination: Women agricultural workers are often paid less than men for the same work. Their contributions are undervalued and treated as "help" rather than professional labor.

Low Participation in Decision-Making: Women rarely participate in farm-level or policy-level decision-making. Their voices are often overlooked in community or cooperative organizations.

Socio-Cultural Barriers: Patriarchal norms limit their mobility, access to markets, and leadership opportunities. Social expectations restrict women's participation in commercial farming activities.

Health and Safety Issues: Exposure to pesticides, long working hours, and lack of protective gear affect women's health. Inadequate healthcare in rural areas worsens the problem.

Contribution of Women in Agricultural Development

Crop Production: Women actively participate in sowing, transplanting, weeding, irrigation, harvesting, threshing, and post-harvest management. They also preserve seeds and maintain indigenous farming knowledge, which is vital for sustainable agriculture.

Livestock Management: Women play a leading role in feeding, cleaning, and milking animals. Small-scale enterprises like poultry, goat rearing, and dairy farming are often managed by women, contributing to both household nutrition and income.

Post-Harvest and Value Addition: Women are heavily involved in cleaning, grading, drying, and storage of produce. They contribute to value-added processing such as making pickles, papad, flour, or dairy products, thereby boosting household income and agro-based industries.

Household Food Security: By managing kitchen gardens, horticulture, and small livestock, women ensure a steady supply of nutritious food for the family. Their role directly impacts nutritional security and reduction of rural poverty.

Natural Resource Management: Women collect and manage water, fodder, and fuel. They help in conserving soil fertility, biodiversity, and traditional seed varieties, supporting ecological sustainability.

Employment and Rural Economy: In many developing countries, women provide 60-80% of agricultural labor. Their contribution is essential for maintaining agricultural productivity and supporting rural livelihoods.

Social and Community Development: Through Self-Help Groups (SHGs) and cooperatives, women farmers engage in collective farming, savings, and small businesses. They strengthen social capital and empower rural communities.

Measures for Empowerment of Women in Agriculture

Land and Property Rights: Ensure equal land ownership and inheritance rights for women farmers. Provide legal support to strengthen their control over agricultural resources.

Access to Credit and Inputs: Offer easy and collat-

eral-free loans through banks and cooperatives. Provide subsidies for seeds, fertilizers, machinery, and irrigation facilities.

Extension Services and Technology Transfer: Develop gender-sensitive extension services to reach women farmers. Use ICT tools, mobile apps, and community-based approaches to spread agricultural knowledge.

Formation of Self-Help Groups (SHGs) and Cooperatives: Encourage women to form groups for collective farming, marketing, and savings. Promote women-led producer companies and cooperatives.

Market Access and Entrepreneurship: Support women in value addition, food processing, and agribusiness. Provide market linkages and e-commerce platforms for selling their produce.

Education and Awareness: Promote literacy and skill development among rural women. Increase awareness about government schemes, legal rights, and agricultural innovations.

Policy Support and Recognition: Recognize women officially as "farmers" rather than helpers. Frame gender-inclusive agricultural policies and allocate specific budget provisions.

Conclusion

Women are the invisible backbone of agriculture. Recognizing their role and addressing gender gaps can significantly enhance agricultural productivity, food security, and rural development. Empowering women farmers is not only a matter of equity but also a necessity for sustainable agricultural development.

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Silent Saboteurs: Insect-Pathogen Alliances Threatening Vegetable Crops

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Abstract

Vegetable crops are particularly vulnerable to intricate interactions between insect vectors and plant pathogens, which can undermine crop health and productivity long before symptoms become visible. Sap-feeding insects, including whiteflies, aphids, and thrips, act as carriers of major viral diseases such as Tomato Leaf Curl Virus, Chilli Leaf Curl Virus, and Cucumber Mosaic Virus, whereas leafhoppers and psyllids transmit phytoplasma-related disorders like brinjal little leaf. These insect-pathogen associations create compounded damage, resulting in substantial yield reductions, heightened pesticide dependence, and increased production costs. The stealthy nature of the vectors, together with the systemic spread of pathogens, often makes infections difficult or impossible to control once established. Effective management relies on an integrated strategy that combines the use of resistant cultivars, vigilant vector monitoring, cultural practices, biological control agents, and judicious chemical applications. Advanced approaches, including RNA interference, precision agriculture technologies, and AI-driven disease forecasting, offer promising tools to improve vector and disease management. This review highlights the biology, economic implications, and sustainable management strategies for key insect-pathogen complexes in vegetable crops, emphasising their importance in protecting both farmer livelihoods and food security.

Introduction

Vegetable crops represent one of the most intensively cultivated and economically significant components of modern agriculture, yet they face a growing and often overlooked threat, the complex alliances between insect vectors and plant pathogens. These intricate interactions function as "hidden saboteurs," compromising crop health and yield well before visible symptoms emerge. Sap-feeding insects such as aphids, whiteflies, and thrips serve as efficient vectors for several economically devastating viral diseases, including Tomato Leaf Curl Virus, Chilli Leaf Curl Virus, and Cucumber Mosaic Virus. Likewise, leafhoppers and psyllids are key transmitters of phytoplasma-associated disorders like brinjal little leaf, while insect feeding injuries

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Vegetable Crop	Disease/ Virus	Transmission Vector	Yield Loss (%)	Notes / Study Conditions	Reference
Tomato	Tomato Leaf Curl Virus (ToLCV) complex	Whitefly (*Bemisia tabaci*)	17-99% (up to 94.9% when infected within 2 weeks of transplanting)	Loss severity increases with earlier infection; variety and season influence impact.	Chintapalli and Rayalcheruvu, 2022
Chilli (*Capsicum annuum*)	Chilli Leaf Curl Virus (ChiLCV) / ChiLCD complex	Whitefly (*Bemisia tabaci*)	>98% when infection occurs at 20 DAT; <43% when infection delayed to 60 DAT	Early infection causes severe fruit loss and poor market quality.	Roy *et al.*, 2021
Okra (Bhendi)	Okra Yellow Vein Mosaic Virus (OYVMV)	Whitefly (*Bemisia tabaci*)	50-90% (up to 98% when infection occurs before 20 DAS)	Yield loss decreases with later infection; resistant genotypes offer partial protection.	Sastry & Singh, 1974; Fajinmi and Fajinmi, 2010
Pumpkin / Cucurbits	Cucumber Mosaic Virus (CMV) & Squash Mosaic Virus	Aphids (non-persistent transmission)	40-80% depending on crop stage and vector density	CMV causes mottling, distortion and stunting reducing yield and market value.	Buggana *et al.*, 2024
Brinjal (Eggplant)	Little Leaf Disease (Phytoplasma)	Leafhopper (*Hishimonus phycitis*)	25-100%	Infected plants become stunted, fail to bear fruit; epidemics reported in Tamil Nadu & Maharashtra.	Kumar *et al.*, 2017

frequently predispose solanaceous and cucurbit crops to secondary infections such as bacterial wilt and fungal diseases. The cumulative impact of these insect-pathogen interactions is considerably greater than the effect of either factor acting alone, leading to severe yield losses, higher pesticide dependence, and escalating production costs. In regions where vegetable crops play a vital role in ensuring nutritional security and farm profitability, such damage represents a critical challenge. A deeper understanding of insect vector biology, their interactions with pathogens, and the environmental conditions that facilitate disease outbreaks is therefore essential. This review seeks to elucidate major insect-pathogen complexes in vegetable crops, assess their economic implications, and discuss ecologically sound strategies to disrupt these damaging interactions for sustainable crop protection.

Unmasking the Silent Saboteurs: Insect-pathogen complexes pose a unique and insidious threat to vegetable production systems. Unlike defoliating or chewing pests that cause immediate and visible injury, insect vectors such as whiteflies, aphids, thrips, and leafhoppers operate covertly, transmitting pathogens across fields well before symptoms manifest. Their high mobility, rapid reproduction, and tendency to peak during critical crop growth stages make them formidable adversaries. By the time symptoms such as leaf curling, mosaic, yellowing, or stunting become apparent, the infection is often widespread and beyond curative intervention, leaving farmers with few options. Compounding the problem, most viral pathogens are systemic, spreading rapidly through the plant's vascular system, which explains why farmers frequently describe these diseases as "incurable."

The Science behind the Alliance: The interaction

between insect vectors and plant pathogens is not incidental but rather the result of co-evolutionary adaptation. Pathogens exploit the feeding behaviour of vectors as a natural transmission mechanism. For instance, viruses such as Tomato Leaf Curl Virus (ToLCV) and Chilli Leaf Curl Virus are transmitted persistently, allowing whiteflies to remain infectious for life and spread disease to multiple plants. Semi-persistent viruses such as Cauliflower Mosaic Virus (CaMV) are retained for hours to days, enabling infection of several plants before the vector loses infectivity. Non-persistent viruses like Cucumber Mosaic Virus (CMV) are acquired and transmitted within seconds during brief probing, resulting in rapid dissemination as vectors sample multiple plants. Interestingly, many pathogens actively manipulate host plant physiology to enhance transmission. Infected plants may emit attractive volatiles or exhibit improved nutritional quality, thereby attracting more vectors and accelerating epidemic spread.

The Double Jeopardy: Feeding Damage Plus Pathogen Load

Insect pests such as whiteflies and aphids are harmful even in the absence of pathogens due to their sap-sucking behaviour, which leads to chlorosis, leaf drop, and general weakening of plants. When combined with their role as pathogen vectors, crops face a compounded challenge: physiological stress from feeding damage coupled with systemic infection. Similarly, chewing pests such as fruit and shoot borers inflict wounds that predispose plants to secondary infections, including bacterial wilt and fungal blights, which can collectively result in near-total crop failure if not addressed promptly.

Economic, Social, and Food Security Implications

The consequences of these insect-pathogen alliances extend well beyond the field. Severe outbreaks can lead to 40-80% yield losses, escalating the frequency and cost of pesticide applications and significantly inflating production costs. Market shortages caused by epidemics often result in sharp price increases, negatively affecting consumers. Additionally, indiscriminate pesticide use to control vectors raises concerns about chemical residues on vegetables, threatening food safety. For smallholder farmers, repeated crop failures may result in economic debt, psychological stress, and in some cases, migration from farming to non-agricultural livelihoods. In North India, for example, recurrent Tomato Leaf Curl Virus outbreaks have driven many growers to abandon tomato cultivation and shift to less profitable cereal crops.

Breaking the Partnership: Toward Integrated Solutions

Effective management of these complex interactions requires a multi-pronged approach. Development and deployment of resistant cultivars such as virus-resistant tomato variety ‘Pusa Rohini’ and okra variety ‘VRO-6’ remain among the most reliable strategies. Advances in molecular breeding, including CRISPR-based genome editing, offer promising avenues for achieving durable resistance. Vector surveillance using yellow sticky traps, light

traps, and pheromone traps can help monitor population dynamics, while reflective mulches reduce vector landings and delay infection onset. Cultural interventions such as adjusted sowing dates, timely rouging of infected plants, field sanitation, and removal of alternate weed hosts are crucial for reducing inoculum sources. Biological control agents, including predators like ladybird beetles and parasitoid wasps, can help maintain vector populations at sub-economic levels, while entomopathogenic fungi such as *Beauveria bassiana* and *Verticillium lecanii* offer additional eco-friendly management tools. Where chemical interventions are necessary, they should be applied judiciously, with rotation of active ingredients to slow resistance development.

Future Perspectives

Emerging technologies hold significant potential to further strengthen integrated pest and disease management strategies. RNA interference (RNAi) techniques may soon allow scientists to block viral replication within vectors, rendering them non-infective. Precision agriculture tools, including drones, IoT-enabled sensors, and AI-based forecasting models, can facilitate timely and site-specific interventions. Ultimately, breaking the cycle of insect-pathogen transmission will require coordinated efforts involving researchers, policy-makers, and farmers to develop cost-effective, environmentally responsible, and socially acceptable management strategies.

Conclusion

Insect-pathogen complexes represent one of the most critical yet underappreciated constraints to sustainable vegetable production. Through their ability to silently transmit viruses and other pathogens, vectors such as whiteflies, aphids, and thrips can transform a healthy crop into near-total loss within a very short period. The resulting yield reduction not only threatens farm profitability but also escalates production costs, market volatility, and pesticide dependence, thereby raising environmental and food safety concerns. Addressing this challenge calls for a truly integrated and holistic management strategy. The deployment of resistant cultivars, continuous vector surveillance, conservation of natural enemies, strict field sanitation, and rational use of insecticides must be implemented in synergy. By adopting such sustainable and science-based interventions, it is possible to disrupt these “silent saboteurs,” safeguard farmer incomes, and ensure the long-term stability of vegetable production and food security

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Modern Farming and Technology in Agriculture

Isha Gupta

Agriculture has always been regarded as the backbone of civilization, supplying food, raw materials, and livelihoods to billions. However, in the 21st century, traditional farming practices are increasingly challenged by the pressures of population growth, climate change, urbanization, and limited natural resources. By 2050, the global population is expected to exceed 9 billion, and food demand is projected to rise by nearly 60 percent. Meeting this demand sustainably requires a transformation in agricultural practices. Modern farming, supported by advanced technologies, has emerged as a solution to ensure food security while minimizing environmental impacts. Modern agricultural technology includes artificial intelligence, drones, vertical farming, the Internet of Things (IoT), hydroponics, aquaponics, and biotechnology. These tools not only increase productivity but also conserve resources such as land, water, and energy. This article explores the major innovations driving the future of agriculture.

Role of AI and Drones in Smart Agriculture

Artificial Intelligence (AI) and drones are revolutionizing the concept of smart farming. Precision agriculture, which relies on data-driven decision-making, is increasingly becoming the norm. AI enables farmers to analyze weather forecasts, soil health, and crop conditions, while drones provide aerial imagery and real-time monitoring. Drones equipped with multispectral and thermal cameras allow farmers to detect water stress, nutrient deficiencies, pest infestations, and crop diseases early. This enables targeted interventions, reducing the overuse of fertilizers and pesticides. Instead of spraying entire fields, farmers can apply chemicals precisely where needed, reducing both costs and environmental harm. AI further enhances this process by analyzing large datasets collected by drones, sensors and satellites. For example, AI algorithms can predict crop yields, optimize irrigation schedules, and recommend sowing times. In India, several startups are now using AI-powered applications that provide farmers with localized weather alerts and pest management strategies. Together, AI and drones ensure efficient use of inputs, minimize losses, and help achieve higher yields with fewer resources. They empower farmers to practice sustainable agriculture while increasing profitability.

Vertical Farming: A Solution to Urban Food Security?

As cities expand and arable land decreases, vertical farming has emerged as a groundbreaking innovation. In vertical farming, crops are grown in stacked layers within controlled indoor environments using artificial lighting and hydroponic or aeroponic

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systems. This approach addresses several pressing challenges. First, it conserves land an important factor in urban areas where space is scarce. Second, it drastically reduces water consumption, often using 70-90% less water than traditional methods. Third, it eliminates dependence on seasonal cycles and external climate, allowing year-round cultivation. For urban populations, vertical farming offers a localized solution to food insecurity. Fresh vegetables and fruits can be produced close to consumers, reducing transportation costs and carbon emissions. Singapore, Japan, and the United States have pioneered large-scale vertical farms that supply urban markets with pesticide-free produce. However, vertical farming also faces challenges such as high energy requirements for artificial lighting and climate control. Nevertheless, with the integration of renewable energy sources and efficient LED systems, vertical farming remains a promising tool for achieving urban food sustainability.

How IoT is Transforming Farm Management

The Internet of Things (IoT) refers to the interconnection of devices through sensors, software, and cloud platforms. In agriculture, IoT has transformed farm management by enabling real-time monitoring and automation. IoT sensors can measure soil moisture, nutrient levels, and microclimate conditions. This data is transmitted to smartphones or computers, allowing farmers to make informed decisions. For instance, an IoT-enabled irrigation system can automatically adjust water supply based on soil moisture readings, preventing both over-watering and water stress. In livestock management, wearable IoT devices track animal health, movement, and productivity. This early detection of illness helps farmers reduce mortality rates and improve animal welfare. Similarly, IoT-connected tractors and harvesters optimize machinery usage and reduce fuel consumption.

The true strength of IoT lies in integration. By combining multiple sensors, drones, and AI-powered analytics, farmers can develop a digital twin of their farms, allowing predictive analysis and resource optimization. The global adoption of IoT in agriculture is rapidly increasing, proving that digital farming is no longer the future it is the present.

The Rise of Transforming Farm Management

Hydroponics and aquaponics represent innovative soilless farming techniques that are redefining how crops are cultivated.

Hydroponics involves growing plants in nutrient-rich water instead of soil. Since the roots are directly exposed to nutrients, plant growth is faster and yields are higher. Hydroponics reduces water usage by up to 90% compared to traditional farming and eliminates the risks of soil-borne diseases. Lettuce, spinach, and herbs are commonly grown hydroponically, making it popular in urban and greenhouse farming.

Aquaponics is an integrated system that combines hydroponics with fish farming. In this closed-loop system, fish produce waste that is converted into nutrients for plants, while the plants filter and purify the water for the fish. This creates a

symbiotic relationship that ensures efficient resource use and sustainability.

Both hydroponics and aquaponics are particularly valuable for regions facing land degradation and water scarcity. They not only produce fresh, chemical-free food but also demonstrate how agriculture can adapt to ecological and environmental challenges.

Biotechnology in Agriculture: GMOs and Beyond

Biotechnology has played a transformative role in agriculture by enabling the development of genetically modified organisms (GMOs) and advanced plant-breeding techniques.

GM crops, such as *Bt* cotton and pest-resistant maize, have been widely adopted for their ability to withstand pests, diseases, and herbicides. These crops reduce dependence on chemical pesticides, increase yields, and improve farmer income. However, GMOs remain controversial due to concerns over food safety, biodiversity, and corporate control of seeds.

Beyond GMOs, new techniques such as CRISPR-Cas9 gene editing offer greater precision in crop improvement. Scientists can now develop crops that are drought-tolerant, nutrient-enriched, and climate-resilient without introducing foreign genes. This opens new opportunities for sustainable farming. Biotechnology also includes the use of biofertilizers, biopesticides, and microbial inoculants that enhance soil fertility and reduce chemical dependency. Together, these innovations demonstrate how biotechnology can balance productivity with ecological responsibility.

Conclusion

Modern farming is no longer defined by plows and fields alone; it is increasingly powered by data, science, and innovation. From AI-driven drones that monitor crops to vertical farms feeding urban populations, IoT networks optimizing resources, soilless systems reducing water usage, and biotechnology engineering climate-smart crops each of these technologies is reshaping the agricultural landscape. For agriculture students and future policymakers, understanding these technologies is essential. They represent not just tools of efficiency, but strategies for survival in a world facing climate stress, population growth, and resource scarcity. By adopting modern farming and technology-driven solutions, agriculture can continue to be the backbone of human civilization stronger, smarter, and more sustainable than ever before.

Agricultural Extension and Rural Development: A Brief Discussion on the Relationship between Extension Services and Rural Livelihoods

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Abstract

Agricultural extension remains a central instrument for improving rural livelihoods by supplying information, building human and social capital, facilitating technology adoption, linking farmers to inputs and markets, and supporting diversification away from subsistence farming. Over the past decades extension has evolved from top-down, supply-driven approaches to pluralistic, demand-driven, participatory and ICT-enabled advisory systems. Evidence shows extension can raise productivity and household incomes, but results are heterogeneous: impacts depend on institutional design, gender sensitivity, financing, agent-farmer relationships, relevance of content, and linkages to markets and services. For extension to contribute meaningfully to rural development and poverty reduction it must be re-capitalized, pluralized (public, private, NGO, producer-organization providers), made demand-responsive, and integrated into broader rural development and food-security strategies.

Introduction

Agricultural extension broadly defined as the processes and institutions that facilitate the flow of information, skills, technologies and services to rural producers and communities has long been considered a public good and a conduit for rural development. This review synthesizes conceptual frameworks, historical evolution, delivery modalities, evidence on effects on livelihoods, and practical policy lessons. It emphasizes pathways through which extension affects five livelihood capitals (human, social, natural, physical, financial) and identifies key constraints and opportunities for strengthening impacts on rural livelihoods. The review draws on foundational policy reviews and recent empirical evaluations.

Conceptual framework: How extension links to livelihoods?

Extension influences livelihoods through multiple, often interacting pathways:

Human capital: Training, farmer field schools, demonstrations, and advisory services increase knowledge and skills, improving management of crops, livestock, and natural resources.

Social capital: Extension that fosters farmer groups, cooperatives, and peer learning builds networks, trust and collective action that reduce transaction costs and improve bargaining power.

Natural capital: Advice on soil health, integrated pest management, and sustainable practices can

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maintain or restore natural assets important for long-term livelihoods.

Physical capital: Extension often facilitates access to inputs, improved seed, tools and infrastructure by informing farmers about availability and use.

Financial capital: By improving productivity, facilitating market access and supporting diversification into high-value enterprises, extension can improve incomes and asset accumulation.

These pathways are mediated by institutions, gender relations, local governance, and markets; hence extension rarely operates in isolation.

Historical evolution and contemporary typologies of extension

Extension approaches have shifted historically:

Traditional general/advisory extension: Public, field-based advisory where agents transfer research-backed messages.

Training & Visit and T&V reforms: 1970s-1990s attempts to systematize contact with farmers.

Farmer Field Schools (FFS): Participatory experiential learning focused on agro-ecological decision making.

Pluralistic and contracted extension: Increasing private sector, NGO, and producer-organization roles; government shifting to stewardship/regulatory roles.

Demand-driven and market-oriented models: Focus on profitability, value chains and commercialization.

ICT-enabled advisory services: Mobile phones, SMS, apps, call centers and broadcast media increasing reach and timeliness.

FAO's policy reviews recommend diversified, multi-actor systems where government plays a coordinating and quality-assurance role while other actors provide specialized services. Contemporary critiques call for "humanising" extension embedding socio-political awareness, equity and power relations into advisory practice, not only technical transfer.

Delivery modalities and innovation in practice

Agricultural extension services utilize various delivery modalities to reach farmers, including individual farm visits, group extension methods like Farmer Field Schools (FFS) and demonstration plots, mass media and radio, ICT platforms such as SMS and smartphone apps, value-chain extension, and market or input dealer extension. Innovative approaches often combine these modalities to maximize impact, such as extension agents supported by SMS alerts, group learning complemented by private advisory inputs, and digital platforms providing critical information on weather, prices, and pest management. The effectiveness of these approaches depends on their relevance, timeliness, cultural fit, and the level of trust between farmers and extension service providers. By leveraging a mix of traditional and digital methods, extension services can better meet the diverse needs of farmers and enhance their productivity and livelihoods.

Evidence on impacts - what works, what doesn't

Empirical evaluations and impact studies

report mixed but instructive findings:

Productivity and Income: Targeted capacity-building projects that strengthen extension services can have positive impacts on productivity and income, particularly when combined with access to inputs and markets. For example, projects that promote high-value crops and provide support for household economic participation can lead to increased adoption and improved livelihoods. However, the effects can vary depending on factors such as gender, region, and program design.

Adoption Pathways: Extension services are most effective when advice is practical, economically attractive, and paired with access to inputs and markets. Isolated advice without an enabling environment is unlikely to lead to significant adoption. Effective extension requires a comprehensive approach that addresses the needs of farmers and provides them with the necessary support to adopt new practices and technologies.

Inclusion and Gender: Extension services often have uneven impacts on women and marginalized groups. Programs that explicitly target female farmers, adapt contact modalities, and address intra-household decision processes can help improve inclusion and equity. This may involve providing training and support specifically tailored to the needs of women and marginalized groups, as well as addressing social and cultural barriers that may limit their participation.

Long-term Resilience: Extension services that emphasize sustainable practices, diversification, and social learning can contribute to long-term resilience in agricultural systems. However, achieving this requires sustained engagement and monitoring, as well as a focus on building the capacity of farmers to adapt to changing circumstances. By promoting resilience and sustainability, extension services can help farmers and agricultural communities to better withstand shocks and stresses, and to improve their overall well-being.

Key constraints that limit impact on rural livelihoods

Agricultural extension services face several key constraints that limit their impact on rural livelihoods. Under-resourcing is a significant issue, with many public extension services suffering from chronic funding and staffing shortages, highlighting the need for re-capitalization and strategic public investment. Top-down, supply-driven design approaches often result in programs that fail to respond to farmers' expressed needs or local contexts, leading to low relevance and uptake. Weak market linkages also hinder the effectiveness of extension services, as technical improvements may not translate into higher incomes without functioning input/output markets and value-chain support. Furthermore, extension services often suffer from gender and social exclusion, reaching male farm managers more than women or youth, unless programs are designed with inclusive outreach. The proliferation of private/paid advice and misinformation can also undermine trust in extension services, emphasizing the need for governments to assure

quality and oversight. Finally, fragmentation and poor coordination among multiple providers can lead to duplication, inconsistent messages, and inefficient resource use, highlighting the importance of improved coordination and governance.

Lessons and good practice for extension that improves livelihoods

Effective agricultural extension services that improve livelihoods incorporate several key lessons and good practices. Firstly, pluralistic systems with public stewardship are essential, where governments ensure equitable coverage, quality assurance, and support for vulnerable farmers, while NGOs and private providers deliver specialized services. Demand-driven, client-centered approaches are also crucial, involving needs assessments, farmer participation in planning, and feedback mechanisms to increase relevance and adoption. Integration across sectors is vital, linking extension with market development, credit, social protection, and infrastructure to produce larger livelihood gains. Additionally, gender-responsive programming is necessary, including scheduling meetings and modalities that reach women, recruiting female agents, and designing content that targets women's constraints. The strategic use of ICTs as complementary tools can expand reach and speed, but should not replace relationship-based extension. Finally, regular monitoring, evaluation, and learning (MEL) are critical, with public investment in MEL essential for improving performance and account-ability, and ensuring that extension services are effective and responsive to farmer needs.

Policy implications and recommendations

To enhance the impact of agricultural extension and advisory services, policymakers should recommit public resources to extension as a public good, targeting smallholders and vulnerable populations, and invest in training, staffing, and institutional capacity. Institutional pluralism should be promoted, with clear roles for public stewardship, private niche providers, and NGO/community delivery for outreach and social mobilization. Extension services should be designed for inclusion, adopting gender targets, youth outreach, and ensuring marginalized groups benefit. Advisory messages should be paired with access to inputs, finance, and market opportunities. Policymakers should also prioritize scaling what works, adapting to local socio-economic realities, and fostering learning and flexibility through feedback loops, participatory monitoring, and iterative program design, allowing extension services to evolve with farmer needs and improve livelihoods.

Future scope of research: Future research in agricultural extension and advisory services should focus on several key areas, including longitudinal studies to assess the sustained livelihood impacts of extension services beyond short-term productivity gains. Comparative studies of pluralistic delivery models across different regions and commodity systems can provide valuable insights into effective approaches. Additionally, research should explore mechanisms to improve women's access and control

over extension-related benefits, as well as the cost-effectiveness and scalability of ICT-enabled advisory services in low-connectivity environments. Investigating the interactions between extension services, climate adaptation services, and social protection can also help identify opportunities for integrated and impactful interventions, ultimately enhancing the lives of farmers and rural communities.

Conclusion

Agricultural extension is neither a silver bullet nor obsolete. It remains a crucial lever for rural development when it is well-designed, sufficiently funded, participatory, inclusive and integrated into broader rural development systems. The shift toward pluralistic, client-oriented and ICT-complemented extension is promising, but realization of livelihood outcomes requires political commitment, institutional reform, market development and careful attention to equity and local context. Policymakers and practitioners must balance technical transfer with socio-political sensitivity, a call well articulated in contemporary reviews that advocate for "humanising" extension and re-capitalizing public stewardship.

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Turning Waste into Wealth: The Promise of Biochar in Modern Agriculture

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Abstract

Biochar, a carbon-rich product derived from the pyrolysis of organic biomass, has gained prominence as a sustainable soil amendment addressing global challenges such as soil degradation, nutrient depletion, water scarcity and climate change. Its application enhances soil physical properties by increasing porosity, reducing bulk density and improving water retention, while chemical properties are improved through pH regulation, increased cation exchange capacity and enhanced nutrient availability. Biochar also positively influences soil biological activity by promoting microbial biomass, diversity and nutrient-cycling functions. These combined effects contribute to improved soil health, crop growth, yield and carbon sequestration. The performance of biochar is strongly influenced by feedstock type, pyrolysis conditions and application strategies. Despite demonstrated benefits, further research is required to optimize production methods, assess long-term field impacts and integrate biochar with other sustainable agricultural practices. Biochar thus represents a promising tool for advancing resilient and sustainable agriculture. Global challenges such as climate change, soil degradation, contamination, water scarcity and food insecurity threaten both the environment and human civilization. To mitigate these pressing environmental challenges, biochar has gained significant scientific attention as an innovative, carbon-rich material produced through the pyrolysis of organic biomass such as crop residues, animal manures and forestry wastes under oxygen-limited conditions. Biochar serves as a versatile and sustainable solution to many complex challenges faced by modern agriculture while simultaneously offering significant environmental benefits. Its growing importance in farming lies in its multifunctional role as a soil conditioner. When incorporated into the soil, biochar enhances its structure, fertility and overall productivity through various physical, chemical and biological mechanisms. Beyond its direct agricultural advantages, biochar contributes to reducing environmental degradation by improving nutrient efficiency and supporting carbon sequestration. The integration of biochar into farming systems thus represents a promising step toward sustainable agriculture, offering multiple benefits such as enhanced soil health, increased crop yields, climate change mitigation and ecosystem protection. As global agriculture strives to meet the food demands of an expanding population while conserving natural resources, biochar stands out as a practical, eco-friendly innovation with the potential to transform the future of farming.

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Biochar Production

Thermal Conversion: The production of biochar through thermal conversion has gained momentum with its increasing applications. It is primarily produced via thermochemical methods such as roasting, gasification, hydrothermal carbonization and pyrolysis. The yield and quality of biochar largely depend on the type of biomass and key process parameters, including temperature, heating rate and residence time. These factors influence both the physical and chemical characteristics of the final product, as variations in process conditions lead to different forms of biochar derived from plant materials.

Gasification: Gasification is a thermochemical process that transforms carbon-containing materials into gaseous products. In the presence of gasifying agents such as oxygen, air or steam, it produces synthesis gas (syngas) rich in hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and trace hydrocarbons at high temperatures. The reaction temperature is a critical factor influencing syngas composition, with higher temperatures favouring the formation of CO and H_2, while reducing the production of CH_4, CO_2 and other hydrocarbon species.

Torrefaction and Flash Carbonization: Torrefaction also known as mild pyrolysis is a biochar production method carried out at 200-300 °C in an inert, oxygen-limited environment. It removes moisture, oxygen and CO_2 from biomass, altering its particle size, surface area, moisture content, heating rate and energy density. The process includes steps such as heating, drying, toasting and cooling and may involve oxidative roasting using an oxidizing agent to generate the required thermal energy. Typical parameters include a heating rate below 50 °C min^{-1} and a holding time under 30 minutes.

Hydrothermal Carbonization: Hydrothermal carbonization produces biochar at 180-250 °C using water as the reaction medium, making it a cost-effective method. Biomass and water are placed in a closed reactor, where hydrolysis, dehydration, cracking and isomerization transform the feedstock into hydrochar. Lignin undergoes dealkylation and hydrolysis to form phenolic compounds, which subsequently repolymerize and crosslink to generate the final carbon-rich product. Undissolved lignin fractions are incorporated into the hydrochar, similar to products from pyrolysis.

Biochar Characteristics: Biochar is a multi-functional soil amendment whose properties are strongly influenced by feedstock type and pyrolysis conditions. pH is a critical factor, affecting metal interactions and pollutant adsorption. Biomass composition plays a key role, as high-ash feedstocks generally produce more alkaline biochar, while higher pyrolysis temperatures further increase alkalinity through oxidation of acidic functional groups. The structural and elemental features of biochar determine its functionality. Surface functional groups, including carboxylic acids and hydroxyls, govern nutrient retention and adsorption potential. Techniques such as Fourier transform

infrared spectroscopy (FTIR), nuclear magnetic resonance (NMR) and scanning electron microscopy (SEM) are widely used to characterize these properties. Pyrolysis generates high surface area and porosity, enhancing absorbency, which can be further improved via activation processes. Biochar stability in soil, crucial for long-term carbon sequestration, depends on the balance of crystalline and amorphous carbon. Stability is typically assessed through thermal, chemical or incubation-based methods, with advanced approaches like 14-C radioisotope tracing offering precise measurements.

Overall, biochar's combination of pH, functional groups, porosity and stability determines its effectiveness in soil improvement, pollutant adsorption and environmental protection. By optimizing feedstock selection and production parameters, biochar can be tailored as a sustainable tool for enhancing soil fertility, mitigating pollution and contributing to climate change adaptation.

Biochar Impacts: Biochar is a sustainable tool to improve soil properties, enhance crop quality and increase yields. It also aids in pollutant removal from soil and water and positively influences soil health, nutrient availability, rhizosphere activity and crop growth.

Soil Health: Soil health refers to the soil's ability to sustain plant growth by providing essential water and nutrients while remaining free of harmful substances. Fertility is determined by its physical, chemical and biological properties, yet many regions, including arid, semi-arid and rainforest areas, face low soil fertility due to poor water retention, nutrient loss and rapid organic matter mineralization. Maintaining adequate soil organic matter and nutrient cycles is crucial for sustainable productivity. Biochar application has shown significant potential to improve soil health by enhancing soil structure, water retention, nutrient content and carbon sequestration; mitigating toxic effects; supporting soil organisms and ultimately boosting plant growth, biomass quality and crop yields.

Soil Physical Properties: Soil bulk density and compaction strongly influence root growth and soil properties. High bulk density (>1.7 g cm^{-3}) reduces pore space and oxygen diffusion, restricting root development and slowing plant growth. Crops like soybean and maize show significant yield reductions in compacted soils. Biochar application can alleviate these issues by reducing bulk density and increasing porosity. Studies show that adding 4-6% biochar, alone or with compost, can lower bulk density by 5-16% and enhance porosity by 8-22%, depending on soil type. Increased porosity improves water, air and heat movement, enhancing soil physical conditions and supporting better root development and crop productivity.

Biochar improves soil porosity and water retention through its internal pores, interactions with soil particles and aggregate formation. It enhances water storage, aeration and hydraulic conductivity, though excessive addition or hydrophobic biochar (from low-temperature pyrolysis) can reduce water availability. Effects vary with feedstock, pyrolysis

conditions and soil type, with lignin-rich biochar being more stable and effective.

Soil Chemical Properties: Biochar effectively mitigates soil acidification due to its alkalinity, strong buffering capacity and reactive functional groups. It can raise soil pH, enhance nutrient availability and release cations such as K^+, Mg^{2+}, Ca^{2+} and Na^+. Long-term applications (e.g., 20 t ha^{-1}) have demonstrated sustained increases in soil pH and reductions in toxic Al^{3+} levels, although effects on crop yield may vary depending on soil type. In saline and sodic soils, biochar improves soil structure, promotes water infiltration, balances cations via its high cation exchange capacity (CEC) and supports microbial activity, thereby alleviating salt stress and enhancing plant growth. CEC, a key determinant of nutrient retention, is enhanced by biochar through surface oxidation and the presence of reactive functional groups (COOH, OH, C-O, phenolic groups). Biochar increases the soil's net negative charge, improving nutrient retention and reducing leaching. Studies have shown variable effects depending on soil type and biochar characteristics, with greater increases in CEC observed in non-calcareous and oxidized biochar-amended soils. Overall, biochar application improves soil chemical properties, enhances nutrient availability and mitigates salinity and acidity stress.

Nutrient Offering and Retention: Biochar improves nutrient retention by stabilizing organic matter, increasing cation exchange capacity and reducing leaching of N, P, K and other essential nutrients. Field studies show that biochar from various sources enhances soil pH, nutrient availability, water retention and microbial activity, supporting long-term fertility and crop productivity, especially in tropical soils.

Soil Biological Properties: Biochar influences soil microbial communities by providing carbon, nutrients and microhabitats, enhancing microbial biomass, diversity and activity. Its effects vary with soil type, biochar source, dosage and pyrolysis conditions. Applications of biochar have been shown to increase microbial biomass carbon (MBC), nitrogen (MBN) and key functional groups involved in nutrient cycling, while promoting beneficial bacteria and fungi, including nitrogen-fixing and phosphate-solubilizing species. Biochar also affects soil enzymes and microbial-mediated processes, supporting soil fertility and plant productivity. However, some biochars contain polyphenols or aromatic compounds that can inhibit certain microbial populations, such as mycorrhizal fungi or alter microbial community composition. Overall, biochar can positively or negatively modulate soil microbiota, with effects depending on its character-istics, application rate and soil context.

Conclusions and Future Perspectives: Biochar is a versatile soil amendment that enhances soil health, nutrient availability, water retention and microbial activity, ultimately improving crop growth and yields. Its effectiveness depends on feedstock type, pyrolysis conditions and application strategies. While current studies highlight its benefits, further

research is needed to optimize production methods, evaluate long-term field effects and explore synergies with other sustainable farming practices. Integrating biochar into agricultural systems offers a promising approach for improving soil management, boosting productivity and promoting environmental sustainability, making it a key tool for future resilient and sustainable agriculture.

Natural Farming: A Way to Protect Land and Health

Shivangi J. Vanapariya and Kuldeep M. Akbari

Natural farming is an agricultural method in which crops are grown without the use of artificial chemical fertilizers, toxic pesticides, or genetically modified seeds. This method works in harmony with the laws of nature and preserves the energy of the soil as well as the natural growth of crops. The main goal of this approach is to carry out farming while maintaining soil health, conserving water, and protecting biodiversity. In natural farming, farmers use natural substances like cow urine, jaggery, milk, curd, cow dung, etc., as fertilizers and pesticides. This method helps preserve soil fertility and living organisms, creating a suitable environment for farming without disturbing the natural ecosystem. Popularized by Subhash Palekar, this method is becoming increasingly popular across the country today.

Main Elements of Natural Farming

Jeevamrut (Natural Microbial Tonic)

Jeevamrut is a natural solution used to enhance microbial activity in the soil. The word "Jeevamrut" comes from *Jeev* (life/microbes) + *Amrut* (nectar/nutrients), meaning a beneficial organic liquid fertilizer for the soil. Jeevamrut feeds the helpful microbes already present in the soil, which in turn improves soil fertility and provides essential nutrients to the crops. It also helps to boost the plants' resistance to diseases.

Generally, the following ingredients are used:

Cow dung (from native Indian cow)	10 kg
Cow urine	10 Liters
Jaggery	1 kg
Pulse flour (such as gram flour)	1 kg
Handful of fertile soil (from topsoil or bunds)	1 handful
Water	200 Liters

Method of Preparation

- ✓ Take a large drum or plastic/cement tank and fill it with 200 Liters of water.
- ✓ Add 10 kg of cow dung and 10 Liters of cow urine into it, and mix thoroughly.
- ✓ Add 1 kg of jaggery and 1 kg of pulse flour (e.g., gram flour).
- ✓ Add a handful of fertile soil taken from your field or from the bunds this soil contains beneficial natural microbes.
- ✓ Cover the tank with a cotton or muslin cloth to prevent debris from falling in, but ensure there is still some airflow.
- ✓ Stir the mixture twice daily (morning and evening) in a clockwise direction for 4 to 7 days.
- ✓ After 4 to 7 days, the mixture will be ready. It can then be applied to crops as a highly effective

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organic input.

Bijamrut

Bijamrut is a natural seed treatment solution used to purify and protect seeds from fungi, bacteria, and other diseases. It is prepared using cow dung, cow urine, a little lime (slaked lime) and soil. Before sowing, the seeds are soaked in this solution for 15 to 30 minutes. After soaking, the seeds are dried in the shade and then sown. This method promotes healthy germination and strengthens crop health.

Generally, the following ingredients are used (for 100 kg of seeds):

Fresh dung of indigenous cow	5 kg
Fresh urine of indigenous cow	5 Liters
Slaked lime	50 grams
Soil from the base of healthy plants or trees	200 grams
Clean water	20 Liters

Method of Preparation

- ✓ Take an earthen or plastic container (not an iron or metal one).
- ✓ Pour 20 Liters of clean water into the container.
- ✓ Add 5 kg of fresh cow dung and 5 Liters of fresh cow urine, and mix thoroughly.
- ✓ Add 200 grams of soil from the root zone of healthy plants or trees (this soil is rich in beneficial microorganisms).
- ✓ Soak 50 grams of slaked lime in a little water and then add it to the mixture.
- ✓ Stir the solution with a wooden stick twice a day (once in the morning and once in the evening).
- ✓ Cover the container and keep it in the shade for 24 hours.
- ✓ After 24 hours, the solution is ready. Soak the seeds in it for 30 minutes before sowing, then dry them in the shade and proceed with sowing. (Use the solution while it is fresh.)

Mulching

Mulching means covering the soil with natural materials like grass, dry leaves, decomposed plant residues, coconut husks, etc. This method helps retain moisture in the soil, reduces the need for pesticides, and promotes the development of beneficial microorganisms. Mulching helps regulate soil temperature and prevents erosion (soil being blown away). Mulch provides a habitat for soil micro-organisms, which increases soil surface fertility.

Wapsa Irrigation Method

Wapsa irrigation is a natural method aimed at conserving water and maintaining moisture in the soil. According to this method, crops are given only as much water as they need. Excessive watering can wash away essential nutrients from the soil and damage its structure. In Wapsa irrigation, crops receive adequate nourishment with minimal water. Examples of this method include drip irrigation, sprinkler irrigation, or occasional watering from a well.

This technique is especially effective in areas facing water scarcity.

Benefits of Natural Farming

- ✓ Without the use of chemical fertilizers, the soil retains its natural microorganisms, earthworms, and biodiversity, which helps maintain soil fertility (productivity).
- ✓ This method allows farming with less irrigation.

Due to mulching and soil conservation, moisture is retained for a longer time, leading to water savings.

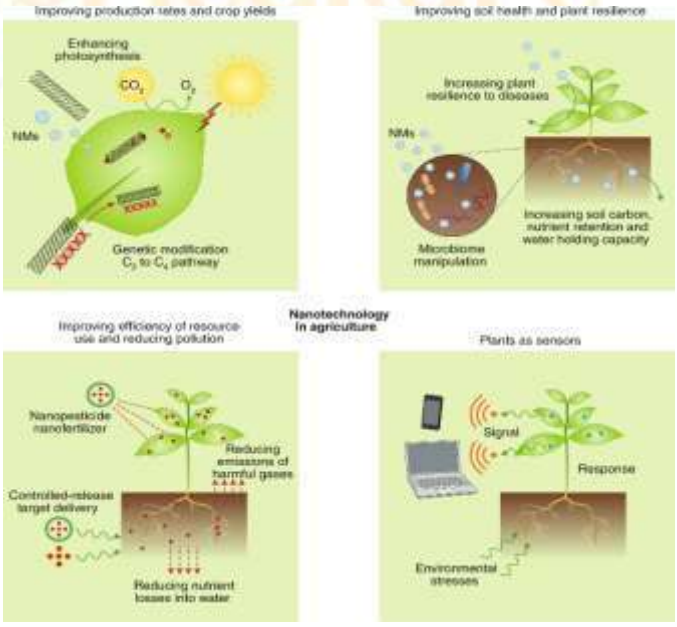
- ✓ Since there is no need to buy chemical fertilizers, pesticides, or expensive seeds, the overall cost of farming is reduced.
- ✓ The produce is free from harmful chemicals, making it safe for human health and rich in nutrition.
- ✓ Natural elements like soil, water, and air remain free from pollution, as no chemical substances are used thus helping in environmental protection.
- ✓ Farmers prepare their own fertilizers, pesticides, and seeds at home, which increases self-reliance in agriculture.
- ✓ Once the soil is prepared for natural farming, it consistently yields high-quality and healthy crops over time.

Nanobiotechnology in Sericulture: Smart Nano-Inputs for Healthier Mulberry Leaves

Gali Suresh and Basant Kumar Dadrwal

Sericulture and Mulberry Nutrition: The Critical Link to Silk Productivity

Sericulture, an agro-based industry with deep cultural and economic roots in Asia, depends fundamentally on the quality of mulberry leaves fed to the domesticated silkworm (*Bombyx mori*). In India alone, over 9 lakh families depend on sericulture for their livelihood, highlighting its socio-economic importance in rural development (Kumar *et al*., 2022). Unlike most agricultural crops, mulberry cultivation has a unique end use. Its leaves serve as the sole food source for silkworms, directly influencing cocoon yield, silk quality, and the profitability of sericulture. Mulberry leaves are rich in proteins, carbohydrates, vitamins, and essential minerals, making them a nutritional blueprint for silk synthesis. The digestibility and biochemical composition of leaves regulate larval growth rate, cocoon weight, and ultimately the length, fineness, and strength of silk filaments (Ramesh *et al*., 2020). For instance, nitrogen-rich leaves promote higher silk gland development, while deficiencies in micronutrients like zinc or iron reduce silk yield and quality (Lakshmi *et al*., 2018). Thus, leaf quality serves as the bridge between mulberry agronomy and sericulture economics. However, mulberry cultivation faces multiple constraints that compromise leaf quality. Heavy dependence on conventional fertilizers often leads to nutrient leaching, soil degradation, and reduced nutrient-use efficiency (Singh and Chauhan, 2019). Pest infestations, diseases, and indiscriminate pesticide use further threaten both leaf productivity and silkworm health. Additionally, climate stressors such as salinity, drought, and rising temperatures are increasingly limiting mulberry physiology, leading to decreased photosynthesis, altered leaf chemistry, and lower silk productivity (Zhou *et al*., 2021).



(Zhang *et al*., 2021)

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These challenges underscore the urgent need for innovative strategies to improve mulberry nutrition and enhance stress tolerance. Among the emerging solutions, nanobiotechnology through smart nanofertilizers, nanopesticides, and engineered nano-biochar holds promise to reshape mulberry cultivation. By improving nutrient delivery, reducing agrochemical loads, and supporting soil health, nanotechnology-driven approaches can help ensure a sustainable future for sericulture (Dubey *et al*., 2023).

Nanobiotechnology: A Green Revolution for Mulberry Cultivation

Nanobiotechnology, the convergence of nanotechnology and biological sciences, is increasingly recognized as a transformative approach for agriculture. At the nanoscale (1-100 nm), materials exhibit unique physicochemical properties such as high surface-to-volume ratio, enhanced reactivity, and controlled release capabilities that make them highly effective in nutrient delivery, crop protection, and stress mitigation (Kah *et al*., 2019). In the context of mulberry cultivation, where leaf quality directly dictates silk yield, nanobiotechnology provides targeted and eco-friendly tools to overcome traditional limitations of fertilizer and pesticide use. Smart nanofertilizers, nanopesticides, and nano-biochar represent three major domains where these innovations can be applied. Smart nanofertilizers enable gradual and sustained nutrient release, thereby reducing wastage and enhancing nutrient-use efficiency. Nanopesticides improve the stability and bioavailability of active ingredients, ensuring better pest and disease control at significantly lower doses (Parisi *et al*., 2015). Nano-biochar, engineered from agricultural residues, enhances soil fertility and stress tolerance by modulating nutrient cycling, water retention, and microbial activity (Mishra *et al*., 2022). The potential of nanobiotechnology in sericulture is not limited to crop improvement but extends to holistic system sustainability. For instance, reduced agrochemical inputs lower environmental contamination, while improved nutrient uptake enhances leaf protein and carbohydrate content factors directly linked to silkworm growth and cocoon yield (Ramesh *et al*., 2020). Moreover, these nano-enabled interventions align with precision sericulture, where resource efficiency and environmental safety are as important as silk quality. Thus, nanobiotechnology offers a "green revolution" for mulberry cultivation, enabling enhanced productivity, improved stress tolerance, and sustainable sericulture practices. The subsequent sections explore the specific applications of nanofertilizers, nanopesticides, and nano-biochar in improving mulberry nutrition and resilience.

Smart Nanofertilizers: Precision Feeding for Mulberry

Nutrient management is one of the most crucial determinants of mulberry leaf quality, and thereby the quantity and quality of silk. Conventional fertilizers, though widely used, suffer from significant inefficiencies often less than 40% of applied nitrogen, 20% of phosphorus, and 30% of

potassium are actually utilized by plants, with the rest lost to leaching, volatilization, or runoff (Subramanian *et al*., 2015). Such losses not only reduce crop productivity but also degrade soil and water ecosystems. In sericulture, where the protein and carbohydrate content of mulberry leaves directly influence silk gland development, these inefficiencies translate into reduced cocoon yield and inferior silk quality (Lakshmi *et al*., 2018).

Smart nanofertilizers offer a revolutionary solution by enabling controlled, site-specific, and sustained nutrient release. Nanoparticles, due to their high surface area and reactivity, can encapsulate essential nutrients and release them gradually in sync with plant uptake, thereby minimizing losses and maximizing efficiency (Kah *et al*., 2019). For mulberry, nano-encapsulated nitrogen, phosphorus, and micronutrients such as zinc, boron, and iron have shown promise in enhancing chlorophyll biosynthesis, boosting leaf protein content, and improving digestibility for silkworms (Prasad *et al*., 2017). For example, studies have demonstrated that the application of nano-urea can increase nitrogen-use efficiency by up to 30% while reducing application rates, resulting in greener, protein-rich mulberry leaves (Choudhary *et al*., 2021). Similarly, zinc oxide nanoparticles improve enzymatic activity in leaves, contributing to higher leaf vigor and better silkworm growth performance (Ramesh *et al*., 2020). These improvements directly correlate with heavier cocoons, longer filament length, and improved silk strength, highlighting the value of nanofertilizers in sericulture. Beyond productivity, nanofertilizers also offer environmental advantages. By reducing over-application and nutrient losses, they lower the risk of groundwater contamination and greenhouse gas emissions, aligning mulberry cultivation with sustainable agricultural practices (Mishra *et al*., 2022). Thus, nanofertilizers represent a precision feeding strategy for mulberry, ensuring higher silk yield with reduced ecological footprint.

Nanopesticides: Shielding Mulberry against Pests and Diseases

Mulberry cultivation is frequently threatened by insect pests and foliar diseases that compromise both leaf yield and nutritional quality, ultimately affecting silkworm growth and silk production. Common pests such as *Diaphania pulverulentalis* (leaf roller), *Glyphodes pyloalis* (leaf webworm), and mites, along with fungal diseases like powdery mildew and leaf spot, cause significant yield losses (Rahmathulla, 2012). Conventional pesticides, though effective, present two major problems:

- ✓ Overuse leads to pesticide residues that are toxic to silkworms, disrupting their growth and cocoon formation.
- ✓ Environmental risks, including soil contamination, pest resistance, and harm to beneficial organisms.

Nanopesticides represent a novel alternative that enhances pest control while reducing ecological and silkworm-related risks. These formulations involve nano-encapsulation or nanoemulsions of active ingredients, which improve pesticide solubili-

ty, stability, and bioavailability (Kah *et al*., 2019). Due to their small size and controlled release, nanopesticides ensure precise targeting of pests and pathogens at lower doses, minimizing off-target effects.

For instance, chitosan-based nanoparticles loaded with fungicides have shown effectiveness against mulberry powdery mildew, while also enhancing plant defense responses (Patil *et al*., 2021). Similarly, silver and zinc oxide nanoparticles have demonstrated broad-spectrum antimicrobial activity against mulberry leaf pathogens, reducing leaf damage and preserving nutritional value (Reddy *et al*., 2020). Importantly, the biodegradable carriers used in many nanopesticide formulations reduce toxicity risks for silkworms, ensuring safer integration into sericulture systems. Another promising frontier is RNAi-based nanopesticides, where double-stranded RNA molecules targeting pest genes are delivered using nanocarriers. Such approaches can provide species-specific pest control, minimizing collateral damage to non-target organisms (Zhang *et al*., 2021). For sericulture, this precision strategy could revolutionize pest management by protecting mulberry leaves without harming silkworms or beneficial soil microbes. Thus, nanopesticides present a dual advantage for mulberry growers: effective and long-lasting protection against pests and diseases, coupled with safety for silkworms and the environment. By replacing hazardous chemical pesticides with nano-enabled formulations, sericulture can move toward a more sustainable and eco-friendly future.

Nano-Biochar: Stress Tolerance and Soil Health Booster

Soil health and abiotic stress management are central to sustaining mulberry productivity, as the crop is often exposed to salinity, drought, heavy metal toxicity, and declining soil fertility. These stresses not only reduce leaf yield but also alter biochemical composition, leading to poor silkworm growth and reduced silk quality (Zhou *et al*., 2021). Traditional amendments such as organic manure and bulk biochar improve soil fertility, but their effectiveness is limited by low reactivity and slow nutrient release. Nano-biochar, a finely engineered form of biochar with particle sizes in the nanometer range, offers unique physicochemical properties large surface area, high porosity, and strong adsorption capacity that make it far more effective than conventional biochar (Mishra *et al*., 2022). Its nano-scale properties enable it to interact dynamically with soil nutrients, water, and microbial communities, thereby creating a more favorable environment for mulberry growth. One of the most promising applications of nano-biochar is in mitigating abiotic stress. By improving water retention and regulating ion exchange, it enhances mulberry tolerance to drought and salinity (Sun *et al*., 2020). Nano-biochar also immobilizes heavy metals such as cadmium and lead in contaminated soils, reducing their bioavailability and preventing their entry into mulberry leaves is a crucial factor since heavy metals can adversely affect silkworm meta-

bolism and cocoon formation (Wang *et al*., 2021). Moreover, nano-biochar fosters soil microbial diversity and enzymatic activity, which contribute to nutrient cycling and organic matter stabilization. This microbial enrichment not only enhances soil fertility but also improves nitrogen and phosphorus uptake efficiency in mulberry, leading to protein-rich leaves that support higher silk yield (Choudhary *et al*., 2021). In sericulture systems, where leaf quality is paramount, nano-biochar thus serves as a dual-purpose soil amendment improving stress resilience while simultaneously boosting soil fertility and leaf nutrition. Its integration with smart nanofertilizers and nanopesticides creates a holistic nanobiotechnology toolkit for sustainable mulberry cultivation.

Integrating Nanobiotechnology in Sericulture: Opportunities and Challenges

The integration of smart nanofertilizers, nanopesticides, and nano-biochar represents a holistic strategy to transform mulberry cultivation and enhance silk production. Each intervention addresses a critical dimension of sericulture: nanofertilizers improve leaf nutrition, nanopesticides protect against biotic stress, and nano-biochar mitigates abiotic stress while restoring soil health. When combined, they create a synergistic nanobiotechnology toolkit capable of ensuring higher mulberry productivity, improved leaf quality, and sustainable cocoon yields. Opportunities are particularly significant in the context of precision sericulture. Nano-enabled inputs can reduce dependency on bulk agrochemicals, minimize production costs in the long run, and improve eco-efficiency (Kah *et al*., 2019). For farmers, this means healthier mulberry plantations with protein- and carbohydrate-rich leaves, leading to faster silkworm growth, heavier cocoons, and superior silk fiber quality (Ramesh *et al*., 2020). At the industry level, widespread adoption of nanobiotechnology could contribute to India's and other silk-producing countries' goals of achieving higher silk output with reduced ecological footprint.

However, several challenges and limitations must be acknowledged before large-scale adoption.

Cost and accessibility: Nano-formulations are often more expensive than conventional inputs, which may limit their adoption among smallholder sericulture farmers.

Scalability and standardization: Field-level data on nano-inputs in mulberry cultivation remain limited, and results vary depending on soil type, climate, and crop management practices (Parisi *et al*., 2015).

Regulatory and biosafety concerns: The long-term impacts of nanoparticles on soil microbes, silkworm physiology, and human health through occupational exposure are still under investigation (Fraceto *et al*., 2016).

Farmer awareness: Effective utilization requires training and awareness among farmers to avoid misuse or over-application.

Therefore, while nanobiotechnology offers tremendous promise for reshaping sericulture into a smart and sustainable enterprise, its success depends

on policy support, farmer training, risk assessment studies, and collaborative research. Integrating these technologies with existing organic and eco-friendly sericulture practices will be essential to ensure safety and public acceptance.

Future Perspectives: Toward Smart and Sustainable Silk Production

The future of sericulture lies in integrating nanobiotechnology with precision farming tools to create a resilient and eco-friendly silk industry. Smart nanofertilizers, nanopesticides, and nano-biochar, when combined with digital technologies such as IoT-based soil monitoring and remote sensing, can optimize mulberry leaf quality while minimizing resource use. Such integration promises higher silk yield, better fiber quality, and reduced ecological footprint, aligning with global goals of sustainable agriculture. However, success will depend on multi-stakeholder collaboration among researchers, policymakers, and farmers to ensure affordability, biosafety, and large-scale adoption. Ultimately, nanobiotechnology offers a pathway to a smart sericulture system, where innovation and tradition converge for sustainable silk production.

Conclusion

Nanobiotechnology offers a transformative opportunity for sericulture, addressing the core challenge of improving mulberry leaf nutrition while reducing environmental stress. Smart nanofertilizers, nanopesticides, and nano-biochar together form a sustainable toolkit to enhance leaf quality, silkworm growth, and silk yield. While challenges such as cost, biosafety, and farmer awareness remain, the integration of these nano-enabled solutions with eco-friendly practices can reshape sericulture into a smart, resilient, and sustainable industry. By bridging science and tradition, nanobiotechnology paves the way for a future-ready silk sector that benefits farmers, consumers, and the environment alike.

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Urban Rooftop Agriculture: Promoting Health and Well-being through Fresh Produce

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Abstract

Rooftops are often overlooked in urban areas, but they have great potential for urban gardening. In many large cities and towns, there's not enough space for kitchen gardening because of rapid urbanization, industrialization, land limitations, building construction, wide roads, offices and marketplaces. Agriculture has been pushed out of cities, leading to concerns about human health due to pesticide residues on vegetables caused by changing climate conditions. This is where rooftop gardens come in. They have become increasingly popular in recent years, especially in larger and more developed cities.

Introduction

Rooftop gardening, also known as rooftop farming or green roofs, is a sustainable practice that entails growing plants on building rooftops. Vegetable can be successfully grown in the available space on rooftop, whether it's the roof itself, a porch, terrace, or balcony. A well-planned rooftop can help fulfil food demand by providing fresh and healthy food and reduce family expenses on vegetables. Furthermore, it saves money for communities by storing runoff, produces a healthier environment by increasing air quality and absorbing carbon from the air and reduces the impact of climate change. Engaging in rooftop garden maintenance encourages healthy habits by reducing stress and promoting relaxation. Rooftop farming also decreases the temperature of the roof and the surrounding air, leading to a more suitable microenvironment and decreasing the urban heat island effect. Furthermore, roof farms absorb carbon emissions and reduce environmental noise. Capturing rainwater and allowing it to be absorbed by plants reduces the overflow impact on infrastructure. Vegetated rooftops provide a pleasant space for relaxation and enjoyment. This type of farming might provide opportunity for employment of people. The farming on rooftops also increases biodiversity and provides habitats for a various insects and birds, contributing to urban ecological balance.

Points to be considered before planning a rooftop vegetable garden

Evaluation of a rooftop's suitability: Assess the

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building's structural soundness and ensure the roof is capable of supporting the load. The growing media and containers can be quite heavy, and the weight increases as the plants grow.

Roof drainage and waterproofing: Established effective strategies for removing additional water from irrigation systems and rainfall. The framework of the roof where you wish to grow your greens must be solid, frost-resistant, and waterproof, especially in the areas where you are going to establish and put the containers. The roof can be made waterproof by applying waterproof polymer coatings. The rooftop waterproofing membrane should be resistant to decay and roots.

Sunlight exposure: Sunlight is essential for successful growing of vegetables. The location should receive at least six to eight hours of sunlight daily. The amount of sunshine available determines which types of vegetables can be grown in roof gardens.

Access to the roof: This is a crucial factor to take into consideration. Typically, access entails steps, and there must be adequate room for moving building and maintenance supplies.

Water availability for irrigation: When plants need frequent watering, consider investing in controlled irrigation systems or drip irrigation. To water rooftop plants, a low-pressure drip irrigation system should be better.

Benefits of rooftop vegetable garden

Terrace gardens enable locally produced, healthy vegetables, enhancing food security and reducing the need for long-distance travel. They help people living in cities to grow vegetables that are nutritious, creating a connection with nature and sustainable food systems.

- ✓ A rooftop garden provides a cool micro-environment in the residence, reducing temperatures. It also provides a green environment.
- ✓ It benefits the ecology and helps retain rainwater.
- ✓ A rooftop garden is an excellent use of vacant space. They also bring aesthetic enjoyment.
- ✓ Creating a comfortable and calm area with minimal time and money can improve mood and detach from the outside world.
- ✓ Plants in rooftop gardens filter and absorb pollutants from the atmosphere, enhancing metropolitan air quality. Plants create oxygen while absorbing carbon dioxide, resulting in cleaner, healthier air.
- ✓ Rooftop gardens promote social interaction and community involvement. They serve as social hubs, educational platforms, and facilitators of community engagement and power.

The above advantages emphasize the significance of rooftop gardening as a sustainable urban practice that improves resource efficiency, community well-being, and environmental resilience.

Challenges in rooftop vegetable garden

Rooftop gardening provides numerous benefits, but there are certain obstacles that must be overcome before it can be done effectively. Understanding and conquering these obstacles is critical to the long-term success of rooftop gardening

in urban locations. Rooftop gardening faces several main problems, including:

Structure limitation: Rooftops are capable of holding a specific weight of garden infrastructure, which includes soil, plants, containers, and water, and must be carefully evaluated. Structural investigations and reinforcements may be required to keep the structure stable and secure.

Maintenance requirements: Rooftop gardens require frequent maintenance, including irrigation, fertilization, trimming, pest control, and soil management. Access to the rooftop, particularly in multi-story complexes, may pose logistical issues for maintenance work.

Resource limitations: Rooftop gardens usually face problems with supply of water and fertility of the soil. Proper irrigation systems are required to ensure the effective utilisation of water. To increase the availability of nutrients and encourage plant growth, appropriate soil amendments or organic matter may be required.

Environmental conditions: Rooftops can be susceptible to a range of harsh weather conditions, such as strong winds, low temperatures, and direct sunlight. Rooftop gardens require careful selection of plant types and varieties that can withstand these kinds of conditions.

Types of rooftop vegetable garden

Container gardening: With only minor modifications to the current roof structure, container gardening is a highly adaptable and less costly type of gardening that works particularly well in urban environments. Container gardening involves setting up pots with growing media and plants on a rooftop. A wide range of items, including waste sinks, plastic pots, earthen pots, grow bags, and iron frames made from discarded iron pipes, can be used to construct containers. Gardening in containers is very helpful for those who lack the resources or motivation to alter the roof's structural components. Another benefit of containers is that they give soil and roots the depth and room they need, which large-scale green roof systems find challenging to provide.

Rooftop hydroponics: In this type of rooftop garden, plants are raised without the need for soil. Using a substrate other than soil, such as peat, coconut coir, perlite, or vermiculite, is known as hydroponic growing. Water is applied to the plants using a low-pressure drip irrigation system, and water-soluble fertilizer mixtures are used to supply nutrients. This method is the lightest and might enable quicker plant development and greater yields.

Selection of growing media for rooftop vegetable garden

In selecting a growing medium for a rooftop garden, examine the average summer rainfall, the average high and low temperatures during the growing season, and the species of plants to be cultivated and their requirements. To minimize the effects of drought on crops in a dry area, employ a water-retaining growth medium. During the last few years, the performance of growth media on rooftops has been examined in various cities, particularly green roofs. It was established that the most import-

Table 1: Season wise vegetables for rooftop vegetable garden

Vegetable	Season - North India	Season - South India	Germination temp. (in °C)	Sowing method	Days to maturity
Brinjal	Feb-Mar, May-June, Oct	Jan-Feb, Oct	21-27	Nursery of 25-30 days & transplanting of seedling	100-110 days
Pumpkin	Jan-Mar	Jun-Jul	20-35	Direct seeded	70-75 days
	Sept-Dec	Dec-Jan			
	May-Jun				
Cucumber	Feb-Mar, Jun	Jun-Jul	16-32	Direct seeded	50-70 days
	Jul	Sept-Oct			
		Dec-Jan			
Beans	Feb-Mar	Jan-Mar	16-30	Direct seeded	45-50 days
Apple Gourd	Feb-Mar	Feb-Mar	20-30	Direct seeded	70-80 days
	Jun-Jul	Jun-Jul			
Bitter Gourd	Feb-Mar	Nov-Dec	20-30	Direct seeded	55-60 days
	Jun-Jul	Dec-Jan			
		Jun-Jul			
Bottle Gourd	Feb-Mar	Nov-Dec	20-30	Direct seeded	55-60 days
	Jun-Jul	Dec-Jan			
		Jun-Jul			
Broccoli	Aug-Sept	Aug-Sept	21-23	Nursery of 25-30 days & transplanting of seedling	90-100 days
Cabbage	Sept-Oct	Jun-Jul,	10-20	Nursery of 25-30 days &	90-100 days
		Oct-Nov		Transplanting of seedling	
Beetroot	Oct-Nov	Aug-Nov	10-30	Direct seeded	80-90 days
Capsicum	Nov-Jan	Jan-Feb	15-25	Nursery of 25-30 days &	95-100 days
	May-Jun	May-Jun		Transplanting of seedling	
		Oct-Nov			
Carrot	Aug-Sept-Oct	Aug-Nov	10-30	Direct seeded	75-80 days
Lettuce	Sept-Oct	Oct-Dec	7-27	Direct/Transplant	45-55 days
Okra	Feb-Mar	Jan-Feb	20-32	Direct seeded	50-60 days
	Jun-Jul	May-Jun			
		Oct-Dec			
Onion	May-Jun	Mar-Apr	10-32	Transplant	150-160 days
		May-Jun & Sept-Oct			
Peas	Sept-Oct-Nov	Sept-Oct-Nov	10-22	Direct seeded	55-60 days
Radish	Aug-Jan	Sept-Nov	10-30	Direct seeded	40-45 days
Spinach	Sept-Nov	Sept-Oct-Nov	10-22	Direct seeded	60 days
	Feb				
Tomato	Jun-Aug	Jan-Feb	20-30	Nursery of 25-30 days &	110-115 days
	Nov-Dec	Jun-Jul & Oct-Nov		transplanting of seedling	
Turnip	Oct-Nov	Oct-Nov	15-35	Direct seeded	40-50 days
Cauliflower	Mid-June	Jun-Jul	25-27	Nursery of 25-30 days &	120-125 days
(Early)		Aug-Sept		Transplanting of seedling	
Cauliflower	Aug-Sept-Oct	Jun-Jul	16-20	Nursery of 25-30 days &	120-125 days
(Late)				Transplanting of seedling	
Cauliflower	Sept-Oct	Jun-Jul	<16	Nursery of 25-30 days &	120-125 days
(Mid-season)		Aug-Sept		Transplanting of seedling	

(Source: India Horticulture Magazine, September- October, 2021)

ant physical quality for growing media is good drainage. This is a significant difficulty for a growing medium because it must provide both efficient drainage and water retention. The ideal growing medium should have the following properties:

- ✓ Effective drainage and aeration system.
- ✓ Provides adequate water retention (without becoming clogged or heavy).
- ✓ High cation exchange capability.
- ✓ Resistance to disintegration and biodegradation.
- ✓ Lightweight, yet strong (resistant to shrinkage and wind displacement).

(A) View of terrace garden with low pressure drip irrigation system (B) Growing of tomato in grow bag (C) Growing of chili in discarded sink (D) Fruiting in zucchini plants

Planning a rooftop vegetable garden

Design: The first and most crucial stage in creating a terrace garden is designing the rooftop garden's plan. To cultivate plants, one can either use pots or cover the entire area with soil. To establish a garden, use iron frames, plastic sheets, grow bags, waste sinks, and plastic or earthen pots. Based on the site's capabilities and limitations, as well as your preferences, requirements, and financial constraints, create an aesthetically pleasing and effective growth plan.

Plant selection: A variety of vegetables can be cultivated in a terrace garden, depending on the available area (Table 1). Consider including vegetables, medicinal, and herbal plants in the garden. A healthy and varied diet is guaranteed when the plants in the yard are diverse, as each item has unique qualities, allowing access to a greater number of essential nutrients.

Preparing the media: The soil should be nutrient-rich, with adequate moisture and minerals. Fresh soil from an agricultural farm, coupled with organic manure and vermicompost, performs well. Old or natural manure are the most effective way to prepare the soil for gardening because they give virtually all of the nutrients required by plants. Nurseries provide soil combinations for home gardening. To provide optimum water retention and drainage in pots and containers, potting soil contains peat moss, vermiculite, perlite, and compost. Home gardeners also choose coco peat because it improves water retention, aerates roots, and protects plants from soil fungus. Lightweight combinations that are free of artificial fertilizers are desirable. Vermicompost is good manures for providing nutrients and maintaining sufficient aeration in the medium.

Planting: Vegetable seeds such as lady fingers, cluster beans, bitter gourds, bottle gourds, coriander, and radish are sown directly into the growth medium. Vegetable seedlings such as brinjal, tomatoes, chilies, zucchini, cabbage, cauliflower, and capsicum need to be nurtured in pots before being moved into polybags. It takes 25 to 30 days for these seeds to become transplant-ready in the field.

Handling: Organic fertilizers and pest management measures are feasible choices. To address pest issues, certain organic insecticides can be mixed with the soil. Bavistin can be used to control fungal infections in plants. A spray made from distilled water mixed

with ginger, garlic, and chili paste works wonders for controlling pests.

Government initiatives to promote rooftop vegetable gardens

Certain state governments are providing 50% subsidies on seeds, fertilizers, and farming equipment as part of the Rashtriya Krishi Vikas initiative and smart city development. A 50% subsidy is available to homeowners who have at least 50 to 300 square feet of space in their garden or balcony. The horticultural and gardening activities carried out on rooftops will contribute to partially restoring climate balance and improving environmental conditions. The following essential skills are intended to be developed in learners through the rooftop gardener training curriculum offered by the Agriculture Skill Council of India (ASCI):

- ✓ Create and implement a rooftop garden in accordance with the provided guidelines.
- ✓ Cultivate and maintain plants in a rooftop garden.
- ✓ Utilize and care for equipment, containers, and gardening tools.
- ✓ Monitor plants, recognize possible harm from insects, pests, and diseases, and figure out how to handle them.
- ✓ Practice health and safety at work: be knowledgeable about procedures for protecting oneself and others, as well as understanding the dangers and precautions involved in planning and executing gardening tasks.

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Quality Seed is the Key to Better Pulse Production in India

Amit Kumar and Shubham Kumawat

Introduction

Pulses are the backbone of India's nutrition security and rural economy. They are an essential source of protein especially for low-income and vegetarian households. Beyond nutrition, pulses shape the income and resilience of India's marginal and small farmers, who constitute over 80% of pulse producers. The majority of pulse cultivation is in rainfed regions and is characterized by low input costs, making pulses critical for farm sustainability, risk spreading, and climate adaptation (Economic Survey 2024-25; State of Marginal Farmers Report, 2024; Yadav *et al*., 2025). Despite India being the world's largest producer, consumer, and importer of pulses, the country faces recurring shortages, with FY24 imports jumping 84% to a six-year high due to poor domestic yields (Drishti IAS, 2024). The main challenges are low productivity, erratic yields, and poor quality much of which can be traced to seed quality and the slow adoption of improved varieties.

Quality Seed: The Game Changer

A central reason for suboptimal yields is the widespread use of farm saved seed, which often lacks purity, vigor, and adaptation to current biotic and abiotic stresses. Despite major advances in breeding, seed replacement rates (SRR) remain extremely low, often below 25% for major pulses like chickpea, urdbean, and moongbean (DA&FW, 2024). In the result; poor crop emergence, greater susceptibility to disease and limited yield response to good management.

Research has shown that adoption of quality certified or pure seed alone can boost pulse productivity by 20-25%, and even 45-50% with good agronomy (Kandir *et al.*, 2022). Few crop examples include:

Chickpea: National Food Security Mission (NFSM) districts using improved seed varieties reported yield gains of 30% over local seed, with Madhya Pradesh and Rajasthan leading the surge (Varma, 2023).

Moongbean/Urdbean: States like Uttar Pradesh and Maharashtra that demonstrated seed hub and minikit distribution saw field-level yield improvements of 20-30% (DA&FW, 2024).

Soybean: Quality seed adoption (regional/ recommended variety) in Madhya Pradesh has helped stabilize both yields and production, despite recent weather shocks (USDA FAS, 2025).

Benefits of Using Improved Quality Seed over Farm Saved Seed in Pulses

Higher and more stable yields: Improved varietal seeds produce robust stands, higher pod set, and

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better recovery from weather and pest/disease stresses.

Uniform Maturity: Pure seed lots mature together, simplifying harvest and reducing losses.

Disease and Pest Resistance: Modern varieties are bred for specific resistance traits, reducing spray costs and supporting sustainable Integrated Pest Management (IPM).

Adaptation and Resilience: Quality regionally recommended varieties offer better performance under drought or extreme weather, which is essential for rainfed systems.

Better Profitability: Higher yield and quality mean better prices and profits, especially for small and marginal farmers who benefit most from small gains in productivity.

Input Efficiency: Good seed enables optimal response to fertilizer, water, and agronomic inputs, making best use of resources.

The Way Forward

For India to become self-reliant in pulses and improve the incomes of its smallholders, a national push to increase seed replacement, promote locally adapted improved varieties, and expand certified seed systems is vital. Farmers should be empowered and educated about the specific varieties best suited for their region, and programs should ensure timely and affordable access to these seeds.

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Declining Soybean Acreage and Production in Madhya Pradesh: Problems and Contributing Factors

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Introduction

Soybean (*Glycine max*) is a key oilseed crop in India and plays a vital role in the economy of Madhya Pradesh (MP), which is the leading soybean-producing state in the country (Fig. 1). The state contributes nearly 41 % of India's total soybean production, making it an agricultural backbone for many farmers in the region. However, in recent years, the acreage under soybean cultivation and its overall production in Madhya Pradesh have shown a declining trend (Fig. 2). This decline has raised serious concerns among policymakers, researchers, and farmers alike, given the crop's importance for edible oil self-sufficiency, livelihoods, and rural economies in the state.

Fig. 1: Soybean Production in Madhya Pradesh in last 20 years (Sources: https://sopa.org)

This article explores the various reasons behind the shrinking soybean area and yield in Madhya Pradesh, analyzing economic, biotic, climatic, technological, and socio-political factors that have collectively led to this downturn.

Drawing insights from recent research papers, government reports, and farmer experiences, the article aims to provide a comprehensive understanding of these challenges and suggests potential remedies for revival and sustainable growth (USDA FAS, 2025; Indian Government/SEA, 2025).

Fig 2: Madhya Pradesh share in total soybean production in India in last 20 years (Sources: https://sopa.org)

Key Factors Affecting Soybean Cultivation in Madhya Pradesh

Economic Constraints: One of the primary reasons for the decline in soybean cultivation is the unfavorable economic returns for farmers. The Minimum Support Price (MSP) offered by the government for soybean has traditionally been low compared to production costs and compared to alternative crops like maize for example satpura plateau of in south MP. This low MSP has resulted in limited government procurement under the Price Support Scheme (PSS), further weakening market confidence for soybean farmers.

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The benefit-cost ratio for soybean cultivation has become unattractive, especially when farmers find better profitability in crops such as maize or pulses. Rising input costs for seeds, fertilizers, pesticides, and labour have further squeezed margins. Many farmers report selling soybean produce at prices lower than MSP or even worse due to weak demand or lack of robust procurement infrastructure. Moreover, market volatility and delayed payments in local mandis discourage soybean farming. These economic deterrents have compelled farmers to reduce soybean acreage or switch to more remunerative crops, thereby shrinking the overall production base.

Biotic Stresses: Soybean fields in MP frequently endure significant pest and disease outbreaks, which remain severe due to both climate shifts and limited adoption of integrated management (Amrate *et al*., 2021; Ramlal *et al.,* 2024). These pest and disease pressures require increased investment in pest management practices. However, many small and marginal farmers lack access to timely and affordable plant protection measures, causing yield losses.

Climatic and Weather Challenges: Soybean in Madhya Pradesh is predominantly rainfed, relying heavily on monsoon rains. Erratic, uneven, and unpredictable rainfall patterns have become a major limiting factor. Frequent sudden rains during the harvesting period result in shattering losses (Nargund *et al.,* 2025). On the other hand, drought spells and dry conditions reduce sowing areas and affect crop establishment.

Rising temperature and climate variability have exacerbated water stress conditions. The lack of efficient irrigation infrastructure in many parts of the state further exposes crops to climatic uncertainty. These weather constraints have led to reduced soybean acreage as farmers shift to more drought-resilient or irrigated crops.

1. Technological Constraints

Although improved soybean varieties with better yields and pest resistance have been developed, their availability and adoption remain limited (Sharma, 2018). Factors affecting techno-logical progress include:

- ✓ Poor seed replacement rates with many farmers using saved or uncertified seed.
- ✓ Limited availability of early-maturing and climate-resilient varieties tailored to local agro-climatic zones.
- ✓ Lack of farmer awareness and access to modern agronomic techniques and integrated pest management.
- ✓ Insufficient extension services and delayed government interventions.
- ✓ Improving seed systems and promoting technology adoption could significantly enhance productivity and area stability.

2. Policy and Market Issues

Additional issues that impact soybean cultivation in Madhya Pradesh include:

- ✓ Fragmented landholdings and labor shortages due to urban migration.

- ✓ Limited crop insurance coverage leading to poor risk tolerance among farmers.
- ✓ Inefficient market linkages and supply chains.
- ✓ Policy uncertainties and lack of long-term roadmaps for oilseed promotion.

These systemic challenges need to be addressed through multi-stakeholder engagement involving government, research institutions, private sector, and farmer organizations.

Conclusion and Recommendations

To reverse declining area and productivity, a coordinated policy push is required:

- ✓ Improve procurement and MSP effectiveness.
- ✓ Strengthen pest and disease monitoring/control programs.
- ✓ Invest in irrigation and support adoption of climate-resilient technologies.
- ✓ Enhance extension capacity for seed and input access.
- ✓ Develop market and insurance support tailored to soy growers.
- ✓ Targeted action on these fronts, guided by ongoing research, is essential to revitalize soybean output and ensure both rural employment and the nation's edible oil security.

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Mitigation Strategies for Unexpected Rainfall during Soybean Sowing Period

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Introduction

Madhya Pradesh holds the distinction of being India's leading soybean-producing state, often referred to as the "Soybean State" due to its substantial contribution to the nation's total output. According to the Soybean Processors Association of India (SOPA), India produced approximately 12.5 million metric tons of soybean in 2024-25, with Madhya Pradesh accounting for a major share (SOPA, 2025). However, erratic and unpredictable rainfall patterns during the sowing period have become a significant challenge, resulting in reduced soybean acreage, poor establishment, and lower yields. This article reviews key problems and evidence-based mitigation strategies specific to soybean cultivation under such rainfall uncertainty.

Problems Caused by Unexpected Rainfall

Heavy or sudden rainfall during sowing floods fields, damages seeds, and impedes timely planting. Limited sunlight due to persistent cloud cover hampers seedling growth. Flooding decreases seed survival and promotes poor crop stands; subsequent rainfall further worsens these effects, leading to decreased productivity in areas like Malwa, Madhya Pradesh (Sharma and Singh, 2023).

Evidence-Based Mitigation Techniques for Soybean Cultivation

Field Preparation Methods

Raised Seed Beds and Ridges: Constructing raised beds 10-15 cm above the natural soil surface helps prevent waterlogging and seed rot. Raised ridges spaced 45-60 cm apart improve drainage and aeration, promoting root development and reducing loss due to excess moisture. On-farm trials have shown yield improvements of 10-15% under high rainfall using raised beds compared to traditional flat sowing (Meena *et al*., 2024; Shete *et al*., 2020; Hoppe *et al.*, 2017).

Proper Drainage Channels: Creating drainage channels (20-30 cm deep and wide) directs excess water away, limits fungal diseases, and enhances seedling survival.

Fig 1: Diagrammatic View of raised seed bed for soybean field View

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Soil Structure Management: Incorporating organic matter and deep ploughing improves soil porosity, water infiltration, and resilience against runoff.

Seed Treatment Techniques

Seed Pelleting: Pelleting involves coating seeds with clay, binders, or protective agents to regulate moisture uptake and ensure uniform sowing. Research demonstrates 10-12% higher germination rates in pelleted seeds under wet soil conditions due to gradual water absorption and stress protection (Rocha *et al.*, 2019; Siddaraju *et al.*, 2024).

Seed Coating with Fungicides/Bioagents: Treating seeds with fungicides (e.g., carbendazim, thiram) and biocontrol agents such as Trichoderma spp. increases resistance to fungal infections and improves survival rates by up to 20% under waterlogged conditions (Jarecki *et al.*, 2022; Siddaraju *et al.*, 2024).

Use of Moisture-Tolerant Varieties: Selecting soybean varieties with early maturity and moisture tolerance, when combined with proper seed treatments, enhances establishment under variable rainfall.

Enhanced Weather Forecasting and Advisory Services: Improved local weather forecasting and timely dissemination empower farmers to adjust sowing dates and adopt suitable mitigation strategies during predicted heavy rainfall events.

Conclusion

Erratic rainfall during the soybean sowing period represents a major threat to crop production in Madhya Pradesh and other important growing regions. Combining improved soil and field preparation, advanced seed treatments, and weather-based advisories provides a robust framework for enhancing the resilience of soybean cultivation. Adoption of these practices, supported by ongoing research and institutional advisories, is critical to safeguard farmer incomes and sustain India's vital role in global soybean production.

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Recycling Fire Extinguishing Powder: A New Source of Phosphorus for Agriculture

Shruthi G. S.

Introduction

Phosphorus is one among the essential macronutrient required for plant growth and development. It is essential for the plant's energy transmission through molecules like ATP (adenosine triphosphate), which powers a number of physiological functions. Phosphorus is vital for root growth, plant development, cell division, as well as crop health because it is an integral part of nucleic acids (DNA and RNA), cell membranes (phospho-lipids) and enzymes. Sufficient availability of phosphorus in farming enhances the quality and quantity of crop production, promotes root growth, increases flowering and seed production. Fertilizers are often applied to raise the level of phosphorus in soils as it often exists in forms that cannot be readily taken by plants. Proper management of phosphorus reduces environmental impacts such as runoff, which can pollute water, and optimizes nutrient uptake. Phosphorus is thus crucial for maintaining long-term agricultural productivity as well as for plant growth. Based on the increased demand pattern of phosphate rock extraction, phosphate rock deposits, which are estimated to be as vast as 60 Gt in the world, would become extinct as early as the coming 64-130 years (Koppelaar and Weikard, 2013). Thus, recycling P-rich waste materials has become a matter of pressing necessity in the food and industrial production line as a result of identification of phosphate rock as a limited and non-renewable essential resource (Sarvajayakesavalu *et al*., 2018; Nenov *et al*., 2020).

The primary sources of raw materials, including mono-ammonium phosphate, come from outside of Europe. Because of their unique ability to release phosphorus and nitrogen, these basic materials are also utilized in agriculture because it provides ample amount of nitrogen and phosphorus that are necessary for plant growth and development. Monoammonium phosphate ($NH_4H_2PO_4$) is the most commonly utilized solid phosphate fertilizer in agriculture (Pratico *et al*., 2010; Dotelli *et al*., 2020). India received approximately 1,36,350 metric tons of MAP from different nations such as China, Israel and others. Most frequently used extinguishing agents are dry fire-extinguishing powders (FEP), which consist of 40-50% mono-ammonium phosphate (MAP), ammonium sulfate, fluxing agents and coloring additives. This substance can be applied in agriculture as fertilizer, *e.g*., after it has been discharged from chemicals necessary for maintaining flowability and water-repellent properties

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(Pratico *et al*., 2010). Process of transformation of raw material in extinguishing powders consists of micro-grinding (pulverization) of phosphate and sulfate and the incorporation of additives so that the same can be made flowable during application. When its entire service life has passed (36 months, according to existing legislation), the issue is raised of how to deal with exhausted extinguishing powders (EEP) so that a high-value, non-renewable raw material (phosphate) could be recovered in near-pure form (Pratico *et al*., 2010). At the EU level, 36 million kilograms of spent extinguishing powders must be treated and disposed of yearly, as stated by the European Sustainable Phosphorus Platform (ESPP) (Pratico *et al*., 2010). The EU, however, only passed the European market of recycled fertilizers in 2019 by the EU Fertilising Products Regulation (FPR). Due to this, EEP's recovery may be a viable substitute for fertilizers produced from raw primary materials when looking at the annual volume production of EEP.

After its expiration date, a national fire extinguisher dealer kindly supplied the fire-extinguishing powder (ABCE class fire, ProPHOS Chemicals S.r.l.) as a mixture of fine particles (99 % under 0.250 mm and at least 44 % below 0.040 mm), which was industrially produced by ProPHOS Chemicals S.r.l. (CR, I). The main components of the powder are coating additives: $NH_4H_2PO_4$ (40 ± 2 %), $(NH_4)_2SO_4$ (52 ± 2 %) and coating additives (~5 %). Heavy metal content: As <0.5 ppm, Cd < 0.2 ppm, total Cr 7.1 ppm, Hg < 0.2 ppm, Ni 2.38 ppm, Pb < 0.5 ppm, Cu 12.6 ppm, Se < 0.5 ppm (Gelsomino *et al*., 2024).

To find out the health hazards of the fire-extinguishing chemicals and materials, Jeong *et al*. (2015) looked at how recyclable they were. They sampled five discarded items from five companies and looked at the nine powders in four new products. The amounts of heavy metals (Pb, Cd, Cr, Hg, Cu, Ni, As, Zn), organic phosphorus, and oil in the fire extinguisher powder that was dumped were found to be below the limits specified by the Wastes Control Act (WCA), the Fertilizer Control Act (FCO), and the Soil Environment Conservation Act (SECA). The arsenic level in a few new and discarded fire extinguisher powder samples was within the permitted range of 45 mg kg^{-1} as specified by the FCO, but it above the acceptable levels specified by the WCA (1.5 mg L^{-1}) and the SECA (25 mg kg^{-1}). Samples contained 6.72 to 38.36 mg kg^{-1} and 0.039 to 2.578 mg L^{-1} of arsenic. Mono-ammonium phosphate, which can also be utilized as fertilizer and often includes up to 0.005% arsenic, is the most commonly applied chemical in ABC dry chemical extinguishers. The result confirmed that powder of fire extinguishers could be recycled as fire extinguisher powder or fertilizer as practiced in Japan, USA and UK. However, it must be pretreated and comply with the regulation of fertilizer and fire extinguisher. Exhausted fire-extinguishing powder had extreme volatility, which prevents proper distribution in the field and occasionally causes issues with pollution management, is among the

most problematic aspects of using this depleted EP (Dotelli *et al*., 2020). In order to address the issue of water surface flotation and provide hydrophilicity, research has suggested both chemical and non-chemical ways to make the waste more soluble. End-of-life extinguisher powder residue was dissolved in aprotic solvents (methyl alkyl ketone, acetone, hexane, pentane, benzene, cyclohexane, toluene, or their blends) by Michelotti (2012). High-pressure filtration was then performed to produce solutions with a high N and P content. A powder with exceptional wettability and hydrophilicity was created and used straight as fertilizer by pulverizing a finely ground extinguisher powder with an average particle size of 30 to 60 µm (Sakamoto *et al*., 2006). These waste processing methods may be costly, energy-intensive, and involve environmentally hazardous solvents. Other farms employ the use of a manure spreader to distribute the extinguishing powders onto the field (Dotelli *et al*., 2020), but this method is not always successful and may have harmful environmental impacts since the dust emissions due to the microscopic particles, which vary in size from 0.250 to 0.040 mm, may raise the possibility of respiratory symptoms (Chongyang *et al.*, 2018).

As per most research works (Pratico *et al.*, 2010; Chia *et a*l., 2015), EEP is very unstable, which frequently makes storage and transportation operations more difficult. For making management much easier, it may be required to compact or agglomerate the EEP with other matrices to create single, solid, and resistant agglomerate. Mixing compost with other organic biomasses and agricultural wastes is one potential remedy. Composting is a good way to get rid of organic waste, especially when it comes to managing waste in cities. This aerobic process helps to lower the volume of waste, destroys any pathogens present in the waste and above all reduce the amount of leachate that is generated during the decomposition process (Hettiarachchi *et al*., 2019).

Compost has a lot of potential for agricultural output because it can include decomposed plants and animal dung that contain different kinds and amounts of nutrients needed for plant growth. Once produced, the compost can be utilized to enhance soil and is usually employed for horticultural or agronomic purposes. Its application enhances the soil's structure and the availability of nutrients (phosphorus and nitrogen compounds) when combined with organic matter (Zajonc *et al*., 2015). Densifying compost would help lower the necessary storage capacity because it typically has a low density and can occupy a large amount of storage volume (Sayara *et al*., 2020). Furthermore, handling compost poses a risk due to the spread of dust, which may contain pathogens and hazardous organic materials (Pampuro *et al*., 2017) that, if inhaled, could result in respiratory issues. Therefore, compost densification is necessary to overcome these risks. The fresh and dry weight of lettuce shoot and roots markedly increased with application of EFP-enriched compost, becoming more evident at the highest rate in the

shoot than in the root fraction (Gelsomino *et al*., 2024).

Conclusion

In conclusion, phosphorus is an indispensable element in plant growth, agricultural productivity and ecosystem health, making its sustainable management essential. The finite nature of phosphate rock reserves and increasing global demand, recycling of phosphorus from secondary sources like exhausted fire-extinguishing powders (EEP) offers an encouraging alternative to conserve this vital nutrient. While EEP contains valuable phosphorus and nitrogen compounds suitable for fertilizer use, challenges related to its volatility, heavy metal content, and environmental safety must be carefully addressed through appropriate pretreatment and regulation compliance. Integrating EEP recycling with composting and densification techniques, nutrient recovery can be improved, waste volume minimized and risks to health from dust emissions lowered. Overall, advancing innovative recycling strategies and regulatory frameworks will be crucial for ensuring a sustainable phosphorus supply and promoting circular nutrient economies in agriculture.

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Cost-Benefit Analysis of Oyster Mushroom Production for Diversification of Income of Small-Scale Farmers of Tripura

Arup Das, Ashok Chhetri and Vijay Kumar

Introduction

Mushrooms belong to the fungi group. Unlike green plants, they do not have chlorophyll and cannot prepare their own food. They grow naturally on dead and decaying organic matter and are often seen in forests. Mushrooms have been used as food by people since very old times. In India, nearly 600 million tonnes of agricultural waste is produced every year. Most of it is either left to rot in the field or burnt. This waste can be put to better use by growing mushrooms. In fact, if only 1% of this waste is used, about 3 million tonnes of mushrooms can be produced (Prakasam, 2012).

India is mainly an agriculture-based country, where farming contributes about one-fifth of the total GDP. In Tripura, around 96 % of the farmers are small and marginal farmers with an average land holding size of 0.49 ha compared to national average of 1.15 ha. For improving the income and livelihood of rural farmers in a sustainable way, mushroom farming can be a very good opportunity, as it requires limited land and uses local resources that are otherwise wasted. Mushroom farming with intensive methods can give good returns and act as an additional source of income. It also creates chances for self-employment, which is very important for rural households to increase their earnings.

To become successful, a mushroom grower must know the production practices as well as the cost and returns from mushroom cultivation. Depending on the availability of raw materials, workers, infrastructure, and market facilities, farmers can plan for small, medium, or large mushroom units. However, it is important to decide the right level of production that makes the farm profitable. The costs and benefits of mushroom cultivation also vary from region to region, which affects the overall profitability of the enterprise (Singh *et al.*, 2010).

Market potential of mushroom: Mushrooms are available in the market in fresh, dried, and preserved forms. Their popularity is steadily increasing due to their pleasant aroma, delicate flavor, high nutritional value, and distinctive taste. They are used in a variety of exotic dishes such as soups, pickles, and sauces, as well as for stuffing and garnishing different food preparations. However, their consumption is still mostly limited to urban and semi-urban areas. Since mushrooms are highly perishable and have a short shelf life after harvest, they are usually sold fresh. This limitation can be overcome through processing, which extends their shelf life. Processed mushrooms are generally packed in food-grade polythene bags or cans. Recognizing the potential, the Government of

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India has identified mushroom cultivation as a priority sector. Despite this, a significant gap exists between demand and supply. With demand rising steadily, the mushroom industry holds immense market opportunities.

Mushroom farming primarily requires two essential inputs for successful cultivation, which are as follows:

Substrate (Cultivation material): Oyster mushrooms can be grown on a wide range of agricultural and forest residues, though they perform particularly well on wheat and paddy straw. In Tripura, paddy is widely cultivated across both hilly and plain regions, either as a single or double crop. This abundance of paddy straw creates favorable conditions and strong potential for expanding mushroom cultivation in the state.

Mushroom Spawn (Seed): Mushroom spawn, commonly referred to as seed, is available in two main forms-spawn produced on paddy grains and spawn developed on wheat grains. The choice of spawn generally depends on the availability of the respective grains in a particular locality.

Economics of oyster mushroom cultivation

The present investigation was carried out at Mushroom Lab, MTTC & VTC, Central Agricultural University (Imphal), Lembucherra, West Tripura. A total of 100 bags of oyster mushroom were taken for cost benefit analysis. For cost estimating, the average expenditure on various variable inputs like straw, spawn, chemicals, labour and other miscellaneous material was taken. The returns were calculated based on the actual price received. The return over variable cost and net returns were calculated by deducting the respective cost from the gross returns. Break-even point (BEP) of output was calculated by using the below given formula.

Variable Costs: Variable cost is directly correlated with the level of output. They include mushroom spawn, cotton, gauze or string, polythene bags, water, firewood, packaging materials, rice bran, agriculture lime, and labor costs.

Benefit-cost ratio: Benefit-cost ratio = Gross income/ total cost

Break-even production and price: Production= Total cost/ price per unit, Price= Total cost/ production

The total variable cost of producing 100 bags of oyster mushrooms amounts to Rs. 22050.00, which translates to an average cost of Rs. 220.50 bag^{-1} (Table 1). The major cost component is manpower (56.7%), followed by paddy straw (18.1%), mushroom spawn (13.6%) and chemicals and miscellaneous items (9.1%). Minor expenses include ropes (1.8%) and polythene bags (0.7%). The average yield recorded from each of the mushroom bag is 2.5 kg thereby yielding 250 kg oyster mushroom from 100 bags whereas the present wholesale price of oyster mushroom is Rs. 150 kg^{-1} generating a gross income of Rs. 37500.00. After deducting the variable costs, the net income amounts to Rs. 15450.00 which corresponds to Rs. 61.80 net returns per kilogram of mushroom (Table 2). The calculated Benefit-Cost (B:C) ratio of 1.7:1 indicates

Table 1: Cost of mushroom production (for 100 bags of 5 kg capacity each)

Variable Cost				
S. No.	**Name of item**	**Unit required**	**Rate per unit (Rs.)**	**Total cost (Rs.)**
1.	Oyster mushroom spawn	100 bags	30.00	3000.00
2.	Polythene bags	100 bags	1.50	150.00
3.	Ropes	5 kg	80.00	400.00
4.	Paddy Straw	500 kg	8.00	4000.00
5.	Manpower	25 mandays	500.00	12500.00
6.	Chemicals and misc.	-	-	2000.00
			Total	**22050.00**

that the enterprise is economically viable and profitable (Table 2). Rawat *et al.* (2020) and Singh *et al.* (2010) also observed B:C ratio of 1.47 and 1.61, respectively for small scale mushroom production unit.

Table 2: Returns from oyster mushroom production

S. No.	Particulars	
1.	Cost of production (excluding fixed cost) per cycle	Rs. 22050.00
2.	Total mushroom production	250 kg
3.	Gross income	Rs. 37500.00
4.	Net income	Rs. 15450.00
5.	Net returns (Rs. kg^{-1})	Rs. 61.80
6.	Benefit cost ratio (B:C)	1.7:1

Break even analysis (BEA) revealed that if unit produced 147 kg mushroom, it did not gain or loss under given total cost of production and actual price (Table 3). Breakeven price is much less than the actual market price of mushroom prevailed in the market. The unit is in profit under given cost and production level.

Table 3: Break-even production and price of oyster mushroom

S. No.	Particulars	Production (kg)	Price (Rs.)
1.	Actual	250	150.00
2.	Break even	147.0	88.20
3.	Gap	103	61.80

Conclusion: The study on oyster mushroom production highlights the economic feasibility and income- diversification potential of mushroom farming for small-scale farmers in the state. The findings demonstrate that mushroom cultivation is a sustainable and profitable venture, offering a viable alternative for small-scale farmers with limited land resources. The production of oyster mushrooms using locally available paddy straw as substrate showed a high benefit-cost (B:C) ratio of 1.7:1 with a net income of Rs. 15,450/- $cycle^{-1}$ and a net return of Rs. 61.80 kg^{-1}. The break-even analysis indicates that the enterprise remains profitable, as the production (250 kg) and market price (Rs. 150 kg^{-1}) exceed the breakeven levels of 147 kg and Rs. 88.20, respectively.

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Biochar: A Sustainable Solution for Productive and Resilient Farms

Harsh Saini and Preeti Sharma

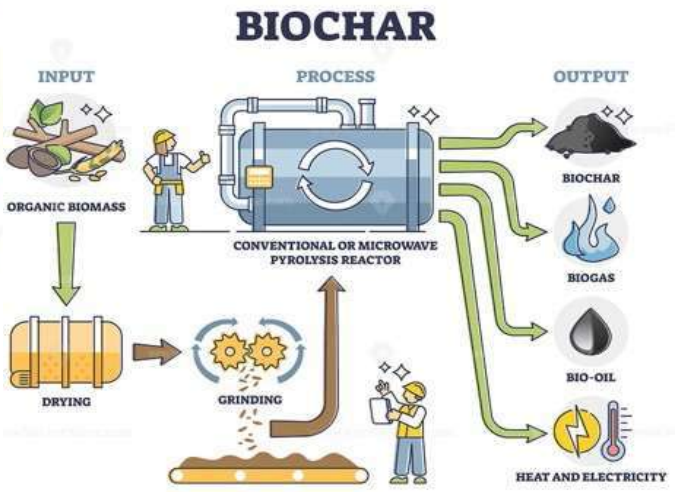
What is Biochar?

Biochar is a porous carbonaceous solid material with a high degree of aromatization and high resistance to decomposition formed through the thermal breakdown of biomass from plants or animals that is thermally decomposed in the absence of oxygen. It has gained considerable interest in recent years due to its versatile use in various agricultural and industrial activities. Biochars exhibit a wide range of physicochemical characteristics, significantly impacting their wide variety of applications. Recent data suggests that the material and process of biochar production significantly affect biochar properties, like elemental ingredient concentrations, density, porosity, and pH, all of which affect the biochar's applicability for diverse applications. It is utilized in waste treatment in various industries to eliminate organic and inorganic pollutants and multiple types of dyes and pigments from textiles. It is used in agriculture to improve the soil's quality. It lowers the rate of nutrient degradation in the soil, improving its quality. Biochar can be used as a power generation fuel due to its high carbon content. Biomass has been identified as an auspicious source of renewable energy, minerals, and chemicals.

How Biochar is produced

How to make biochar: A closer look into biochar production

Biochar is produced during pyrolysis, a thermal decomposition of biomass in an oxygen-limited environment. The quality of feedstocks, or materials burned, have a direct impact on the quality of the final biochar product. Ideally, clean feedstocks with 10 to 20 percent moisture and high lignin content must be used some good examples are field residues and woody biomass.



Using contaminated feedstocks, including feedstock from railway embankments or contaminated land, can introduce toxins into the soil, drastically increase soil pH and/or inhibit plants from absorbing minerals. The most common contaminants are heavy metals including cadmium, copper, chromium, lead,

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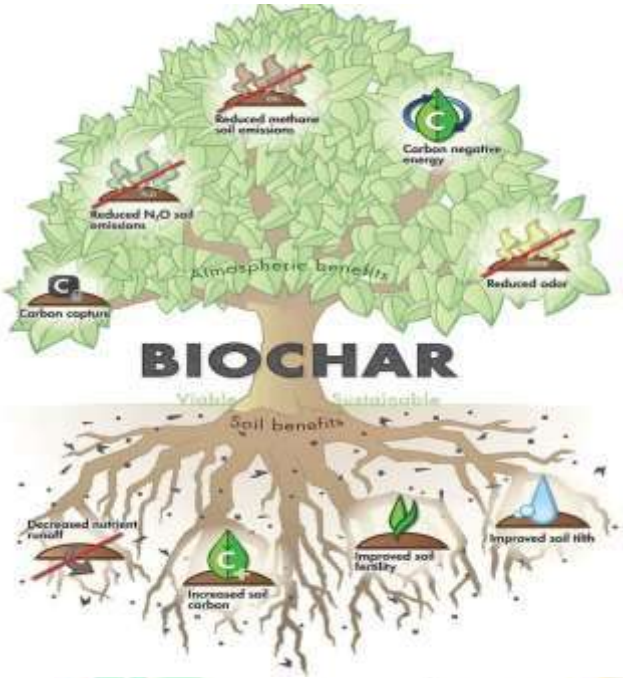
zinc, mercury, nickel and arsenic and Polycyclic Aromatic Hydrocarbons.



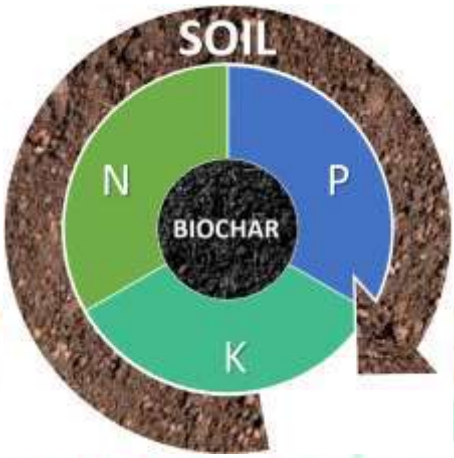
Biochar can be manufactured through low-cost, small-scale production using modified stoves or kilns, or through large-scale, cost-intensive production, which utilizes larger pyrolysis plants and higher amounts of feedstocks. One of the most common ways to make biochar for on-farm use is through pyrolysis using a top-lit updraft biochar machine.

Benefits of Biochar Application in Agriculture

Better Water Retention: If you look at biochar under an electron microscope, you can see an extraordinary moonscape of holes upon holes. What's this mean? Biochar is an amazing sponge that will hold (absorb) huge amounts of water. All those little holes also provide very convenient condos for soil microbes better water retention.

Healthier Soil / Lower Acidity - pH of 8: The plants' soil that has a nice, neutral pH of say 6.5 to 7, but most soils in the developing world are acid to very acid 4 to 5.5. In the acidic soils, most plants can't take up nutrients, even if they are present in the soil. However, stick some biochar in this soil, and you can push the pH as much as a whole point higher. As the pH rises, more and more nutrients become available to crops.

Soil fertility: biochar can improve soil fertility, stimulating plant growth, which then consumes more CO_2 in a positive feedback effect.



Reduced fertilizer inputs: Biochar can reduce the need for chemical fertilizers, resulting in reduced emissions of greenhouse gases from fertilizer manufacture;

Reduced N_2O and CH_4 emissions: Biochar can reduce emissions of nitrous oxide (N_2O) and methane (CH_4), two potent greenhouse gases from agricultural soils;

Enhanced soil microbial life: Biochar can increase soil microbial life, resulting in more carbon storage in soil.

Energy generation: The heat energy and also the bio oils and synthesis gases generated during biochar production can be used to displace carbon positive

energy from fossil fuels.

Challenges and Considerations

Variation in Quality: The effectiveness of biochar can differ widely depending on the type of raw material and the method used to produce it. Different production techniques can result in biochar with varying levels of carbon content and nutrient-holding capacity, which may affect its benefits for soil health. Small-scale methods, like drum kilns, sometimes produce biochar that is less effective compared to more controlled pyrolysis processes.

Cost and Economic Feasibility: Setting up biochar production units requires a significant investment. Small drum kilns may cost around ₹5,000, while larger tractor-mounted systems can exceed ₹30,000. Such costs can discourage small farmers, even though these tools have the potential to improve productivity and soil quality over time.

Environmental and Health Concerns: If biochar is produced incorrectly, it may contain harmful compounds such as polycyclic aromatic hydro-carbons (PAHs) or dioxins. These substances can contaminate the soil and water, potentially posing risks to plants, livestock, and humans.

Knowledge and Adoption Barriers: Many farmers lack awareness of biochar's benefits and how to use it correctly. The absence of standardized guidelines for production and application makes adoption inconsistent, slowing down the wider use of this sustainable practice.

Policy and Regulatory Gaps: India currently does not have a comprehensive policy to regulate biochar production, quality standards, or incentives. Without clear policies, scaling up biochar use and integrating it into mainstream agriculture remains a challenge.

Case Studies and Applications in India

Himachal Pradesh: Pioneering State-Supported Biochar Initiative

Himachal Pradesh has launched India's first state-supported biochar programme, aiming to address forest fire hazards and enhance soil health. The project utilizes biomass from pine needles, lantana, and bamboo, converting them into biochar through pyrolysis. This initiative not only mitigates fire risks but also improves soil fertility and sequesters carbon. Local communities are engaged in biomass collection, earning income and contributing to sustainable practices. The programme is expected to generate approximately 28,800 carbon credits over ten years, aligning with the state's environmental goals.

Maharashtra: Enhancing Sugarcane Yields with Biochar

In Maharashtra, farmers have adopted biochar to improve soil health and increase sugarcane yields. The application of biochar has led

to significant improvements in soil organic carbon levels, resulting in enhanced crop productivity. Union Minister Nitin Gadkari has advocated for the use of biochar, highlighting its benefits in reducing input costs and boosting farmer income. Affordable biochar production tools, such as drum-type and tractor-mounted pyrolysers, have been introduced to facilitate widespread adoption among farmers.

Punjab and Haryana: Promoting Sustainable Agriculture

Biochar initiatives in Punjab and Haryana focus on utilizing agricultural residues to produce biochar, enhancing soil fertility and promoting sustainable farming practices. These projects aim to reduce dependence on chemical fertilizers, improve water retention in soils, and sequester carbon, contributing to both environmental sustainability and increased agricultural productivity.

These case studies demonstrate the transformative potential of biochar in Indian agriculture, offering solutions to environmental challenges while enhancing soil health and farmer livelihoods.

Conclusion

Biochar is a valuable tool for modern agriculture, offering solutions for improving soil fertility, enhancing water retention, and increasing crop productivity while also contributing to carbon sequestration. Although challenges like variable quality, production costs, and limited farmer awareness exist, ongoing research, innovation, and field applications are unlocking its potential. As more farmers and policymakers recognize the benefits of biochar, its adoption is likely to grow, supporting more sustainable and resilient agricultural systems. By refining production methods and promoting practical applications, biochar can play a key role in shaping a productive and environmentally responsible future for agriculture.

Maitake: The Microbial Slayer

Shruthi S., Sneha C. and Maheshwari M.

Introduction

As contemporary medicine struggles with antibiotic resistance, researchers and doctors are looking to nature's pharmacy for solutions. The maitake mushroom (*Grifola frondosa*), a giant, leaf-like fungus that grows at the base of hardwood trees in temperate forests. Although recognized for centuries in East Asia for its health-benefiting effects, it is now gaining global recognition as a powerful natural antimicrobial agent, and thus has become known as "The Microbial Slayer."

Ethnomedicinal Background

Traditionally, in Chinese and Japanese medicine, maitake has been utilized to cure all sorts of illnesses from fatigue and hypertension to diabetes and cancer. Historically, the healers of the day felt that it was able to "rebalance the body's defenses" something that contemporary immunological research is now attesting to. It is said to have earned the name "dancing mushroom" due to the delight that it invoked when discovered growing in the wild both for its flavor and its medicinal potential.

A Powerhouse of Bioactive Compounds

The medicinal properties of Maitake mushrooms can be attributed to their diverse and abundant bioactive compounds. These include:

Polysaccharides (Beta-glucans): Maitake is particularly rich in beta-glucans, complex carbohydrates that are known for their immune-modulating effects. Several specific fractions of these polysaccharides have been isolated and studied.

D-fraction: This is one of the most well-studied compounds in Maitake. It is a protein-bound beta-glucan that has demonstrated significant anti-cancer and immune-enhancing properties.

MD-fraction: A more potent form of the D-fraction, the MD-fraction is also known for its powerful immune-stimulating effects.

SX-fraction: This beta-glucan has been shown to have a positive impact on metabolic health, particularly in regulating blood sugar levels.

Proteins and Glycoproteins: In addition to polysaccharides, Maitake contains proteins and glycoproteins that contribute to its health benefits, including anti-tumor and immune-modulating activities.

Antioxidants: Maitake is a good source of antioxidants, such as: Flavonoids and Phenolic Compounds: These compounds help to protect the body against oxidative stress and damage from free radicals.

L-ergothioneine: A potent antioxidant amino acid

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that has been dubbed the "longevity vitamin".

Vitamins and Minerals: Maitake mushrooms are a good source of essential vitamins and minerals, including: Vitamin D: Especially when wild-harvested and exposed to sunlight, Maitake can be an excellent source of this vitamin, which is crucial for bone health.

B Vitamins: Including niacin and riboflavin.

Minerals: Such as Potassium and Phosphorus

Mechanism of Microbial Action

Maitake has broad-spectrum antimicrobial action, i.e., it inhibits gram-positive and gram-negative bacteria, fungi, and certain viruses. It achieves this by:

- ✓ Activation of the immune system - initiates phagocytosis, release of cytokines, and activation of T-cells.
- ✓ Disruption of microbial cell walls/membranes - results in leakage and death of microbes.
- ✓ Inhibition of microbial enzyme and replication - particularly useful against viruses.
- ✓ Biofilm inhibition - prevents chronic infection by halting the formation of microbial colonies.

Grifola frondosa and Its Promising Role in Natural Antimicrobial Therapy

- ✓ A 2022 *in vitro* research proved that maitake extract considerably inhibited *Staphylococcus aureus* and *Candida albicans*.
- ✓ D-fraction supplementation of animal models showed improved resistance against bacterial pneumonia and viral infection.
- ✓ Recent studies indicate maitake can minimize the development of multi-drug-resistant *E. coli* and *Pseudomonas* strains.
- ✓ These findings underscore its potential not only as a supplement but also as a phytopharma-ceutical candidate.

Comparative Insight: Maitake vs. Antibiotics

Feature	Maitake Mushroom	Conventional Antibiotics
Source	Natural, fungal	Synthetic or microbial
Action	Immune-boosting + direct antimicrobial	Primarily direct antimicrobial
Resistance development	Low	High
Side effects	Minimal	Can include gastrointestinal distress, allergies
Spectrum of activity	Broad (bacteria, fungi, viruses)	Often limited to bacteria

Maitake doesn't replace antibiotics but can be an adjunctive or preventive therapy, especially in immune-compromised or chronic conditions.

Future Research Directions

Maitake's full potential is yet to be discovered. Potential avenues for research include:

- ✓ Isolation of new antimicrobial peptides and secondary metabolites.
- ✓ Synergy with conventional antibiotics in the fight against resistant strains.
- ✓ Nanoformulation of maitake extract for targeted drug delivery.
- ✓ Clinical trials for infectious disease prevention and recovery.

These avenues could pave the way to the inclusion of maitake into evidence-based medicine.

Safety and Consumption

Maitake is usually accepted as safe (GRAS) as a food or supplement. At high doses in extract

form, though, they might interact with antihypertensives, antidiabetic medications, or immune-modulating agents. Therapeutic usage necessitates proper standardization of dosage and clinical supervision.

Conclusion

At a time when microbial resistance is compromising global health, maitake mushroom is a shining hope. It fills the gap between ancient knowledge and modern technology, a defensive armor for the immune system as well as a direct assault upon destructive pathogens.

Maitake - The Microbial Slayer is more than a slogan it is an actual potential to capitalize on the healing power of nature in the fight against one of medicine's greatest foes.

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Climate Change and Water Neutrality: Securing Freshwater in an Era of Crisis

Vipin Kumar Mishra, Ambrish Kumar and Sweta Garg

Abstract

Climate change is intensifying global water insecurity, threatening ecosystems, human livelihoods, and sustainable development. Rising temperatures accelerate evaporation, unpredictable rainfall patterns drive droughts and floods, and glacial melt contributes to long-term river flow reductions and sea-level rise. With only 0.5% of Earth's water available as usable freshwater and this supply shrinking due to climate change new approaches are urgently needed. Water neutrality, which balances withdrawals with replenishment through conservation, reuse, and ecosystem restoration, offers a pathway toward resilience. This article explores the links between climate change and water, highlights key global indicators, and outlines strategies to achieve water neutrality at community, industry, and policy levels.

Introduction

Climate change has emerged as the defining challenge of the 21st century, with water resources being among the most severely affected sectors. The global hydrological cycle is increasingly destabilized due to rising temperatures, altered precipitation patterns, accelerated glacier retreat, and more frequent extreme events such as droughts, floods, and cyclones (IPCC, 2022). Water scarcity, once considered a regional challenge, is now a global crisis, affecting not only arid and semi-arid regions but also water-rich basins due to seasonal variability and declining water quality (WWAP, 2020). Alarmingly, only 0.5% of Earth's total water is accessible and usable freshwater, a resource that is declining steadily due to over-extraction, pollution, and climate-induced changes in recharge and availability (UNESCO, 2019). By 2050, an estimated 5.7 billion people could be living in water-scarce regions, compared to 3.6 billion today (United Nations, 2023). Moreover, the year 2023 recorded a net glacier water loss of more than 600 gigatons the highest in five decades underscoring the accelerated pace of cryospheric degradation (Zemp et al., 2023). These data points illustrate the urgency of addressing water as the central vector of climate change impacts. Against this backdrop, the concept of water neutrality, which emphasizes balancing withdrawals with replenishment, has emerged as a critical framework for securing sustainable and equitable water use across sectors and scales.

The Link between Climate Change and Water

Climate change primarily manifests as a water crisis, altering the quantity, quality and reliabi-

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lity of freshwater supplies.

Extreme weather events: Intensified rainfall, storms, and floods disrupt urban and agricultural systems while increasing contamination risks (IPCC, 2022).

Glacial melt and snowpack decline: In 2023, glaciers lost over 600 gigatons of water, the largest annual loss recorded in fifty years (World Glacier Monitoring Service, 2023). This threatens river basins like the Ganges, Indus, and Andes, which depend on glacial meltwater.

Sea-level rise: Global sea levels have risen by approximately 20 cm since 1900 due to thermal expansion and ice melt, leading to saltwater intrusion into freshwater aquifers (WMO, 2021).

Ecosystem degradation: Loss of wetlands and vegetation reduces natural water storage and groundwater recharge, while also increasing soil erosion (Molden, 2013).

Water insecurity translates into human insecurity: destabilizing communities, intensifying competition for resources, and triggering migration. By 2050, up to 5.7 billion people could live in areas of water scarcity compared to 3.6 billion today (UNESCO, 2020).

Figure 1: Climate Change Impacts on Water Sector and Energy Requirements

Climate Change and Water Resources: Key Indicators

Indicator	Value and Source
Usable freshwater (Earth's total water)	0.5% (Gleick, 2014)
Annual glacier water loss (2023)	600+ gigatons, largest in 50 years (WGMS, 2023)
Sea-level rise since 1900	20 cm (WMO, 2021)
People in potential water-scarce areas	1.9 billion (2010s) → 2.7-3.2 billion (2050) (UNESCO, 2020)
People at flood risk	1.2 billion today → 1.6 billion by 2050 (IPCC, 2022)
Countries struggling with water management	40% (UN Water, 2019)

These statistics illustrate that climate change simultaneously reduces water availability and increases exposure to water-related hazards, creating a double burden of scarcity and excess.

The Importance of Water Neutrality

Water neutrality seeks to ensure that all anthropogenic water withdrawals whether for agriculture, industry, or domestic purposes are offset by equivalent volumes of replenished water through technological, ecological, or governance measures (Hoekstra *et al.*, 2011). Unlike traditional water management approaches, which focus primarily on supply augmentation or demand reduction, water neutrality provides a holistic framework that integrates water efficiency, recycling, ecological restoration, and stakeholder collaboration. The urgency of achieving water neutrality stems from several converging factors. First, climate change is reducing renewable freshwater availability by altering rainfall distribution and accelerating evapotranspiration rates (Kundzewicz *et al.*, 2018). Second, water demand is expected to increase by 20-30% by 2050 due to rising populations, industrial

growth, and agricultural intensification (OECD, 2012). Third, water insecurity is closely linked to political instability, food insecurity, and ecosystem collapse, making it both an environmental and socio-political issue. Achieving water neutrality could significantly reduce risks of transboundary water conflicts, biodiversity loss, and economic vulnerability, while also contributing to climate mitigation by restoring carbon-rich ecosystems such as wetlands and mangroves (Ramsar Convention Secretariat, 2021).

Figure 2: Water Neutrality as a Pathway to Net Zero

Strategies for Achieving Water Neutrality

Achieving water neutrality requires an integrated portfolio of technical, ecological, and governance-based strategies tailored to local contexts yet aligned with global sustainability goals.

Rainwater Harvesting and Storage Systems: Rainwater harvesting enhances water availability during dry periods and reduces dependence on groundwater extraction. Techniques range from rooftop collection in urban areas to large-scale percolation tanks and check dams in agricultural landscapes (UNEP, 2022).

Wastewater Treatment and Reuse: Advanced wastewater treatment technologies such as membrane bioreactors, constructed wetlands and decentralized greywater systems enable the safe reuse of water in agriculture and industry, significantly reducing freshwater withdrawals (Jiménez and Asano, 2008).

Climate-Smart Agriculture (CSA): Agricultural water use accounts for nearly 70% of global withdrawals, making CSA essential for water neutrality. Practices include drip and sprinkler irrigation, deficit irrigation scheduling, mulching, and the adoption of drought-tolerant crop varieties (FAO, 2018).

Wetland and Aquifer Restoration: Wetlands act as natural sponges that store water, recharge aquifers, and filter pollutants. Restoration of degraded wetlands and aquifers enhances resilience to floods and droughts while contributing to biodiversity conservation (Moomaw *et al*., 2018).

Infrastructure Innovation: Investment in efficient distribution systems, leakage control, smart meters, and flexible water grids reduces non-revenue water losses and ensures adaptive allocation during climate shocks (World Bank, 2020).

Fig, 3: Dimensions of Water Security in the Context of Climate Change

Governance and Policy Integration: Institutional frameworks must promote cross-sectoral coordination, transboundary water cooperation, and incentive mechanisms such as water credits, pricing reforms, and corporate disclosure of water footprints (Hoekstra, 2017).

These strategies, when implemented synergistically, provide a pathway toward resilient, equitable, and climate-adaptive water systems.

Case Studies

Coca-Cola India: Criticized for groundwater depletion, Coca-Cola pledged water neutrality, restoring ponds, building recharge structures, and promoting farmer irrigation efficiency. Independent assessments claimed replenishment of 160% of operational water use (TERI, 2011).

Israel: Through drip irrigation, desalination, and wastewater reuse (85% of irrigation demand), Israel has achieved near water neutrality in agriculture (Tal, 2016).

Singapore's Four National Taps: Integrating imported water, desalination, rainwater harvesting, and wastewater reuse, Singapore has become a model for urban water neutrality (PUB, 2020).

Kenya's Sand Dams: Community-led rainwater harvesting structures enhance groundwater recharge and resilience in semi-arid regions (Lasage *et al*., 2015).

Challenges

Despite progress, water neutrality faces significant barriers:

Measurement difficulties: Water footprints (blue, green, grey) vary regionally and lack standardized assessment (Hoekstra *et al*., 2011).

Economic costs: Desalination and ZLD are energy-intensive and costly, sometimes increasing carbon footprints (Gude, 2017).

Equity issues: Corporate neutrality claims may offset water use far from extraction points, leaving local communities vulnerable (Liu *et al.*, 2017).

Governance gaps: Weak institutions and lack of cross-border cooperation hinder adoption.

Conclusion

The intertwined crises of climate change and water scarcity highlight the pressing need for systemic transformations in water governance and management. Water neutrality provides a technically sound and globally relevant framework to balance human withdrawals with ecological replenishment, thereby ensuring resilience in the face of climatic uncertainty. Beyond technical measures, achieving water neutrality requires cross-sectoral cooperation, stakeholder participation, and political commitment at national and international scales. Future water security depends not only on technological innovation but also on embedding principles of sustainability and justice into water allocation and governance. As climate change accelerates the depletion of finite freshwater resources, water neutrality offers a pragmatic and ethical blueprint to safeguard ecosystems, secure livelihoods, and foster socio-political stability in the Anthropocene.

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Varietal Development of Sugarcane for Jaggery, Khandsari and Raw Sugar Industry

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Abstract

Sugarcane is one of the most important commercial crops in India, providing raw material for sugar, ethanol, jaggery (gur) and khandsari industries. Nearly half of the cane produced in the country is diverted to the jaggery and khandsari sector, which plays a significant role in rural livelihood and employment generation. Unlike sugar factories, where recovery percentage is the primary selection criterion, jaggery production requires varieties with high juice purity, low reducing sugars and desirable product quality traits. This article highlights the major parameters for good jaggery varieties, discusses the importance of varietal development for khandsari and raw sugar, and lists key sugarcane varieties suitable for these purposes.

Introduction

Sugarcane (*Saccharum spp*. complex) is grown extensively in tropical and subtropical regions of India. While the organized sugar industry consumes a large share of cane, the jaggery and khandsari industries together utilize nearly 50% of the total production. These cottage industries are particularly important for smallholder farmers as they provide quick returns, local employment, and a market for cane unsuitable for factory crushing. For jaggery production, juice quality parameters such as high sucrose, low fibre, high purity, and low reducing sugars are critical to ensure good recovery and desirable product characteristics. Hence, varietal development targeted at the gur industry is a key priority alongside sugar and ethanol-focused breeding.

Parameters for Good Jaggery Varieties

Cane and Juice Quality

- ✓ High sucrose content (Brix % ≥ 18-20%)
- ✓ Low fibre content (10-12%) for efficient juice extraction
- ✓ High juice purity (> 85%)
- ✓ Low reducing sugars (< 1%) to reduce hygroscopicity
- ✓ Low non-sugar impurities (ash, gums, phenols, starch)

Jaggery Quality

- ✓ Golden yellow to light brown color
- ✓ Hard, crystalline, and non-sticky texture
- ✓ Pleasant sweet taste without bitterness
- ✓ Longer shelf-life with minimal microbial spoilage
- ✓ Retention of minerals (Fe, Ca, Mg, P) and vitamins

Processing Attributes

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- ✓ High juice recovery (≥ 75%)
- ✓ Reduced scum formation during boiling
- ✓ Quick settling of impurities
- ✓ Easy clarification without excess use of lime

Agronomic Traits

- ✓ Early to mid-early maturity for timely jaggery preparation
- ✓ High yield with good ratooning ability
- ✓ Resistance to major pests and diseases such as red rot, smut, and wilt
- ✓ Wide adaptability to different climatic zones

Varietal Development for Khandsari and Raw Sugar

- ✓ Khandsari industry requires varieties with good crystallization ability, medium fibre and high sucrose.
- ✓ Raw sugar industry demands high purity juice, low reducing sugars and high sugar recovery with less molasses.
- ✓ Breeding programs are increasingly focusing on dual-purpose varieties suitable for both organized mills and cottage industries.

Promising Varieties for Jaggery and Khandsari

For Jaggery (Gur)

CoJ 64, CoJ 85, CoJ 88: Widely cultivated in Punjab, Haryana, and subtropical India; produce bright-colored, hard jaggery.

Co 86032: Popular in Maharashtra and southern states, valued for stability and yield.

BO 91: Suitable for Bihar and eastern India.

Co 0238: A high-yielding, dual-purpose variety now extensively adopted in subtropical India.

CoLk 14201: Recently identified as an excellent jaggery variety in Uttar Pradesh, producing golden-yellow, non-hygroscopic jaggery with high sucrose and good disease resistance.

For Khandsari: Co 775, Co 8021, CoS 767

Dual-purpose (Sugar + Jaggery): Co 0238, Co 86032, Co 0212 etc.

Conclusion

The jaggery and khandsari sectors contribute significantly to India's rural economy by providing quick returns and supporting cottage industries. Development of varieties tailored to these industries requires a focus on juice quality, processing efficiency, and product acceptability rather than sugar recovery alone. Varieties such as CoJ 85, CoJ 88, CoJ 64, Co 86032, BO 91, Co 0238, and CoLk 14201 have proven valuable in different regions for producing high-quality jaggery. Future breeding programs must emphasize region-specific, disease-resistant, and climate-resilient varieties to meet the rising consumer demand for natural sweeteners and to ensure sustainable growth of the jaggery and khandsari industries.

Vertical Farming: The Future of Urban Food Production

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Abstract

Vertical farming is becoming a game-changing method for city-based agriculture, offering eco-friendly answers to problems like limited land, climate change, and increasing urban populations. By growing crops in stacked layers with the help of hydroponics, aeroponics, and LED lights, these farms save space, use less water, and reduce the need for chemicals. They allow fresh produce to be grown year-round close to consumers, cutting down on transport and emissions. Successful examples such as AeroFarms in the U.S. and Sky Greens in Singapore show how effective this approach can be. Although high energy use, crop limitations, and expensive start-up costs remain challenges, improvements in automation, renewable energy, and AI are helping the sector progress. Vertical farming could not only provide sustainable food for cities but also play a role in growing food in tough environments and even in space.

Introduction

As more people live on Earth and urban areas expand, providing enough food without harming the environment is a growing concern. Traditional agriculture needs vast land areas and a lot of water, but both are limited. Vertical farming introduces a new way of growing crops, offering a fresh perspective on how cities can produce their own food.

What is Vertical Farming?

Vertical farming means growing plants in layers stacked on top of each other, often inside tall buildings, warehouses, or specially designed towers. Instead of spreading crops across wide fields, they are grown upward to make better use of limited city space. This modern method blends farming with new technologies like hydroponics, aeroponics, LED lights, and artificial intelligence. The idea is straight-forward: if cities can't expand outward, they can grow upward.

Just as high-rise buildings hold many people, vertical farms can produce large amounts of food in small areas, bringing agriculture right into urban centers (Despommier, 2010).

Hydroponics and Beyond: The Core Technologies

At the core of vertical farming is the idea of growing plants without soil. One of the most widely used methods is hydroponics, where crops are placed in water enriched with nutrients rather than in the ground. This technique allows farmers to carefully

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control water, nutrients, and pH levels, which helps plants grow faster and produce greater yields.

Other important techniques include:

Aeroponics: Plants are grown in an air or mist environment, using far less water than traditional farming.

Aquaponics: A system that combines fish farming with plant growth, where fish waste provides nutrients for crops, and the plants help clean the water.

LED Lighting: Special energy-saving lights mimic sunlight, allowing crops to grow indoors all year round.

These technologies not only reduce the need for fertile farmland but also save water and minimize the use of chemicals (Specht *et al.*, 2014).

Sustainably with Vertical Farming in Cities

The advantages of vertical farming go far beyond saving space:

Local, Fresh Produce Year-Round: Because vertical farms operate in climate-controlled environments, they can produce food consistently throughout the year. This ensures fresh vegetables and herbs are available in urban areas, even during harsh winters or droughts.

Reduced Transportation Costs and Emissions: Traditional agriculture often requires transporting food over long distances, which contributes to carbon emissions and food spoilage. Vertical farms bring food production closer to consumers, reducing both cost and environmental impact.

Sustainability and Resource Efficiency: Vertical farming uses up to 70-90% less water than conventional farming. By recycling water and nutrients, these systems dramatically reduce waste. Some farms even integrate renewable energy sources, such as solar panels, to power their operations.

Resilience against Climate Change

With extreme weather events threatening crop yields globally, vertical farming provides a climate-resilient alternative. Controlled environments shield crops from floods, droughts, and pests. (Kalantari *et al.*, 2017).

Steps to Start Vertical Farming in Cities

Transforming urban buildings into vertical farms is an effective way to bring food production closer to city residents. With proper planning, even unused rooftops, basements, or high-rise floors can be converted into thriving farms (Al-Kodmany, 2018). Steps to be followed:

Select the Right Space: Choose unused areas such as rooftops, warehouses, or empty rooms in tall buildings. Ensure there is access to electricity and water.

Install Layered Growing Systems: Use racks, shelves, or tower structures to grow plants in multiple layers. This makes efficient use of vertical space and increases the number of crops grown in a small area.

Choose a Growing Method

Hydroponics: Growing plants in nutrient-rich water (Lettuce, Spinach, Kale, Tomatoes, Cucumbers, Strawberries, and Chilies) (Touliatos *et al.,* 2016).

Aeroponics: Growing plants in air or mist, using very little water (Lettuce and Arugula, Herbs- Basil and Mint, and Root crops- Potatoes).

Aquaponics: Combines aquaculture and hydroponics (Lettuce and Pak choi, Coriander and Parsley, fruiting crops-Tomatoes and Chilies).

Use Sensors, Lighting and Climate Control: Use LED grow lights to provide the correct light spectrum for plants. Smart sensors can monitor water quality, pH, and nutrient levels, reducing human error and increasing efficiency. Automated systems help regulate temperature, humidity, and nutrient levels for consistent growth.

Harvest and Distribute Locally: Fresh produce can be harvested year-round and delivered directly to local markets, supermarkets, or restaurants, reducing transportation needs (Touliatos *et al.,* 2016).

Microgreens in Vertical Farming

One of the most popular crops for vertical farms is microgreens. Mini greens with many benefits, microgreens are becoming more popular with health-focused people living in cities. These soft, young plants are picked just a few days after they start growing and are full of flavor and nutrients. They're not just a food trend and also, they're a smart and eco-friendly way to get good nutrition, especially in today's busy world where space is limited (Choe *et al*., 2020).

Real-World Examples of Vertical Farming Innovations

Several pioneering projects around the world are proving the potential of vertical farming:

AeroFarms (USA): Located in New Jersey, AeroFarms operates one of the largest vertical farms globally, using aeroponics to produce leafy greens with 95% less water than field farming.

Sky Greens (Singapore): A vertical farm that uses rotating towers to maximize sunlight exposure, producing vegetables in one of the most land-scarce countries in the world.

Spread Co. (Japan): This farm combines robotics and automation to plant, harvest, and package lettuce efficiently.

Infarm (Europe): Based in Berlin, Infarm builds modular vertical farming units that can be installed in supermarkets, restaurants, and distribution centers, making farm-to-table literally possible.

Challenges and Limitations

Even though vertical farming has great potential, it also comes with some challenges:

High Energy Use: Vertical farms need a lot of electricity to run LED lights, pumps, and climate control systems. Renewable energy can reduce this, but the overall cost is still higher than traditional farming.

Expensive Setup: Building vertical farms requires modern technology and infrastructure, which makes them costly to start. This is especially difficult for developing countries.

Limited Crops: Most vertical farms grow leafy greens, herbs, and a few fruits. Staple foods like rice,

wheat, or corn are harder and less profitable to grow in this system.

For vertical farming to succeed worldwide, these issues need to be solved (Beacham *et al.*, 2019).

The Future of Vertical Farming

Vertical farming has strong potential to shape the future of food. With advancing technology and cheaper energy, these systems will become easier to adopt in cities. In the future, vertical farms could not only feed urban populations but also support food production in space, something NASA is already experimenting with for future missions.

Conclusion

Vertical farming is a fresh way of reimagining agriculture for the modern era. By building farms upward and using advanced technology, cities can produce more food in smaller areas while saving resources and protecting the environment. While there are still difficulties to overcome, progress in hydroponics, robotics, and renewable energy is driving the industry forward. As technology improves, it may become an essential part of urban life, ensuring fresh and sustainable food for the future.

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Biochar: A Sustainable Solution for Modern Agriculture

Bhupender

Introduction

Indian agriculture today stands at a cross-roads. On one side, farmers face the rising cost of chemical fertilizers; on the other, they must meet the increasing demand for food production. This situation has created an urgent need for low-cost, sustainable solutions that can improve soil fertility without harming the environment. One such solution lies in an age-old practice, now backed by science Biochar. Often referred to as "black gold," biochar can rejuvenate soils, increase yields, and promote climate-resilient farming.

What is Biochar?

Biochar is a carbon-rich, black material produced from organic waste such as crop residues, husks, twigs, or wood chips. It is made through a process called pyrolysis, in which biomass is heated at high temperatures (300-700°C) under limited oxygen. This controlled burning turns the waste into a porous, stable form of charcoal.

The special structure of biochar makes it unique it contains numerous tiny pores that give it a large surface area. These pores act like a natural sponge, capable of holding nutrients and water for a long time, which directly benefits crop growth.

Benefits of Biochar in Farming

Improves Nutrient Availability: Biochar reduces nutrient losses by locking in essential elements like nitrogen, phosphorus, and potassium. This ensures that fertilizers are used more efficiently, lowering input costs for farmers.

Enhances Water Retention: In drought-prone regions, biochar proves especially useful. Its porous nature helps soils store more water, making it available to crops during dry spells.

Boosts Crop Yields: Field trials have shown that crops such as rice, maize, wheat, and pulses respond positively to biochar application. Healthier soils result in stronger root systems and higher productivity.

Supports Long-Term Soil Health: Unlike compost or manure, which decompose within a year or two, biochar is highly stable. A single application can improve soil fertility for several years, contributing to long-term sustainability.

Environment-Friendly: By utilizing agricultural waste (like parali), biochar reduces open-field burning, thereby lowering air pollution. It also stores carbon in the soil for centuries, helping mitigate climate change.

Challenges in Adopting Biochar

Limited Awareness: Many farmers are still unaware of biochar and its benefits.

High Initial Cost: Setting up pyrolysis units requires investment, making large-scale adoption difficult.

Quality Issues: Biochar's effectiveness depends on

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the raw material and production method. Without standard guidelines, performance may vary.

Soil Variability: Different soils respond differently to biochar; what works in one field may not work the same way in another.

Way Forward

Biochar holds the promise of being a game-changer for Indian agriculture. To make it successful, the following steps are essential:

- ✓ Conducting farmer awareness campaigns through extension services.
- ✓ Promoting low-cost, village-level biochar units.
- ✓ Providing government support or subsidies for production and application.
- ✓ Encouraging research to develop standardized methods for different crops and soils.

Conclusion

Biochar is more than just a soil amendment it is a tool for sustainable farming. By improving soil fertility, reducing dependency on costly fertilizers, and utilizing farm waste, it can enhance both farmer income and environmental health. While challenges exist, collective efforts from researchers, policymakers, and farmers can unlock the true potential of this "black gold." With wider adoption, biochar could become a cornerstone of eco-friendly and profitable agriculture in India.

Spine Gourd Farming: A Profitable Vegetable Crop

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Introduction

Spine gourd (*Momordica dioica*), also known as kantola, kakrol, teasel gourd, or small bitter gourd, is a perennial climbing cucurbitaceous vegetable crop cultivated mainly during the rainy season in India, Bangladesh, Nepal, and Southeast Asian countries. It is valued for its nutritional richness, being a good source of protein, iron, vitamin C, carotenoids, and dietary fiber. The fruits are less bitter compared to bitter gourd, making them a popular choice for curries, fries, and pickles. Apart from culinary uses, spine gourd has traditional medicinal applications for curing diabetes, liver disorders, inflammation and digestive problems. Increasing market demand, particularly during the rainy season when supply of other vegetables is limited, makes this crop highly profitable for farmers.

Varieties

Indira Kankoda-1 (IK-1): Released by Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur (Chhattisgarh). It is a high-yielding selection, tolerant to common pests and diseases, and produces uniform, tender green fruits.

Rajendra Kantola-1: Developed at Rajendra Agricultural University, Bihar. It is early maturing and suitable for cultivation in the eastern states.

Kantola Selection-1 (local types): Maintained by farmers in Meghalaya, Odisha, Jharkhand, and West Bengal, known for good fruit set and high carotene content.

Climate and Soil: It grows well in specific climate conditions and it suitable for tropical and subtropical areas with warm and humid weather. The ideal temperature for its growth is between 25-30°C. The crop performs well in the rainy season, but it can also be cultivated in summer if irrigation is provided. Spine gourd is a perennial climbing plant with tuberous roots and needs staking or trellis support for healthy vine growth and good fruiting. It prefers sandy loam to clay loam soils that are fertile, well-drained, and rich in organic matter, with a soil pH of 6.0-7.5. Waterlogged or low-lying fields are not suitable, as excess moisture can damage the roots and lower the yield.

Propagation Methods: Propagation of spine gourd is generally done through tuberous roots or stem cuttings since the crop is dioecious and seed propagation leads to a higher proportion of male plants, which are non-fruiting. For commercial cultivation, farmers usually select healthy tubers from previous crops, weighing about 40-60 g each

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and plant them at a spacing of 2.0 m × 1.5 m. About 8,000-10,000 tubers are required per hectare. Before planting, tubers should be treated with fungicides like carbendazim to prevent soil-borne diseases. In case of stem cuttings, 20-25 cm long cuttings with 2-3 nodes are used for planting. For ensuring fruit set, a ratio of 10:1 female to male plants is maintained, as the presence of some male plants is necessary for pollination.

Manure and Fertilizers: The field is prepared thoroughly with deep ploughing and harrowing, followed by incorporation of 20-25 tonnes of well-decomposed farmyard manure (FYM) ha^{-1}. Raised beds or ridges are preferred to avoid water stagnation. Fertilizer requirement for spine gourd is moderate, with a recommended dose of 60-80 kg nitrogen, 40-50 kg phosphorus, and 50-60 kg potassium ha^{-1}, applied in split doses. Half of nitrogen along with full phosphorus and potassium is applied at planting, while the remaining nitrogen is top-dressed in two equal splits at 30 and 60 days after planting. Foliar sprays of micronutrients such as zinc sulphate and boron are also beneficial in enhancing flowering and fruit setting. Mulching with crop residues or polythene sheets helps in conserving soil moisture, suppressing weeds, and improving fruit quality.

Irrigation: Irrigation plays a vital role in spine gourd cultivation, especially during dry periods. Though the crop is grown primarily during the monsoon season, it requires supplemental irrigation in case of rainfall shortage. Drip irrigation is highly recommended for maintaining optimum soil moisture and promoting better growth of vines and tubers.

Intercultural Practices: Weed management is crucial during the initial growth stages, and manual weeding combined with mulching is generally practiced. Since spine gourd is a climbing plant, trellis or bower systems made from bamboo poles, wires, or iron angles are erected to provide proper support to the vines, which enhances aeration, light interception, and ultimately improves yield and fruit quality.

Harvesting and Yield: Harvesting of spine gourd begins about 80-90 days after planting, and fruits are picked when they are tender, green, and spiny. Harvesting is done at intervals of 3-4 days to ensure continuous fruiting. Each plant yields around 40-50 fruits per season, and the average yield ranges from 8-12 tonnes ha^{-1} under good management practices. Fruits are packed in bamboo baskets or plastic crates and marketed in local as well as distant markets. Since the crop is available during the rainy season when other vegetables are scarce, it fetches a premium price, thus offering good profitability to growers.

Pests and Diseases

Major Pests

Fruit fly (*Bactrocera cucurbitae*): Causes fruit damage.

Control: Use pheromone traps, bagging of fruits, or application of neem seed kernel extract (NSKE).

Red pumpkin beetle: Feeds on leaves and flowers.

Control: Soil application of carbaryl or neem cake.

Diseases

Powdery mildew (*Erysiphe cichoracearum*)

Downy mildew (*Pseudoperonospora cubensis*)

Fusarium wilt (*Fusarium oxysporum*)

Control: Use disease-free planting material, crop rotation and fungicidal sprays (mancozeb, carbendazim).

Conclusion

In conclusion, spine gourd is an underutilized yet nutritionally rich cucurbit with vast potential in Indian horticulture. With proper agronomic practices including the use of healthy planting material, balanced fertilization, effective pest and disease management, and improved post-harvest handling, farmers can enhance productivity and profitability. Considering its high nutritional value, increasing consumer demand, and adaptability to diverse agro-climatic conditions, spine gourd cultivation can significantly contribute to crop diversification, nutritional security and sustainable income for farmers, especially in rainfed and tribal areas of India.

Big Data and Artificial Intelligence in Agricultural Statistics: Opportunities and Challenges

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Abstract

The integration of Big Data and Artificial Intelligence (AI) into agricultural statistics offers transformative opportunities for enhancing productivity, sustainability, and resilience in farming systems. These technologies enable precise monitoring, predictive analytics, and optimized resource management. However, their adoption faces challenges such as data quality issues, infrastructure limitations, and the need for skilled personnel. This article explores the potential benefits and obstacles associated with the application of Big Data and AI in agricultural statistics, emphasizing the importance of addressing these challenges to fully realize their advantages.

Introduction

Agriculture, a cornerstone of global food security and economic stability, is undergoing a significant transformation through the integration of digital technologies. Big Data and Artificial Intelligence (AI) are at the forefront of this revolution, offering unprecedented capabilities in data collection, analysis, and decision-making. These advancements promise to enhance agricultural productivity, sustainability, and resilience. However, the implementation of these technologies also presents a range of challenges that must be addressed to ensure their effective utilization.

The Role of Big Data and AI in Agricultural Statistics

Big Data in Agriculture: Big Data refers to the vast volumes of structured and unstructured data generated from various sources such as satellite imagery, sensor networks, weather stations, and market transactions. In agriculture, this data encompasses information on soil health, crop performance, climatic conditions, and market trends. The analysis of Big Data allows for the identification of patterns and trends that can inform decision-making processes.

Artificial Intelligence in Agriculture: AI involves the use of algorithms and machine learning models to analyze data, make predictions, and automate tasks. In agriculture, AI applications include crop disease detection, yield prediction, precision irrigation, and supply chain optimization. By processing large datasets, AI can provide insights that enhance efficiency and productivity in farming operations.

Opportunities Presented by Big Data and AI

Enhanced Decision-Making: The integration of Big Data and AI enables farmers and policymakers to make informed decisions based on real-time data and

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predictive analytics. For instance, AI models can forecast crop yields, allowing for better planning and resource allocation. Similarly, Big Data analytics can identify market trends, helping farmers to align production with demand.

Improved Resource Management: AI-driven precision agriculture techniques optimize the use of resources such as water, fertilizers, and pesticides. By analyzing soil moisture levels and weather patterns, AI systems can recommend optimal irrigation schedules, reducing water wastage. This not only conserves resources but also minimizes environmental impact.

Early Detection of Pests and Diseases: AI-powered image recognition and sensor technologies can detect early signs of pests and diseases in crops. By identifying these threats promptly, farmers can take targeted actions to mitigate damage, reducing the need for broad-spectrum pesticide applications and enhancing crop health.

Supply Chain Optimization: Big Data analytics facilitate the optimization of agricultural supply chains by providing insights into production, transportation, and market dynamics. This leads to reduced food waste, improved logistics, and better alignment of supply with consumer demand.

Challenges in Implementing Big Data and AI in Agriculture

Data Quality and Accessibility: The effectiveness of Big Data and AI relies heavily on the quality and accessibility of data. In many regions, especially in developing countries, data collection infrastructure is inadequate, leading to incomplete or inaccurate datasets. Additionally, data silos and lack of standardization hinder the integration and sharing of information.

Infrastructure Limitations: Implementing AI and Big Data solutions requires robust technological infrastructure, including high-speed internet, data storage facilities, and computational resources. In rural areas, these infrastructure components are often lacking, posing significant barriers to the adoption of digital agriculture technologies.

Skill Gaps: The deployment of AI and Big Data in agriculture necessitates a workforce with specialized skills in data science, machine learning, and agronomy. There is a shortage of professionals with the requisite expertise, and existing training programs may not be accessible to all farmers, particularly those in remote areas.

Privacy and Ethical Concerns: The collection and analysis of large volumes of data raise issues related to data privacy and ethics. Farmers may be reluctant to share data due to concerns over ownership, security, and potential misuse. Establishing clear data governance frameworks is essential to address these concerns and build trust among stakeholders.

Case Studies and Applications

India: Satellite Data for Crop Management

In India, the integration of satellite data with AI has led to significant improvements in crop management. For example, Indian farmer Lokeswara Reddy utilized satellite data from Cropin, facilitated by Syngenta, to optimize sowing times, manage

irrigation, and forecast weather patterns. As a result, his net profit per acre increased from 5,000-10,000 rupees to 20,000 rupees, demonstrating the potential of digital agriculture in enhancing farm income.

IIIT-Allahabad: Real-Time Crop Disease Detection

Researchers at the Indian Institute of Information Technology (IIIT) Allahabad developed an AI-based technology for real-time crop disease detection. The system uses a combination of AI, Internet of Things (IoT), deep learning, and federated learning to analyze crop health through leaf images and environmental data. With a detection success rate of up to 97.25%, this innovation offers a breakthrough for Indian agriculture, particularly in remote areas.

Strategies for Overcoming Challenges

Enhancing Data Infrastructure: Investing in data collection infrastructure, such as weather stations, soil sensors, and satellite imaging, is crucial for obtaining high-quality data. Governments and private sector entities should collaborate to build and maintain these infrastructures, ensuring data is accurate, timely, and accessible.

Capacity Building and Training: Developing training programs that equip farmers and agricultural professionals with skills in data analysis and AI is essential. These programs should be tailored to the local context and delivered in accessible formats, such as mobile applications and community workshops.

Establishing Data Governance Frameworks: Creating clear policies regarding data ownership, privacy, and sharing can address ethical concerns and build trust among stakeholders. These frameworks should be developed collaboratively, involving farmers, policymakers, and technology providers.

Promoting Public-Private Partnerships: Collaboration between governments, research institutions, and private companies can facilitate the development and deployment of AI and Big Data solutions. Public-private partnerships can pool resources, share knowledge, and scale successful initiatives.

Conclusion

The integration of Big Data and AI into agricultural statistics holds immense potential for transforming farming practices, enhancing productivity, and ensuring food security. While challenges such as data quality, infrastructure limitations, and skill gaps exist, they are not insurmountable. Through concerted efforts in infrastructure development, capacity building, and policy formulation, these challenges can be addressed. By harnessing the power of digital technologies, agriculture can move towards a more sustainable and resilient future.

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Pest Management Strategies against Major Insect Pests of Chilli

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Introduction

Chilli, *Capsicum annuum* L. (Solanales: Solanaceae) is one of the important commercial spice cum vegetable crop cultivated widely in the world. Chilli peppers are primarily used as a spice to add flavour and pungency to food and also used in various culinary preparations. Capsaicin, the compound responsible for the pungency in chilli peppers is being used in traditional medicine to cure various human ailments like arthritis, muscle pain and neuropathy (Chilliwiki, 2024). Mexico was considered to be the native home of chilli and it was first introduced in to India by the Portuguese in Goa in the middle of 17th century. India is the largest producer, consumer and exporter of chilli, contributing about 40% of the world's chilli production followed by China, Thailand, Ethiopia and Indonesia (FAO statistical yearbook, 2024). The chilli crop is subjected to attack by about 57 insect and non-insect pests (Venugopal *et al.,* 2018) of which the yellow thrips, *Scirtothrips dorsalis* Hood (Thripidae: Thysanoptera) and tarsonemid mite, *Polyphagotarsonemus latus* (Banks) (Tarsonemidae: Acari) are the most devastating pests. The thrips and mites have relatively shorter life cycle, complete several generations in a single crop season and multiply at a faster rate accounting for huge losses. Affected leaves curl upward and downward resulting in a typical damage symptom known as "leaf curl syndrome/murda complex". The crop is attacked at both vegetative and reproductive stages by the regular pest, *S. dorsalis* which causes a quantitative yield loss of 11 to 75 per cent and 60 to 80 per cent, qualitatively (Venugopal *et al.,* 2019). This is the trend till 2020-21, but there is a havoc caused by another invasive thrips species i.e. *Thrips parvispinus* which is commonly called as South East Asian thrips/black thrips. This pest species attacking the chilli flowers and feeds on the pollen, later dwindling the yield tremendously. Because of its severity, the chilli farmers resort to abandon the crop or plough the standing crop. There were instances of burning of the crop also. Fruit borers also cause huge loss by attacking the borers.

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There is need of comprehensive management of both sucking and borer pests in the chilli ecosystem.

Pest management strategies during nursery: Thrips and mites are major pests attacking chilli seedlings for which the following management strategies can be recommended. The beds should be raised and apply 1 kg of neem seed kernel powder along with10 kg of vermicompost. Apply 80 g fipronil 0.2G granules in the bed to manage these sucking pests. Before sowing go for seed treatment using imidacloprid 70 WS @ 8 g kg^{-1} of seed.

Pest management strategies in the main field

Thrips: Thrips can be controlled by spraying insecticides like broflanilide 300 g l^{-1} SC @ 0.2 ml l^{-1} or cyantraniliprole 10.26 % OD @ 1.2 ml l^{-1} or fipronil 05 % SC @ 2 ml l^{-1} or fluxametamide 10% w/w EC@ 1 ml l^{-1} or spinetoram 11.70 % SC@ 1 ml l^{-1}. Apart from that install blue, white and yellow coloured sticky traps at 20 number $acre^{-1}$. Guard crops like jowar or maize can be sown in 2 rows in order to curb the movement of these thrips from one field to another. Frequent intercultural operations better to kill the pupae.

Black thrips (*Thrips parvispinus*)

Yellow thrips (*Scirtothrips dorsalis*)

Leaf curling due to thrips damage

Fruit scarification due to thrips

The synthetic inbsecticides can be interchanged with the biopesticides like azadirachtin 1500 ppm @ 3 ml l^{-1} or *Lecanicillium lecnaii/Beauveria bassiana/ Metarhizium anisopliae* @ 5 g l^{-1}.

Mites: These mites can be controlled by spraying any of the insecticides like chlorfenapyr 10 % SC @ 2 ml l^{-1} or cyenopyrafen 30 % @ 2 ml l^{-1} or diafenthiuron 50 % WP @ 1.2 g l^{-1} or fenazaquin 10 % EC @2.5 ml l^{-1} or fenpyroximate 05 % EC @ 1.2 ml l^{-1} or spiromesifen 22.90 % SC @ 1 ml l^{-1}.

Aphids: Aphids can be controlled by spraying of flonicamid 50 % WG @ 0.4 g l^{-1} or imidacloprid 70 WS @ 0.7 G l^{-1} or tolfenpyrad 15 % EC @ 2 ml l^{-1} or acephate 50 + imidacloprid 1.8 SP @ 2 g l^{-1} and also mechanically these can be managed using yellow sticky traps @ 20 no. $acre^{-1}$.

Whiteflies: Whiteflies can be controlled by spraying any of the insecticides like acetamiprid 20 % SP @ 0.2 g l^{-1} or dimpropyridaz 120 g l^{-1} SL @ 2 ml l^{-1} or pyriproxyfen 10 % EC @1.70 ml l^{-1}. Yellow sticky traps can also be installed @ 20 $acre^{-1}$ for its effective management.

Fruit borers: Chilli fruits are attacked by *Helicoverpa armigera*, *Spodoptera litura* and *Utetheisa pulchella*. These can be controlled by spraying insecticides like spinosad 45 SC@ 0.32 ml l^{-1} or chlorantraniliprole 5.2% + novaluron 8.5 SC @ 1 ml l^{-1} or flubendimide 39.35 SC @ 0.25 ml l^{-1}. Install pheromone traps @ 20 $acre^{-1}$ and change the lure every 25 days and also keep trap crops like castor and marigold. The bio pesticides like HaNPV and SlNPV can be sprayed @ 5 ml l^{-1} for their effect-

ive management.

Conclusion

Chilli is a major spice cum vegetable crop is being attacked by many insect and non insect pests. Among them, thrips, mites, whiteflies and fruit borers are the major ones dwindling the yield. Based on proper monitoring of the pest, any of the above pest management strategy can be adopted for obtaining higher yields.

Seaweed Farming: The Untapped Ocean Opportunity

Alisha Sinha

Introduction

Agriculture has traditionally been associated with soil, crops, and livestock, but the 21st century is redefining its scope. With climate change, depleting freshwater resources, and the increasing demand for sustainable food and energy, scientists and entrepreneurs are turning to the ocean as the new frontier of farming. Among the various marine resources, seaweed farming has emerged as a promising opportunity that combines food security, livelihood generation and environmental conservation. Globally, seaweed cultivation is a billion-dollar industry, dominated by countries like China, Indonesia, and South Korea. India, with its 7,500 km long coastline and rich biodiversity, holds immense potential but has only tapped a fraction of this opportunity. Seaweed farming is not only a source of food, feed, and fertilizer but also a raw material for biofuel, pharmaceuticals, cosmetics, and even biodegradable packaging. At a time when the world is looking for climate solutions, seaweed stands out as a naturally it absorbs carbon dioxide, cleans seawater, and requires no freshwater or fertilizers.

This article explores the untapped potential of seaweed farming, its applications, challenges, and the way forward for India.

What is Seaweed Farming?

Seaweeds are marine algae that grow along rocky shorelines, shallow waters, and sometimes deep seas. Unlike terrestrial crops, they do not need soil, irrigation, or synthetic fertilizers. Seaweed farming involves the cultivation of specific species of algae such as *Kappaphycus*, *Gracilaria*, *Sargassum*, and *Ulva* using ropes, nets, or rafts placed in seawater.

The process is relatively simple: fragments of seaweed are tied to ropes or nets and suspended in shallow waters. Over a period of 45-60 days, they grow rapidly and are harvested for commercial use. With proper training, a coastal farmer can start seaweed cultivation with low investment and reap multiple harvests annually.

The Global Importance of Seaweed

Seaweed farming has expanded rapidly in Asia and the Pacific, making it one of the fastest-growing sectors in aquaculture. According to the Food and Agriculture Organization (FAO), over 35 million tonnes of seaweed are produced annually worldwide, valued at nearly USD 15 billion.

- ✓ China leads the industry, accounting for nearly 60% of global production.
- ✓ Indonesia and the Philippines dominate the export of carrageenan and agar, two valuable extracts from red seaweeds.
- ✓ South Korea and Japan focus on high-value edible seaweeds such as nori and wakame.

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Seaweed has become a staple in Asian cuisines, health supplements, and the cosmetics industry. Its global demand is projected to increase significantly as industries look for natural, renewable, and eco-friendly raw materials.

Seaweed Farming in India: Current Scenario

India's long coastline and tropical climate are ideal for seaweed cultivation. Coastal states like Tamil Nadu, Gujarat, Andhra Pradesh, and Odisha have natural habitats for various seaweed species. However, India contributes less than 1% of global production indicating a huge gap between potential and reality.

The Central Marine Fisheries Research Institute (CMFRI), along with agencies like the National Fisheries Development Board (NFDB) and ICAR, has been promoting seaweed farming among fisherfolk and coastal communities. Pilot projects in Tamil Nadu and Gujarat have shown that seaweed cultivation can provide an additional income of ₹15,000-20,000 month^{-1} for coastal families.

The Pradhan Mantri Matsya Sampada Yojana (PMMSY) launched in 2020 includes provisions to support seaweed farming with infrastructure, seed banks, and financial assistance. The government also aims to produce 1 million tonnes of seaweed by 2025, making it a sunrise sector for India's blue economy.

Applications of Seaweed

The versatility of seaweed is one of its biggest strengths. It is used across multiple sectors:

Food and Nutrition: Seaweed is rich in proteins, vitamins, minerals, and antioxidants. It is consumed as a staple in Japan, Korea, and China in the form of sushi wraps, soups, and salads. In India, edible seaweed products such as snacks, noodles, and powders are slowly gaining popularity among health-conscious consumers.

Agriculture and Fertilizers: Seaweed extracts like liquid biofertilizers enhance soil fertility and promote plant growth. They improve seed germination, increase crop yields, and make plants resistant to pests and diseases. Farmers in India are beginning to use seaweed-based bio-stimulants as eco-friendly alternatives to chemical fertilizers.

Pharmaceuticals and Cosmetics: Seaweed contains bioactive compounds used in medicines for blood pressure, cholesterol, and weight management. The cosmetics industry uses it in creams, shampoos, and face masks due to its skin-hydrating and anti-aging properties.

Industrial Applications: Carrageenan and agar, extracted from red seaweeds, are widely used as gelling and thickening agents in food processing, textiles, and biotechnology.

Biofuel and Bioplastics: Seaweed can be processed into bioethanol and biogas, offering renewable alternatives to fossil fuels. Additionally, biodegradable packaging from seaweed-based films is gaining traction as a replacement for single-use plastics.

Environmental Benefits of Seaweed Farming

Seaweed farming is not just an economic activity; it also delivers ecological benefits:

Carbon Sequestration: Seaweed absorbs 20 times

more carbon dioxide than trees, helping mitigate climate change.

Oxygen Production: It releases oxygen into the water, supporting marine life.

No Freshwater Use: Unlike land crops, seaweed needs no irrigation, reducing pressure on scarce freshwater resources.

Wastewater Treatment: Seaweeds absorb excess nutrients like nitrogen and phosphorus, cleaning coastal waters and preventing algal blooms.

Biodiversity Support: Seaweed farms provide shelter and breeding grounds for fish and shellfish.

Thus, seaweed farming aligns with the goals of sustainable agriculture and the blue economy.

Challenges Facing Seaweed Farming in India

Despite its potential, seaweed farming in India faces several challenges:

Limited Awareness: Most coastal communities are unaware of the benefits and opportunities of seaweed cultivation.

Infrastructure Gaps: Lack of hatcheries, processing units, and cold storage limits scalability.

Environmental Risks: Overharvesting of natural seaweed beds can harm marine ecosystems.

Market Linkages: Farmers often lack access to direct buyers and depend on middlemen, reducing profits.

Policy and Regulation: Absence of clear policies for leasing coastal waters and sustainable farming practices creates uncertainty.

Addressing these barriers requires coordinated efforts between government, research institutions, and private players.

The Way Forward

To make seaweed farming a success story in India, the following steps are crucial:

Capacity Building: Training programs for fisherfolk and women self-help groups.

Infrastructure Development: Setting up seed banks, nurseries, and processing plants.

Financial Support: Subsidies, low-interest loans, and insurance schemes for seaweed farmers.

Research and Innovation: Developing high-yield, disease-resistant seaweed strains.

Public-Private Partnerships: Encouraging industries to invest in seaweed farming and processing.

Export Promotion: Positioning India as a global supplier of high-quality seaweed products.

If implemented effectively, seaweed farming can provide livelihoods to thousands of coastal families while contributing to India's sustainable development goals.

Conclusion

Seaweed farming represents a perfect example of how agriculture is moving beyond land and soil to embrace oceans and sustainability. It offers triple benefits: food and income security for coastal communities, raw materials for diverse industries, and ecological services that combat climate change. For India, the untapped ocean opportunity is waiting to be harnessed. With scientific support, policy backing and entrepreneurial initiatives, seaweed farming could transform India into a global hub for marine bio-resources.

As agriculture students and future policymakers, understanding this hidden potential is vital. Seaweed is not just algae it is a symbol of how innovation and nature can work together to shape the future of farming.

Fungal Proteomics as a Tool to Study Plant Microbe Interactions

Manjari and Smriti

Introduction

Proteomics is defined as the systematic analysis of the proteome, the protein complement expressed by a genome, cell, tissue or organism. Proteins play a critical role in diverse biological processes through interactions with other proteins, DNA and other molecules. Consequently, fungal proteomics is defined as the study of the intracellular and extracellular protein complement of fungi. Fungi are responsible for causing harmful diseases in plants; therefore, a detailed analysis of their biochemistry is important to understand the mechanism of disease caused by them. Multiple techniques, including mass spectrometry, genome and transcriptome sequencing and advances in bioinformatics, are used to study fungal proteomics.

Techniques to study the Proteome of Fungi

Recent advances in proteomic technologies offer an exciting opportunity to reveal the fluctuations of fungal proteins and enzymes. An alternate approach is to tag proteins of interest with epitopes that can be detected with commercially available antibodies (Aslam *et al.*, 2016).

There are various methods to study the proteome of fungi (Bianco and Perrotta, 2015)

Gel-based approaches: Gel-based separation techniques rely on one-dimensional or two-dimensional polyacrylamide gel electrophoresis (SDS-PAGE or 1-DE and 2-DE), which are very popular methods for their robustness and simplicity. For several decades, SDS-PAGE has been one of the most used tools for the separation and pre-fractionation of protein extracts

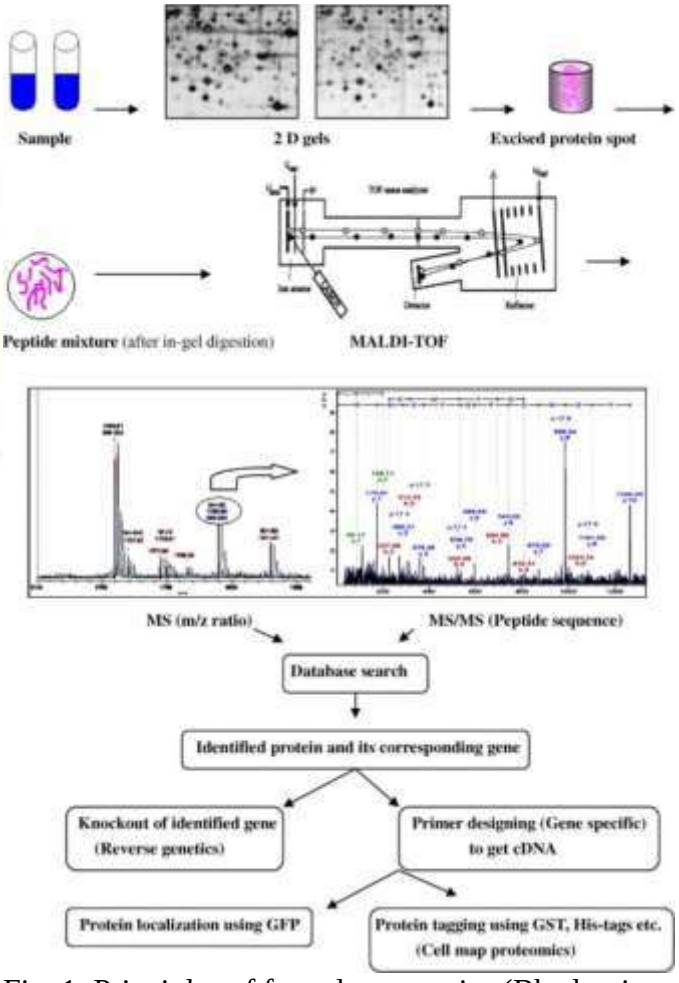

Fig. 1: Principles of fungal proteomics (Bhadauria *et al.* (2007)

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Gel-free approaches: Among different possible approaches to study proteins, MS-based proteomics represents the most attractive technology that should probably be considered as complementary to gel-based applications rather than a mere replacement.

Conclusion

Proteomics will play a significant role in future research in disease management and biotechnological uses of fungi. Although the assignment of biological roles of both *in silico* annotated and unannotated genes remains a significant challenge, it is clear that this phenomenon will accelerate our understanding of fungal biology and yield the identification of many new enzymes for biotechnological uses.

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Fiddlehead Fern: A Nutrient Enriched Wild Edible Green

Shivani and Shweta

Introduction

Fiddlehead fern (*Matteuccia struthiopteris* (L.) Todaro) commonly known as the ostrich fern belongs to the family Onocleaceae and is native to North America. It is a forest dwelling plant which requires partial shade and enough moisture for its growth and is suited for grown in spring season in cool and wet climate. They are mainly used as immature vegetative fronds when they are tightly curled and after unfurling, they grow into a tall vegetative frond known as trophophylls. They are resistive to floodwater because of their dense foliage and suitable to grow on slightly acidic soils with high organic matter for upland cultivation. The rhizomes are extracted for starch and young fiddlehead ferns are used as a vegetable while all other parts had been traditionally used to make medicines, lotions and baths. In India, fiddlehead plants are commonly found in hilly damp areas of Jammu & Kashmir, Himachal Pradesh, Uttarakhand etc. where they naturally grow on their own in open conditions without any proper care or cultivation practices. They hold the soil together with the help of their rigid crowns and prevent soil erosion. It propagates in three ways: spores, cloning and tissue culture propagation. Spores are released in winter months from dried fertile fronds and grows at temperature below 5ºC whereas asexual reproduction is done by horizontal roots and lateral meristems. It is consumed as a fresh spring vegetable and is preserved by drying, freezing, salting and canning to extend its shelf-life (Aderkas, 1984). In dried form they can be preserved for 2-3 years with the help of salt. In open conditions, 50% harvesting in consecutive years is beneficial to maintain plant vigour and health whereas in controlled conditions a great number of harvestings can be done. Fiddleheads are not consumed raw or improperly cooked as it can lead to toxicity due to presence of plant toxin. Therefore, they should be boiled properly before consumption to avoid illness promoting pathogens (Bruneau *et al*., 2000).

Fig. 1: Edible Fiddlehead ferns (croziers)

Nutritional importance: Fiddleheads are a rich source of omega-6 and omega-3 fatty acids making them a valuable vegetable in vegetarian diet as these are majorly found in fish, seeds and nuts. They are rich in carotenoids (lutein, neoxanthin, violaxanthin, β-Carotene), antioxidant ascorbate, minerals (phosphorus, iron, magnesium, zinc and calcium), Vit-A, Vit-C and phenolic compounds. It is low in calories and fat and have high protein digestibility

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(Dvorakova *et al.,* 2021). They contain 85-87% water, 4.2 g protein, 3.1 g carbohydrates, 0.5 g fat, 1.12 g fibre per 100 g fiddlehead greens and have high potassium and low sodium content which is helpful for maintaining heart health (Bushway *et al.*, 1982).

Fig. 2: Immature young fern fronds

Benefits and Uses

- ✓ It improves overall health due to presence of more than 6 biologically active compounds which provides multiple health promoting benefits.
- ✓ It aids in the reduction of cancer cells due to presence of pinosylvin an anti-proliferative compound, promote heart and skin health, strengthens the immunity and treats the migraine (Li *et al.,* 2013).
- ✓ They were used as medicine in Russia for treating intestinal worms whereas in China their rhizomes were used to treat cold, dysentery haemato-chezia, uterine haemorrhage and pinworms (Zhang *et al.,* 2013).
- ✓ They have anti-inflammatory properties which help in reduction of cardiovascular diseases, regulates hormonal disorders, prevent arthritis and allergies (Delong *et al.,* 2011).
- ✓ Fern starch is used in the preparation of noodles, cakes, soft beverages and even whiskey while fern leaves are commonly used to make herbal tea (Liu *et al*., 2012).
- ✓ Before cooking, fiddlehead fibres are removed as outer chaff consist of tannins responsible for bitter taste and to remove dirt before consuming.
- ✓ They contain good extent of dietary fibres in comparison to other leafy greens and berries.

Fig. 3: Fiddlehead chaff (fibres)

Future scope

In the contemporary scenario, fiddlehead is a seasonal vegetable harvested from the wild and is present only in limited areas. It provides great opportunity to the small scale and marginal farmers as a business startup to cultivate fiddleheads in different climates and varied regions to meet the consumer demand and to expand its availability all over India which in return generate revenue as well. In addition to this, it is beneficial to processing industry for preparation of products like fiddlehead pickles, dried powder, ready to eat foods, value-added products, canning for year-round availability and selling it on commercial scale. It is a superfood for health-conscious consumers as it is high in healthy fats. There has been limited knowledge and research on fiddlehead production, varieties, nutritional, medicinal components, processing and

breeding on which researchers should work. By this approach, it can be brought from wild to cultivated form and can be saved from turning extinct.

Conclusion

Ferns are powerhouse of nutrients which improves overall well-being and can be called as protective food because they contain all the essential vitamins, minerals and fatty acids which protects human health against bacteria, viruses and are equipped with anti-diabetic, anti-diarrhoeal and anti-inflammatory properties. The production, processing and consumption of fiddleheads not only fulfil the demand of the society but also promotes the food and nutritional security of India.

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Transforming the Future of Agriculture through Blockchain and Artificial Intelligence

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Introduction

Blockchain and Artificial Intelligence are revolutionizing agriculture by boosting transparency, improving crop yields, and enabling smarter decisions. From supply chain traceability to Artificial Intelligence powered disease detection and automated farming, these technologies are helping farmers reduce waste, increase profits and farm sustainably. Technology is changing how we farm. Two major innovations Blockchain and Artificial Intelligence (AI) are helping farmers grow more food, make better decisions, and manage resources more efficiently. Blockchain and Artificial Intelligence are transforming farming by increasing supply chain transparency, improving resource management, enhancing predictive capabilities, and automating tasks through smart contracts and robotics. Blockchain provides secure, transparent records of agricultural products from farm to table, while AI analyzes data to predict crop yields, forecast weather, detect diseases, and optimize irrigation. Together, these technologies enable more efficient, sustainable, and profitable "smart farming" practices, addressing challenges like food security, resource scarcity and market volatility.

Blockchain: Block chain is a digital system that stores data in secure blocks. Once added, the data cannot be changed or deleted. It ensures transparency, trust, and traceability in transactions very useful for the food supply chain.

Blockchain in agriculture: Blockchain is a digital system that records and secures data. In agriculture, it helps track the journey of food from farm to table, ensuring safety, quality, and transparency in the supply chain.

AI in Agriculture: AI is the use of smart machines or software that can think, learn, and make decisions. In agriculture, AI is used to analyse data, predict outcomes, and automate tasks. Together, these technologies are creating "smart agriculture" a more efficient, productive and sustainable way of farming.

Blockchain Helps Agriculture

Improves Traceability: Blockchain records every stage of food production from planting to delivery. This helps track where food comes from, how it was grown, and if it's safe to eat.

Builds Trust in the Supply Chain: With block-chain, everyone (farmers, buyers, retailers, and

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consumers) can view real-time updates on a single, secure platform. This builds trust between producers and consumers.

Prevents Food Fraud: By using blockchain, fake or spoiled products can be quickly identified and removed, reducing fraud and waste.

Supports Fair Pricing: Blockchain eliminates the need for multiple middlemen. Farmers can directly connect with buyers, which helps them get better prices for their crops.

Data Security: Offers a secure way to store and share critical agricultural data, protecting farmers' information and intellectual property.

Smart Contracts: Automates transactions between farmers, suppliers and buyers, reducing intermediaries and ensuring fair pricing.

Certification and Verification: Allows farmers to provide verifiable records of their compliance with standards, such as organic or fair-trade certifications.

Improved Crop Insurance: Streamlines the insurance process by creating a transparent and efficient system to assess risk based on recorded data like yields and weather.

AI Transforming Agriculture

Crop Monitoring and Disease Detection: AI-powered drones and sensors scan fields to detect diseases, pests, or low-nutrient levels early helping prevent crop loss.

Predictive Analytics: AI tools use weather data, soil reports, and market trends to predict the best time to plant, water, and harvest crops.

Automated Machinery: Smart tractors and robots use AI to plant seeds, spray fertilizers, and harvest crops, reducing manual labour and increasing accuracy.

Livestock Management: I systems monitor animals' health, diet, and movement. This helps in early illness detection and improves productivity.

Precision Agriculture: Uses computer vision and machine learning to accurately allocate resources like water and fertilizer based on real-time data, optimizing usage.

Enhanced Resource Management: Optimizes water usage and irrigation by analysing soil moisture, weather, and plant stress indicators.

The Integrated Future

Sustainable and Resilient Agriculture: AI and blockchain contribute to more sustainable practices by reducing waste, optimizing resource use, and enhancing food security.

Increased Profitability: Greater efficiency, reduced losses, and better market access through predictive analytics lead to increased profits for farmers.

Farming 4.0: This combination of AI, IoT, and blockchain ushers in the Fourth Agricultural Revolution, or "Agriculture 4.0," characterized by smart, data-driven, and autonomous operations.

Future Agriculture using of AI

Application of AI in agriculture provides farmers with real-time crop insights, helping them to identify which areas need automating irrigation, fertilization, or pesticide treatment and detecting diseases early. Innovative farming practices such as vertical agriculture can also increase food production

while minimizing resource usage.

Blockchain for natural farming

Blockchain technologies can track all types of information about plants, such as seed quality, crop growth and even generate a record of the journey of the plant after it leaves the farm.

Real-Life Examples

- ✓ IBM Food Trust uses blockchain to track food from farm to table.
- ✓ Microsoft AI for Earth supports agricultural AI tools to monitor crop health.
- ✓ Smart farming start-ups like Agri Digital and Farm Trace combine blockchain and AI to improve efficiency.

Benefits of Using Blockchain and AI in Agriculture

- ✓ Increases transparency and accountability
- ✓ Reduces waste, cost and fraud
- ✓ Helps make data driven decisions
- ✓ Improves crop yield and profitability
- ✓ Encourages sustainability and climate smart farming
- ✓ Blockchain and AI are no longer future technologies they're already making farming smarter.
- ✓ Whether it's a small organic farm or a large agricultural company, these tools offer clear advantages in quality, safety, and productivity.
- ✓ For the future of food, embracing these technologies is a smart move.

Disadvantages of AI in agriculture

Disadvantages of AI in agriculture include high implementation costs that exclude small farmers, potential for job displacement and skill gaps for rural workers, the need for reliable internet connectivity in many rural areas, and concerns over data privacy, security, and ownership. Additionally, there are challenges with limited and biased data, a lack of human expertise, potential biases in algorithms, and the slow adoption process due to resistance to change and the need for significant infrastructure.

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Eyes in the Sky, Intelligence on the Ground: Revolutionizing Crop Protection with AI-Powered Pest and Disease Detection

Suvojit Bose, Sourav Mollick, Subhadwip Ghorai and Soham Hazra

Abstract

This article explores the untapped potential of underutilized and forgotten vegetable crops in India, highlighting their importance for nutrition, food security, and climate resilience. Drawing from a comprehensive review in The Pharma Innovation Journal, it discusses the reasons for their neglect, including a lack of research and knowledge. The document showcases several power-packed performers such as Spine Gourd, Elephant Foot Yam, Pointed Gourd, and Winged Bean, detailing their nutritional and medicinal properties as well as basic cultivation practices. By reintroducing these resilient crops, the article argues for a more sustainable and diverse agricultural future, urging a collective effort to reclaim our food heritage.

Why do we ignore them?

The reasons these vegetables have fallen out of favor are multi-faceted. The review paper notes that a lack of planting materials, limited knowledge of their medicinal and health benefits, and a lack of formalized research on their cultivation have all contributed to their decline. However, as the world faces new challenges related to climate change and nutritional deficiencies, these resilient crops are getting a second look from farmers, researchers, and consumers alike.

The Power-Packed Performers

Let's explore a few of these unsung heroes, with details from the provided paper and general cultivation practices.

Spine Gourd (Kakrol)

Often called the "king of gourds," spine gourd (*Momordica dioica*) is a spiny, small, green vegetable native to the Indian subcontinent. The review paper lists *M. dioica* (Kartoli) as a high-priority crop for research. It is a nutritional powerhouse, rich in protein, antioxidants, and vitamins. Known for its anti-cancer and anti-diabetic properties, it is a vegetable that should be a staple in every Indian household.

Cultivation: This is a perennial creeper that thrives in tropical and subtropical climates. It is best grown from root tubers, which can be planted in well-drained loamy soil. It requires a trellis or support system to climb. The plant is resilient and requires minimal care once established, making it perfect for small-scale and kitchen gardens.

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Elephant Foot Yam (Suran)

This large, starchy tuber is a popular vegetable in many parts of India, but its cultivation is far from widespread. The paper from The Pharma Innovation Journal lists *Amorphophallus campanulatus* (Elephant Foot Yam) as a key underutilized crop. Known for its high fiber, protein, and Omega-3 fatty acid content, elephant foot yam has a unique texture and flavor. Its medicinal properties are also well-documented, particularly in fighting inflammation and improving digestion.

Cultivation: Suran is a relatively easy crop to grow. It prefers warm, humid climates and loamy, well-drained soil rich in organic matter. The corms are planted in pits, and the plant requires moderate watering. After planting, the crop takes around seven to nine months to mature, after which the corms can be harvested.

Pointed Gourd (Parwal)

A popular vegetable in eastern and northern India, pointed gourd (*Trichosanthes dioica*) is known for its delicate flavor and versatility. The review paper also recognizes this vegetable as an important underutilized crop. It is a good source of vitamins A and C, carbohydrates, and minerals. It also has medicinal uses, including improving liver function and aiding in weight loss.

Cultivation: Parwal is a perennial dioecious creeper, meaning male and female plants are required for fruit production. It can be propagated by planting stem cuttings or rooted cuttings. It thrives in warm, humid climates and needs trellising. It is a hardy crop, tolerant to a wide range of soil conditions, and its fruits can be harvested continuously for several months.

Winged Bean (Goa Bean)

Often called the "soybean of the tropics," the winged bean (*Psophocarpus tetragonolobus*) is a multi-purpose plant where almost every part is edible: the pods, leaves, flowers, and even the tuberous roots. It is exceptionally rich in protein, making it a valuable meat substitute, and is also a good source of vitamins, iron, and calcium. The provided paper highlights the winged bean as a high-priority crop for active research and improvement.

Cultivation: This is a tropical perennial vine that is typically grown as an annual. It requires a hot, humid climate and a trellis system to support its growth. Winged beans can be grown in a variety of soils, as long as they are well-drained and have adequate moisture. The plant is self-pollinating and can be harvested for its pods in about two to three weeks after flowering.

Amaranth (Chaulai)

Amaranth is a versatile crop, grown for both its nutritious leafy greens and its gluten-free seeds, which are a "pseudo-cereal." The leaves are a powerhouse of vitamins (A, C, K), iron, and calcium, while the seeds are a rich source of high-quality protein and lysine, an essential amino acid often lacking in other cereals. The research paper identifies Amaranth as a high-priority crop for study and improvement.

Cultivation: Amaranth is a warm-weather crop that

is sensitive to frost. It grows well in well-drained, loamy soils. Seeds can be sown directly into the ground or started indoors and transplanted. It is relatively low-maintenance, though consistent watering is important, as is keeping the area free of weeds. Amaranth can be harvested for its leaves in as little as 25 days, with multiple harvests possible from the same plant.

Horse Gram (Kulthi)

This drought-resistant legume is a true survivor, thriving in arid conditions where other crops fail. Horse gram (*Macrotyloma uniflorum*) is packed with protein, calcium, iron, and dietary fiber. It is known for its medicinal properties, including helping to manage blood sugar levels and acting as a diuretic. It is a staple in many traditional South Indian cuisines.

Cultivation: Horse gram is an exceptionally hardy crop that requires minimal land preparation and is often grown as a rainfed crop with very little irrigation. It tolerates a wide range of soils, from light sandy to heavy clay, and prefers a warm, dry climate. The seeds are typically sown during the late monsoon season, and the crop is ready for harvest in approximately 90 to 120 days.

Jack Bean (Sain)

A lesser-known legume, jack bean (*Canavalia ensiformis*), is highlighted in the paper as a valuable underutilized vegetable. It is often consumed when young and tender, as a mature bean can be tough. It is known for its high protein content and is considered a valuable resource for food security due to its hardiness.

Cultivation: Jack beans are a tropical legume that grows as an annual. They can be grown in a variety of soil types and are drought-tolerant. They do not require a lot of care, but a trellis or support system is beneficial for the climbing vines.

Ivy Gourd (Kundru)

Also known as tindora or little gourd, ivy gourd (*Coccinia grandis*) is a common vegetable in South India and other parts of Asia. The paper lists it as a high-priority crop for research and commercialization. It is known for its medicinal properties, particularly in treating diabetes, and is a good source of dietary fiber.

Cultivation: Ivy gourd is a perennial vine that is often grown from cuttings. It requires a warm, humid climate and a trellis. It is a very productive plant that requires regular harvesting to encourage new growth.

White Yam (Ratalu)

A common tuber vegetable in India, white yam (*Dioscorea rotundata*) is a significant source of carbohydrates, and the paper notes its potential for providing food security in challenging climates. It is rich in potassium and Vitamin C and is a great source of energy.

Cultivation: White yam is a vining crop that requires a long, frost-free growing season. The tubers are planted in ridges or mounds, and the vines need to be supported by stakes or a trellis. It prefers well-drained, fertile soil. The tubers are harvested when the leaves turn yellow and die.

Reclaiming Our Food Heritage

The paper you provided emphasizes that underutilized vegetables have abundant nutritional potential, therapeutic qualities, and resilience to harsh environmental circumstances. By reintroducing these and other underutilized vegetables into our diets, we can not only enhance our nutrition but also support local biodiversity and agriculture. These crops offer a path towards greater food security, less dependence on a few dominant species, and a more sustainable future for farming in India.

The next time you're at the local market, keep an eye out for these vegetables. Your health, and the planet, will thank you.

Fodder Deficit and Livestock Sustainability in Jammu & Kashmir: Challenges and Opportunities

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Abstract

Livestock plays a pivotal role in the livelihood of farmers and pastoral communities in Jammu and Kashmir (J&K), contributing nearly 9% to the state GDP and 45% to the agricultural GDP. However, the sector is constrained by a chronic shortage of feed and fodder, with an overall deficit of nearly 50% across regions. Diverse agro-climatic conditions ranging from subtropical Jammu to the temperate Kashmir valley and the cold arid Ladakh shape cropping patterns, rangeland resources, and pastoral systems. This review presents an updated overview of livestock distribution, fodder resources, grazing land use, and feed deficits in J&K. It highlights the dependence of nomadic groups on rangelands, the challenges of shrinking pastures, and the nutritional inadequacy of available crop residues. The review further discusses seed management, forage constraints, and opportunities for fodder innovation. Interventions such as improved seed replacement, silage-making, hydroponic fodder, regulated grazing, and establishment of fodder banks are emphasized as strategies to bridge the fodder deficit and enhance livestock productivity in the Himalayan state.

Introduction

Livestock plays a vital role in the livelihood security and economy of Jammu and Kashmir (J&K). It contributes nearly 9% to the state GDP and 45% of the agricultural GDP, a share even higher than horticulture (Directorate of Economics and Statistics, J&K, 2012-13). The state is unique with its four macro-climatic zones subtropical Jammu, temperate Kashmir valley, intermediate mid-hills, and cold arid Ladakh. The human to animal ratio is nearly 1:1, reflecting the centrality of livestock in household economies. However, fodder scarcity has emerged as a critical bottleneck, leading to reduced productivity and increased reliance on low-quality feed resources (FAO, 2019).

Agro-Climatic Zones and Livestock Distribution

J&K is divided into three major regions: Jammu (subtropical and intermediate), Kashmir (temperate valley), and Ladakh (cold arid). Each region has distinct cropping and livestock patterns. Jammu supports paddy, maize, and wheat with cattle and buffaloes, while Kashmir is dominated by rice, maize, oilseeds, and crossbred cattle and sheep. Ladakh, with its high-altitude cold desert, is home to yak, pashmina goat, sheep, and barley-based farming systems. The diversity of agro-climatic conditions has led to diverse livestock systems but also variable feed availability.

Cropping Patterns and Fodder Production: The state has limited area under fodder cultivation,

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typically 3-4% of gross cropped area. Crop residues, including paddy straw, maize stover, and wheat straw, form the bulk of fodder resources. Green fodder availability is highly seasonal, with deficits especially pronounced in winter months. Kashmir valley relies heavily on paddy straw, while maize stover dominates in Jammu. Despite the significance of fodder, its cultivation is often secondary to food and cash crops.

Grazing Lands and Pastoral Livelihoods: Rangelands and pastures constitute a significant source of feed. Locally termed Margs and Bahaks in Kashmir and Doksa in Ladakh, these grazing lands support nomadic groups like Gujjars, Bakerwals, and Changpas. Over 25% of the state's population depends wholly or partially on rangeland-based pastoral systems (Khan *et al*., 2017). However, overgrazing, weed invasion, and encroachment have led to degradation of these resources, reducing their productivity and quality (Sharma *et al*., 2020).

Table 1: Region-wise fodder requirement and availability in J&K (on DM basis)

Region	Requirement (lakh MT)	Availability (lakh MT)	Deficit (%)
Jammu	100.08	54.10	45.9
Kashmir	43.95	20.06	54.3
Ladakh	4.68	1.43	69.4

Fodder Deficit in Jammu and Kashmir: The overall fodder deficit in J&K is nearly 50%. Regional estimates show Jammu has a deficit of 46%, 54% in Kashmir and 69% in Ladakh (Directorate of Economics and Statistics, J&K, 2012-13). Seasonal scarcity, especially during winter, exacerbates the problem. Crop residues, though abundant, are nutritionally poor. Consequently, livestock productivity remains low compared to national averages (Yadav and Singh, 2018).

Seed Management and Fodder Crop Improvement: Seed replacement rates (SRR) for fodder crops in J&K are below national standards. Efforts over the last decade have improved SRR to around 25-32%, but this remains insufficient. Adoption of high-yielding, short-duration fodder varieties and enhanced seed availability are crucial for bridging the fodder gap.

Constraints in Forage Production: Major constraints include small landholdings, limited priority to fodder crops, and shrinking pastures. Crop residues have low nutritive value, with low protein and digestibility. Encroachment, invasive weeds, and lack of quality fodder seed further exacerbate the problem.

Interventions and Opportunities

Several strategies are needed: (1) Genetic improvement of livestock; (2) Introduction of high-biomass fodder varieties; (3) Silage-making and hay preservation to ensure year-round availability; (4) Establishment of fodder banks in remote villages; (5) Pasture management through rotational grazing; (6) Promotion of hydroponic and vertical fodder systems; and (7) Strengthening seed systems to achieve SRR above 33%. These interventions can significantly reduce the fodder deficit and improve livestock productivity.

Conclusion

Livestock and fodder resources are central to the socio-economic fabric of Jammu and Kashmir.

However, with nearly half of the fodder demand unmet, urgent interventions are required. Integrating fodder crop improvement, silage technologies, regulated grazing, and waste-to-wealth utilization of crop residues can bridge the deficit. Collaborative efforts involving government agencies, research institutions, and pastoral communities are essential for ensuring sustainable livestock production in this Himalayan region.

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Natural Colours from Banana

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Introduction

Food colours or pigments have great importance in determining the taste and flavor of food. The instability and degradation of natural food colors during preservation of food affects the quality of food in the global market. To sustain uniformity in the color of the food product, many synthetic and natural colors are being added intentionally to the food. Now a days the application of food colorants has expanded significantly, driven by advancements in food processing technologies, evolving consumer preferences, and the globalization of food markets. Modern food colorants can be broadly categorized into natural and synthetic types. Natural colorants, such as carotenoids, anthocyanins, chlorophylls, and betalains, are extracted from plants, algae, and other natural sources. Synthetic colorants, on the other hand, are chemically produced and offer advantages such as higher stability, consistent quality, and a broader range of colours. While synthetic colorants have dominated the market due to their cost-effectiveness and vibrant hues, concerns about their safety and potential health risks have led to a growing demand for natural alternatives. Consumers are increasingly seeking "clean-label" products, preferring natural and minimally processed ingredients, which has driven innovation in the development of sustainable, plant-based food colorants.

The functionality of food colorants extends beyond aesthetics; they also serve as indicators of chemical changes during processing and storage, influencing the shelf life and sensory attributes of food. However, the stability of colorants is influenced by factors such as pH, temperature, light, and interaction with other food components, presenting challenges in formulation and storage. The present project aims to explore the current trends, challenges, and innovations in the field of food colorants, with a focus on natural sources, extraction methods, stability enhancement, and their implications for consumer health and food industry practices. By addressing these aspects, this research contributes to the broader understanding of sustainable and health-conscious food production. Biocolorants are those coloring agents, which are obtained from the biological sources. Biocolorants are mainly derived from pigments like antho-cyanidin, carotenoids etc., These colorants, extracted from plants, microorganisms, algae, and fungi, offer a sustainable and eco-friendly alternative to chemically synthesized dyes, aligning with the increasing consumer demand for natural and health-conscious products. From time immemorial, color has been an important criterion for acceptability of products like textiles, cosmetics, food and other items. In Europe, it was practiced during the Bronze

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Age. The earliest written record of the use of natural dyes was found in China dated 2600 BC. According to Aberoumand that in Indian subcontinent, dyeing was known even in the Indus Valley period (2500 BC) and has been substantiated by findings of colored garments of cloth and traces of madder dye in the ruins of Mohenjodaro and Harappa civilization (3500 BC). In Egypt, mummies have been found wrapped in colored cloth. Chemical tests of red fabrics found in the tomb of King Tutankhamen in Egypt showed the presence of alizarin, a pigment extracted from madder. The cochineal dye was used by the people of Aztec and Maya culture period of Central and North America. By the 4th century AD, dyes such as woad, madder, weld, Brazil wood, indigo and a dark reddish-purple were known. Brazil was named after the woad found there. Henna was used even before 2500 BC, while saffron is mentioned in the Bible. Use of natural biocolourants in food is known from Japan in the shosoin text of the Nara period (8th century), which contains references regarding coloring soybean and adzuki-bean cakes. Thus, it appears that colored processed foods had been taken by the people of some sections during that period. Today, bio colourants are recognized for their dual benefits imparting colour while often exhibiting bioactive properties such as antioxidant, antimicrobial, and anti-inflammatory effects. One of the key advantages of bio colourants is their biodegradability and reduced environmental impact compared to synthetic counterparts. How ever, their application in the food industry presents challenges, including variability in pigment yield, stability issues under varying pH, temperature, and light conditions, and scalability of production. Advances in biotechnology, such as microbial fermentation, genetic engineering, and green extraction methods, have opened new avenues for improving the production, stability, and functional properties of bio colourants. The shift toward bio colourants is also driven by regulatory constraints on synthetic dyes, as well as growing awareness of their potential health risks. Governments and food safety authorities worldwide are encouraging the adoption of natural alternatives to ensure consumer safety and promote sustainability. This project aims to develop into the science and applications of bio colourants, examining their sources, extraction methods, stability challenges, and functional benefits. By exploring the latest innovations and trends in the development of bio colourants, this research contributes to the growing body of knowledge on sustainable and health-oriented solutions for the food industry.

Banana is the world's highest-producing fruit crop, amounting to over 100 million tonnes of production annually. The increasing demand for bananas has led to a significant rise in global production, emphasizing their status as the most consumed fruit. However, banana crop production generates massive quantities of by-products/waste such as stems, leaves, and inflorescence (flower). Banana inflorescence is the edible product among these by-products. This inflorescence is also known

as the banana flower, navel, heart, pendant, and bell in different countries and regions. This banana inflorescence has been used as a food as well as a medicinal product in countries such as Thailand, China, Sri Lanka, and India due to its nutritional and medicinal benefits.

Some studies have proven the medicinal properties, such as antioxidant activity, anticancer, antiglycemic, and antimicrobial within the banana inflorescence. These properties are based on the chemical composition of banana inflorescence. The banana inflorescence has shown a rich profile of bioactive compounds, including phenolic acids, flavonoids, saponins, triterpenes, and anthocyanins. Anthocyanins are polyphenolic natural pigment flavonoids found in many vegetables and fruits. Chemically, anthocyanin is a derivative of flavylium cation. More than 23 anthocyanins have been reported in natural products. Anthocyanin pigments are found in many plants, such as grapes, berries, cabbage, purple potatoes, black carrots, banana spathe and hibiscus. Anthocyanins are natural plant pigments which contribute to a range of colours in fruits, vegetables, and flowers. Chemically-different anthocyanin groups can be found in different colours such as red, orange, purple, violet, and blue. Anthocyanins are generally found in vacuoles and sub-epidermal cells within the plant tissues. These compounds are pH-sensitive and water-soluble and have antioxidant activity. These compounds are gaining high scientific attention, owing to their potential medicinal benefits and the fact that they are sources of a synthetic colouring agent. Food colorants play an essential role in enhancing the visual appeal and marketability of food products. They are used across a variety of categories, including confectionery, beverages, dairy, and processed foods. Colorants are crucial for creating visually appealing candies, chocolates, and gum. Bright, vibrant colours are used to differentiate products and make them more enticing to children and adults alike. Example, Red candies often use synthetic dyes like Allura Red to create an intense, consistent hue. Many soft drinks, energy drinks, and even juices are coloured using food dyes to make them more attractive to consumers. For instance, cola drinks are often coloured with Caramel E150a, while lemon-lime sodas may use Brilliant Blue FCF for a bright, appealing appearance. Example: The use of Carmine (derived from cochineal insects) in soft drinks to produce red or pink hue. Dairy products such as ice cream, yogurt, and cheese often use colorants to enhance their appearance. This helps maintain product consistency, especially in flavoured dairy items like strawberry or blueberry yogurt. Example, Annatto is commonly used in cheeses, especially cheddar, to give them a uniform orange colour.

Functional Properties: The banana bract contains anthocyanins, such as delphinidin, pelargonidin, paeonidin, and malvidin. Gunavathy et al. used petroleum ether to extract the bract and found alkaloids, as well as glucoside and flavonoid compounds, after its extraction with ethyl acetate.

It also found alkaloid, saponin, flavonoid, terpenoid, coumarin, glucoside, phenolic compounds, and steroids, after its extraction with methanol, and it found coumarin and phenolic compounds after its extraction with water. The current study examined the "Phytochemical contents, antimicrobial and antioxidant activities of the methanolic leaf extract of banana bract". The phytoconstituents and functional groups in banana bract extract had been investigated using Gas Chromatography-Mass Spectroscopy (GC-MS) and Fourier Transform Infrared (FTIR) analysis. Concurrently, the agar well-plate method was used to assess antimicrobial activity against ten bacterial strains. DPPH (1,1-diphenyl-2-picrylhydrazyl), reducing power activity, phospho-molybdenum activity, hydrogen peroxide activity, and nitric oxide inhibitory activity were employed to assess antioxidant activity. Alkaloids, saponins, tannins, flavonoids, terpenoids, coumarins, cycloglycosides, total phenols and steroids were found in the phytochemical analysis.

Antibacterial Properties: Banana inflorescence has been tested for its antimicrobial activity including antibacterial and antifungal effects. Respective studies attempted to examine the antimicrobial effect on Gram-positive bacteria such as *Bacillus cereus, Bacillus subtilis, Staphylococcus aureus, Streptococcus pneumoniae, Listeria monocytogenes,* and *Brochothrix thermospacta* and Gram-negative bacteria such as *Escherichia coli, Proteus mirabilis, Pseudomonas aeruginosa, Salmonella typhimurium, Enterobacter sakazakii, Yersinia enterocolitica, Vibrio parahaemolyticus, Klebsiella pneumoniae, and Shigella flexneri* as well as some pathogenic fungi such as *Candida albicans* and *Cryptococcus albidus* found that ethanol extracts of banana flowers exhibit higher antibacterial effect than chloroform, ethyl acetate, acetone, and methanol for tested strains of *B. cereus, S. aureus, B. subtilis, E. coli, S.flexneri, K pneumonia*. Another study conducted by concluded that proteins extracted from the banana flower of *Musa sapientum* L, exhibited an antibacterial effect using agar well diffusion method.

Anti-oxident properties: Banana bract is recognized for its strong antioxidant properties, which are primarily attributed to its bioactive compounds such as flavonoids, tannins, alkaloids, and saponins. These compounds play a significant role in neutralizing harmful free radicals in the body, helping to reduce oxidative stress and prevent cellular damage. Antioxidants can be assessed by different methods according to the literature such as 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity, 2,2′-azinobis 3-ethylbenzthiazoline-6-sulfonic acid (ABTS) radical cation, and ferric reducing antioxidant power (FRAP), N, N-dimethyl-p-phenylenediamine dihydrochloride (DM PD), oxygen radical absorbance capacity (ORAC).

Anti-cancer properties: Cancer is a growing public health concern worldwide. Hence there is an urgent need to find anticancer pharmaceutical products. Phenols, flavonoids, and antioxidant compounds are known as anticancer agents. A recent comprehensive review of cancer preventive and therapeutic charact-

eristics of the bioactive phytoconstituents identified in banana and banana by-products shows the anticancer properties examined in banana inflorescence (Mondal *et al*., 2021). The existing research body on banana inflorescence highlights the anticancer impact. An attempt by Nadumane and Timsina (2014) examined the anti-cancer activity of Musa paradisiaca flower extract on the cervical cancer cell line HeLa employing Thin layer chromatography (TLC) HPLC and LC-MS analysis (Nadumane and Timsina, 2014). Previous studies demonstrated the cytotoxic activity of banana inflorescence on human colorectal cancer cells, HT29 and HCT116. Nadumane and Timsina (2014) found that ethanolic extracted banana inflorescence was more highly active and prominent towards Hela cells than non-cancerous cells which exhibit the selectivity of anticancer compounds available in banana inflorescence extract.

Anti-inflammatory properties: Anti-inflammatory property of BBA in lipopolysaccharide (LPS)-stimulated RAW 264.7 macrophage-like cells was studied by Abeer *et al.*, 2023. LC-ESI/MS/MS analysis identified the presence of various phenolics compounds, flavonoids and anthocyanin in banana bract. Banana bract showed in vitro antioxidant activity. LPS stimulation decreased the cell viability whereas banana bract treatment preserved the macrophage cell viability against LPS. Banana bract suppressed the LPS-stimulated NO, pro-inflammatory and PGE2 production in RAW 264.7 cells. Banana bract increased the endogenous anti-oxidants level against LPS-stimulation. Banana bract inhibited the nuclear translocation of NF-κB under LPS-stimulated conditions. Altogether, the phyto-constituents present in BBA would have acted synergistically to bring anti-inflammatory activity**.**

Conclusion

The use of bio-colorants in food products has gained significant attention as consumers increasingly prefer natural and health-promoting ingredients over synthetic additives. Bio-colorants, derived from sources such as fruits, vegetables, algae, and microorganisms, offer vibrant colors and potential health benefits due to their bioactive compounds. This study evaluates the efficacy of bio-colorants in various food products, focusing on their stability, compatibility, and sensory appeal. Factors such as pH, temperature, processing conditions, and storage impact their performance and application in different food matrices. The study also explores the nutritional advantages and regulatory aspects of bio-colorants, emphasizing their role in meeting consumer demand for clean-label and sustainable food products.

Women Empowerment in Agriculture: Challenges and Opportunities

Priya Rani

Introduction

Agriculture is the backbone of India's economy, providing livelihood to nearly 58% of the population (Government of India, 2020). Within this sector, women represent an essential yet often invisible workforce. They contribute to every stage of farming sowing, transplanting, livestock care, harvesting, and food processing yet their labor is undervalued and their rights remain limited. Globally, studies show that empowering women farmers could increase agricultural productivity by 20-30% and reduce world hunger significantly (FAO, 2011). Thus, women's empowerment in agriculture is not just a gender issue but a socio-economic and developmental necessity.

Historical Role of Women in Agriculture

Women's involvement in farming is as old as agriculture itself. Traditionally, they were custodians of indigenous seeds, soil fertility, and household nutrition. Tribal and rural women in India continue to conserve biodiversity by maintaining kitchen gardens and practicing agroecology. However, mechanization and commercialization shifted recognition and decision-making to men, reducing women's visibility and rights (Agarwal, 2018).

Importance of Women in Agriculture

Women constitute about 43% of the global agricultural workforce (FAO, 2011). In India, their contribution is even more significant. Beyond manual labor, women ensure food security at the household level through crop selection, seed preservation, and nutrition management. Research indicates that women invest a higher proportion of income in health and education, creating intergenerational benefits (World Bank, 2012). If women had the same access to land and resources as men, agricultural productivity could rise by nearly one-third, helping lift millions out of poverty.

Challenges Faced by Women Farmers

Despite their central role, women face multiple obstacles:

Land Ownership: Only 13% of women in India own agricultural land (World Bank, 2012). Lack of ownership prevents them from accessing loans, subsidies, and insurance.

Credit and Technology Access: Without collateral, women struggle to obtain financial services. Training and new technologies often bypass women farmers.

Wage Inequality: Women earn 20-30% less than men for the same work (NABARD, 2021).

Work Burden: Women manage both household responsibilities and farming, leading to overwork and stress.

Climate Change: Erratic rainfall, floods, and droughts increase women's vulnerability, especially when men migrate to cities for work (UN Women,

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2018).

Government Policies and Programs

Several initiatives aim to support women in agriculture:

Mahila Kisan Sashaktikaran Pariyojana (MKSP): Promotes women farmers' collectives and training.

National Rural Livelihood Mission (NRLM): Encourages women-led enterprises.

Pradhan Mantri Fasal Bima Yojana: Crop insurance program, though landless women remain excluded.

Self-Help Groups (SHGs): Provide access to microcredit and strengthen bargaining power.

While these initiatives are valuable, limited awareness and cultural norms reduce their reach. Effective implementation is key.

Climate Change and Women Farmers

Women bear the brunt of climate change because of their dependence on natural resources. In times of drought, they walk farther for water; during floods, they face loss of crops and livestock. Their limited access to climate-resilient technology, irrigation, and weather information further weakens their ability to adapt. Providing women with drought-resistant seeds, solar-powered irrigation, and mobile-based weather alerts can significantly enhance resilience.

Success Stories

Maharashtra: Women's collectives adopted organic farming, reducing costs and improving soil health.

Bihar: Women Farmer Producer Organizations (FPOs) gained bargaining power by dealing directly with markets.

Andhra Pradesh: Women trained in natural farming reduced pesticide dependence and improved nutrition.

Kenya & Bangladesh: Women's cooperatives using solar irrigation and microfinance demonstrated the global potential of women-led agricultural growth.

NGOs and Cooperatives

Organizations like SEWA (Self Employed Women's Association) and Kudumbashree in Kerala provide training, microfinance, and collective bargaining opportunities. Cooperatives like Amul have empowered rural women to lead dairy enterprises, boosting both income and confidence.

Education, Training, and Digital Empowerment

Education and digital literacy are critical for empowerment. Many women remain excluded from extension services and modern farming knowledge. Digital platforms such as e-NAM (electronic National Agriculture Market) and mobile apps in local languages can help women farmers access markets, weather forecasts, and financial services. With training in new technologies such as drones, smart irrigation, and organic methods, women can lead the transition toward sustainable agriculture (World Bank, 2012).

Opportunities for the Future

- ✓ Legal recognition of women as farmers with equal land rights.
- ✓ Gender-sensitive agricultural training.

- ✓ Affordable childcare and social infrastructure to ease women's dual burden.
- ✓ Expanding women's participation in Farmer Producer Organizations (FPOs).
- ✓ Promoting digital and financial inclusion.
- ✓ Mainstreaming women in climate-smart agriculture.

Conclusion

Women are the backbone of agriculture, yet their contributions remain undervalued. Empowering women through land rights, access to resources, training, and leadership roles is both an economic necessity and a moral imperative. As studies show, closing the gender gap in agriculture would not only improve productivity but also reduce poverty, hunger, and inequality. When women farmers are empowered, entire communities benefit leading to food security, gender equality, and sustainable development.

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The Commercial Importance of Turmeric and Its Global Exploitation

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The commercial importance of turmeric (*Curcuma longa*) extends far beyond its traditional role as a culinary spice. It has evolved into a multi-billion dollar commodity that drives a global industry, fueled by its unique bioactive compounds, particularly curcumin. Its economic value is rooted in a rich history of use in Indian and South Asian cultures, which has been validated and amplified by modern scientific research. However, this commercial success also highlights complex ethical and legal issues, particularly concerning the protection of traditional knowledge from exploit-ation.

The Foundations of Turmeric's Commercial Value

The commercial significance of turmeric is a result of its multifaceted utility and the growing global demand for natural, functional products. Its applications can be categorized into several key sectors, each contributing to its massive economic footprint.

The Food and Culinary Industry

This is the oldest and largest market for turmeric. The dried and powdered rhizome is an essential ingredient in countless cuisines, imparting a distinct earthy flavor and a vibrant golden-yellow color. It is the cornerstone of curry powders and is used widely in marinades, sauces, and rice dishes.

Natural Food Colorant: Beyond flavor, turmeric is a highly sought-after natural food additive. It is used to color a wide variety of processed foods, including mustards, cheeses, butter, and pickles, as a safe and natural alternative to synthetic dyes. The push for "clean label" products free from artificial ingredients has significantly increased its demand in this sector.

The Nutraceutical and Pharmaceutical Industry

This is the fastest-growing market for turmeric, driven by extensive scientific research into its health benefits. The primary bioactive compounds are curcuminoids, with curcumin being the most prominent.

Dietary Supplements: Curcumin is now a staple in the dietary supplement industry, marketed in capsules, tablets, and powders. It is prized for its potent anti-inflammatory and antioxidant properties. People use curcumin supplements for a range of health conditions, including joint pain, digestive issues, and to support overall wellness.

Functional Foods and Beverages: Turmeric extracts are increasingly being added to functional foods and beverages, such as health teas, shots, and energy bars, to enhance their nutritional profile.

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Traditional Medicine: The modern pharmaceutical interest in turmeric is rooted in its long history in traditional medicine systems like Ayurveda and Traditional Chinese Medicine. Its use for treating a variety of ailments, from inflammatory conditions to digestive disorders, provides a strong traditional basis for its modern applications.

The Importance of Turmeric's Bioactive Compounds

The commercial viability of turmeric is directly linked to the concentration and activity of its key chemical constituents. Understanding these compounds is crucial to appreciating its global importance.

Curcuminoids: The Golden Key to Health

The vibrant yellow-orange color of turmeric is a tell-tale sign of its richness in curcuminoids. The most important of these are curcumin, dimethoxy-curcumin, and bisdemethoxycurcumin.

Curcumin: As a polyphenol, curcumin is the most studied and commercially valuable component. Its importance lies in its anti-inflammatory effects, which are attributed to its ability to inhibit molecules that play a central role in inflammation. Its powerful antioxidant properties enable it to neutralize harmful free radicals, protecting cells from oxidative stress and damage, which are linked to aging and many chronic diseases.

Poor Bioavailability: A major challenge in the commercial exploitation of curcumin is its poor bioavailability the body's limited ability to absorb and utilize it. This has spurred a wave of innovation in the nutraceutical industry, leading to the development of enhanced formulations that combine curcumin with other substances like piperine (from black pepper) to significantly improve its absorption.

Essential Oils: Aromatic and Therapeutic Synergy

Beyond curcuminoids, turmeric rhizomes contain a variety of essential oils, which contribute to its distinctive earthy aroma and possess their own therapeutic benefits.

Turmerone and Ar-turmerone: These are key components of turmeric's essential oil. They have been studied for their potential neuroprotective and antimicrobial properties. The combined effect of curcuminoids and essential oils in whole turmeric is believed to create a synergistic effect, where the total benefit is greater than the sum of its individual parts. This is why some researchers and traditional medicine practitioners advocate for the use of whole turmeric over isolated curcumin.

The importance of turmeric, therefore, lies not just in the “wonder drug” reputation of curcumin but in the holistic interaction of its various compounds.

Commercial Exploitation in Non-Food Industries

The versatility of turmeric extends well beyond the kitchen and the pharmacy, finding applications in other significant commercial sectors.

The Cosmetics and Personal Care Industry

Turmeric has a rich history in traditional skincare rituals across Asia. This traditional knowledge has now been commercialized globally.

Anti-inflammatory Skincare: The anti-inflammatory and antioxidant properties of curcumin make it a popular ingredient in modern skincare products. It is incorporated into face masks, serums, and creams aimed at reducing blemishes, soothing irritated skin, and promoting a healthy, natural glow.

Anti-aging Properties: As an antioxidant, curcumin helps to combat the free radical damage that contributes to premature aging. This makes turmeric extracts a valuable ingredient in anti-aging formulations and wellness products.

The Textile and Dyeing Industry

Turmeric has been used as a natural dye for centuries, particularly for coloring textiles.

Natural Yellow Dye: The curcumin pigment in turmeric produces a brilliant yellow color on fabrics like cotton, silk, and wool. With a growing interest in sustainable and eco-friendly fashion, natural dyes are gaining traction as an alternative to synthetic chemical dyes, which can be harmful to the environment.

Sustainable Practices: The use of turmeric as a dye aligns with the principles of a circular economy and sustainable manufacturing, as it is a biodegradable and non-toxic alternative.

Animal Feed and Agriculture

Turmeric and its extracts are also finding a place in modern agriculture.

Livestock Feed Additive: Turmeric powder is sometimes added to animal feed for its antimicrobial and anti-inflammatory properties, which can help improve digestion and overall gut health in livestock.

Natural Pesticide: In organic farming, turmeric is used as a natural pesticide and soil enhancer, as some of its compounds can deter pests and fungi.

The Ethics of Commercial Exploitation: A Case Study in Biopiracy

The rising commercial value of turmeric has raised crucial ethical and legal questions, particularly regarding the appropriation of traditional knowledge.

The Turmeric Patent Case: A Landmark Victory

The most famous example of the ethical complexities of turmeric's commercial exploitation is the Turmeric Patent Case of the mid-1990s. In 1995, the U.S. Patent and Trademark Office (USPTO) granted a patent to two Indian-American scientists for the use of turmeric powder as a wound-healing agent. The patent claimed that its use for this purpose was a novel invention.

The Challenge: The Indian government, through the Council of Scientific and Industrial Research (CSIR), swiftly challenged the patent. They argued that the use of turmeric as a wound-healing agent was not a new discovery but a traditional practice that had been documented in ancient Ayurvedic and Sanskrit texts for thousands of years and was part of India's collective knowledge.

The Outcome: The USPTO, after reviewing the evidence of prior art provided by the CSIR, revoked the patent in 1997. This landmark case was the first successful challenge to a U.S. patent based on the traditional knowledge of another country. It set a crucial precedent for the protection of indigenous knowledge from biopiracy the unethical appropriati-

on of biological resources and traditional knowledge.

The Broader Implications

The turmeric patent case was a wake-up call for nations with rich biodiversity and traditional knowledge systems. It highlighted the vulnerability of undocumented traditional practices to foreign patent claims and spurred action.

Protection of Traditional Knowledge: In response to the case, the Indian government established the Traditional Knowledge Digital Library (TKDL), a database of traditional Indian knowledge related to medicine and other fields. The TKDL is a powerful tool used to prevent biopiracy by providing verifiable evidence of prior art.

Fair and Equitable Benefit Sharing: The commercial success of turmeric also underscores the need for equitable benefit sharing. As the global demand for turmeric and curcumin increases, it is critical to ensure that the farmers who cultivate the crop receive a fair price for their labor. Fair-trade practices and direct sourcing models are being adopted to ensure that the economic benefits of turmeric's global exploitation reach the communities that have nurtured its wisdom for centuries.

In conclusion, the commercial importance of turmeric is undeniable, but it is a narrative that is inseparable from its cultural roots and the ethical challenges of intellectual property. It is a powerful example of how a traditional spice has become a global commodity, and how its journey highlights the ongoing need to protect and respect indigenous knowledge in a globalized world.

The Economic Landscape of the Crop Breeding Industry

Nivetha A. L., Vengatesh M. and Shridevi S.

The economic landscape of the crop breeding industry is a dynamic and complex domain, characterized by significant investment, technological innovation, market consolidation, and a robust intellectual property framework. It is a multi-billion dollar sector that serves as the foundation for global food production, creating value far beyond the initial sale of a seed.

The Size and Structure of a Global Market

The crop breeding industry is a powerful economic engine, with a market size that reflects its critical role in global agriculture. Recent market analyses estimate the global crop breeding technology market to be valued at approximately $15 billion in 2023, with projections for substantial growth in the coming years. This growth is driven by the relentless demand for more productive, resilient, and nutritious crops to feed a population that is expected to reach nearly 10 billion by 2050.

Market Concentration and Key Players

The industry is moderately concentrated, with a few large multinational corporations dominating the landscape. These companies have a significant market share due to their vast investments in research and development (R&D) and their global distribution networks. The “Big Four” or “Big Six” in the agri-chemical and seed sectors companies like Bayer (which acquired Monsanto), Syngenta, Corteva, and BASF are the most influential players. These companies operate on a global scale, providing a wide range of products including seeds, crop protection chemicals, and digital farming solutions.

However, the market is not exclusively controlled by these giants. A vibrant ecosystem of small and medium-sized enterprises (SMEs), academic institutions, and public research bodies also contributes to the industry's innovation. Many of these smaller players focus on niche markets or specialize in particular crops or breeding technologies, offering a crucial source of genetic diversity and innovation. For instance, some firms may specialize in developing new varieties of specialty vegetables, while others may focus on advanced genomic tools for a specific region.

Investment and Innovation: The business of crop breeding is capital-intensive and research-driven. Developing a new crop variety can take anywhere from 8 to 15 years and requires hundreds of millions of dollars in investment. This long-term commitment and high cost of R&D are significant barriers to entry, which further contributes to market concentration. The sheer scale of investment in R&D

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by the leading private sector companies often outpaces that of many public research institutions, though public research remains vital for foundational scientific breakthroughs. In recent decades, there has been a notable shift towards greater private sector investment in agricultural R&D, particularly in developed nations.

The Driving Force of Technology

The crop breeding industry is being revolutionized by the convergence of biology, data science, and engineering. Traditional breeding, which relies on selecting desirable traits through many generations of cross-pollination, is now supplemented and accelerated by cutting-edge technologies.

Genomics and Data-Driven Breeding: The genomics revolution has transformed plant breeding from an art to a data-driven science. Genomic selection and marker-assisted selection (MAS) are now standard tools. By analyzing the genetic makeup of thousands of plants, breeders can identify individuals with desired traits at a very early stage, dramatically shortening the breeding cycle. This "high-throughput phenotyping," which uses sensors, drones, and automated imaging to collect massive amounts of data on plant performance, has accelerated the development of new varieties and reduced the time to market.

Genetic Engineering and Gene Editing: Technologies like genetic engineering (GE) and gene editing (e.g., CRISPR-Cas9) are at the forefront of the industry. Genetic engineering involves introducing a specific gene from another organism to confer a new trait, such as pest resistance (e.g., *Bt* cotton) or herbicide tolerance. Gene editing, by contrast, is a more precise tool that can make small, targeted changes to a plant's existing DNA. These technologies offer an unprecedented level of control over a crop's genetic makeup, enabling breeders to introduce beneficial traits much faster than with conventional methods. The economic value of these technologies lies in their ability to create highly specific and valuable traits that command a premium in the market.

Artificial Intelligence and Big Data: AI and big data analytics are increasingly being used to manage and interpret the vast datasets generated by modern breeding programs. Machine learning algorithms can identify patterns and predict which genetic crosses are most likely to produce the desired outcome, making the breeding process more efficient and cost-effective. This allows companies to optimize their R&D pipelines, allocate resources more effectively, and bring superior products to market faster.

The Crucial Role of Intellectual Property (IP): Intellectual property rights are the lifeblood of the crop breeding industry, providing the legal and financial framework that incentivizes innovation. Given the high costs and long timelines of R&D, companies rely on IP protection to recoup their investments and generate a profit.

Plant Breeders' Rights (PBR): The primary form of IP protection in the plant breeding sector is Plant Breeders' Rights (PBR), also known as Plant Variety

Protection (PVP). PBR grants the breeder of a new plant variety an exclusive right to produce and market the variety for a specific period, usually 20 to 25 years. This system is administered globally by the International Union for the Protection of New Varieties of Plants (UPOV). A key feature of PBR is the "breeder's exemption," which allows other breeders to use a protected variety for further breeding work without permission from the rights holder. This is designed to promote continuous innovation.

Patents: Patents play an increasingly important role, particularly for novel traits developed through genetic engineering and gene editing. While PBR protects the new variety as a whole, patents can protect a specific gene, a process, or a technology used to create the variety. For example, a company might have a patent on a specific gene sequence that confers drought tolerance, regardless of the crop it is in. This provides a stronger, more comprehensive form of protection than PBR and allows companies to monetize their technological breakthroughs across a range of crops. The intersection of PBR and patents is a complex and often controversial area of IP law, with ongoing debates about its impact on innovation, access to genetic resources, and the rights of small farmers.

The Economic Impact of IP: IP protection underpins the business models of modern breeding companies. It enables them to generate revenue through the sale of patented seeds and licensing agreements. Without this protection, competitors could easily copy new varieties, and the incentive for private sector investment in long-term, high-risk R&D would vanish. While critics argue that strong IP can lead to market concentration and higher seed prices for farmers, proponents counter that it is a necessary condition for the continued innovation that benefits all of society.

Strategic Trends and the Future Outlook

The economic landscape of the crop breeding industry is constantly evolving in response to global challenges and technological advances.

Mergers and Acquisitions: The industry has seen a wave of major mergers and acquisitions in recent years, a trend driven by the desire to consolidate market share, acquire new technologies, and expand geographical reach. The acquisition of Syngenta by ChemChina and Monsanto by Bayer are prime examples. These consolidations have created integrated companies that can offer a complete package of seeds, crop protection products, and digital services, creating significant synergies and competitive advantages.

Public-Private Partnerships: There is a growing trend of collaboration between the public and private sectors. Public research institutions often focus on fundamental research and developing new breeding methods, while private companies specialize in commercializing the outputs. These partnerships are crucial for translating scientific discoveries into practical, marketable products that benefit farmers worldwide, especially in developing countries where private investment may be limited.

Sustainability and Consumer Demands: The industry is increasingly focused on developing varieties that address global sustainability goals. This includes breeding for traits like reduced fertilizer and water requirements, enhanced nutritional value (biofortification), and resistance to new and emerging diseases driven by climate change. Consumer demand for organic and non-GMO products is also a significant market trend, leading to parallel investment in traditional breeding methods and the development of crops that meet these specific consumer preferences.

In conclusion, the crop breeding industry is far more than a simple agricultural sector. It is a sophisticated, technology-driven, and capital-intensive industry with a complex economic model. Its landscape is defined by the interplay of a few dominant multinational corporations, a network of innovative smaller firms, massive R&D investments, and a crucial intellectual property framework. As the world confronts the challenges of food security and climate change, the economic health and continued innovation of the crop breeding industry will be more critical than ever.

Role of Geographical Indications in Crop Improvement

Shridevi S., Vengatesh M. and Nivetha A. L.

Geographical Indications (GIs) play a significant, though indirect, role in crop improvement. While they do not directly alter a crop's genetic makeup, they create a powerful economic and legal framework that incentivizes the preservation, cultivation, and enhancement of unique, traditional crop varieties. This process enhances biodiversity, protects local knowledge, and contributes to a more resilient and sustainable agricultural system.

GI's Role in Conserving Genetic Diversity

The most fundamental role of a GI in crop improvement is its ability to serve as a powerful tool for conservation. In an age dominated by a few high-yielding, genetically uniform crops, GIs provide a commercial incentive for farmers to continue cultivating traditional, locally adapted varieties.

Economic Incentive for Conservation: A GI tag legally identifies a product's unique qualities as being a direct result of its geographical origin. This often leads to a premium price in the market. By granting a GI tag to a crop, it recognizes the unique qualities that are due to its local soil, climate, and traditional farming methods. This economic benefit encourages farmers to continue growing these unique traditional varieties rather than switching to generic, high yielding hybrids that might fetch a lower price. For example, the GI tag for Basmati Rice in India incentivizes farmers to continue cultivating this specific long-grain, aromatic rice, thereby protecting its unique genetic makeup from being replaced by generic, high-yield varieties.

On-Farm Conservation: GIs promote on-farm conservation of agro biodiversity. This is one of the most effective ways to preserve genetic resources. By keeping a cultivar in its natural environment, it continues to evolve and adapt to local pests, diseases, and climate variations. This dynamic evolution is crucial for building resilient crops. The GI tag provides the economic backbone for this conservation effort, turning it from a cultural practice into a profitable business model.

Fostering Traditional Knowledge and Sustainable Practices

GIs are not just about a product; they are about the entire system of production. The GI framework often protects the traditional knowledge and cultivation practices that have been developed over centuries, which are integral to the crop's unique qualities.

Protecting Traditional Farming Methods: The GI registration process requires a detailed code of pract-

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ice that specifies the traditional methods used in cultivation and processing. Adherence to these standards is mandatory for a product to bear the GI tag. This ensures that traditional knowledge, which may include specific planting seasons, natural pest control methods, or unique harvesting techniques, is not lost. For example, the GI for Darjeeling Tea protects the specific cultivation and processing methods, such as unique plucking and withering techniques that are essential for its distinct flavor profile. These traditional methods often enhance the plant's health and ability to resist disease in the long run.

Encouraging Natural and Organic Farming: Many traditional cultivars thrive in their local environments without the need for extensive chemical inputs. The GI framework can formalize and promote these low-input, organic, or near-organic farming methods. By associating a premium product with sustainable practices, GIs create a market-driven incentive for more environmentally friendly agriculture. This, in turn, contributes to soil health and long-term crop productivity, which is a form of continuous improvement.

Quality Improvement and Standardization

While GIs are about preserving tradition, they also create a framework for continuous improvement and quality control. The premium market for GI-tagged products demands a consistent and high-quality product, which motivates farmers to invest in better practices.

Mandatory Codes of Practice: The GI framework requires all producers to adhere to a strict Code of Practice or "Specification of Product." This document outlines the standards for cultivation, harvesting, and processing. It includes details such as the specific seed variety to be used, the geographical area of production, and quality parameters. This standardization ensures that the quality and characteristics of the GI-tagged product remain consistent, building consumer trust and brand value.

Collective Action and Innovation: The GI system encourages the formation of producer associations. These associations provide a platform for farmers to share knowledge and collaborate on improving farming techniques. The collective effort can lead to the adoption of better post-harvest management, disease monitoring, and non-chemical pest control strategies. For example, a farmers' association for a GI-tagged mango variety might collaborate with a local agricultural university to develop better pest management strategies that do not compromise the mango's unique traditional qualities. This collective action fosters a gradual, community-based crop improvement.

Legal Protection against Misappropriation and Bio piracy

GIs play a crucial role in preventing the "bio piracy" of a crop's unique genetic traits and associated traditional knowledge. They provide a powerful legal tool to protect the intellectual property of a community.

Protecting a Name and Brand: A GI tag legally associates a product with its geographical origin,

providing a strong legal basis to prevent its name from being used for products grown elsewhere or for fraudulent purposes. This protects the brand value and ensures that the premium price is reserved for genuine products. For example, a company cannot sell “Darjeeling Tea” if it was grown in Kenya. This legal protection gives farmers a secure market and motivates them to continue their cultivation.

The Turmeric Patent Case and Its Lessons: The famous Turmeric Patent Case in the mid-1990s is a landmark example of the importance of protecting traditional knowledge. The U.S. Patent and Trademark Office granted a patent for the use of turmeric powder as a wound-healing agent. The Indian government successfully challenged the patent by demonstrating that this was a traditional practice. While turmeric didn't have a GI tag at the time, the case highlighted the vulnerability of traditional knowledge. GIs now provide a formalized legal framework to protect such knowledge from being appropriated by external entities for commercial gain.

The Economic and Long-Term Impact on Crop Improvement

The role of GIs in crop improvement extends beyond immediate conservation and legal protection. They are a powerful economic tool that transforms the value of agricultural products and contributes to long-term sustainability.

Value Addition and Market Growth: GIs turn a traditional crop from a low-value commodity into a high-value, branded product. The premium price that GI-tagged products command provides a strong financial incentive for farmers to invest in quality inputs, improved irrigation, and better post-harvest handling. This financial security allows for long-term planning and investment in the cultivar itself.

Empowering Rural Communities: By ensuring that the benefits of the premium price stay with the producers in the GI-protected region, GIs empower rural communities. This helps to sustain local economies, reduce dependence on large-scale commodity markets, and make farming a more viable and profitable livelihood.

A Strategy for a Resilient Future: In a world facing climate change and increasing food security challenges, the preservation of traditional cultivars is of paramount importance. These crops are a living library of genetic traits for resilience and adaptation. By providing an economic reason for their continued cultivation, GIs are playing a critical role in building a more diverse, resilient, and sustainable global food system for the future. They prove that tradition and innovation can go hand-in-hand to solve modern problems.

Biofortified Crops for Nutrition Security

Vaibhav Thakur

Abstract

Malnutrition is still a major problem in the world, especially in developing nations with less diverse diets. A sustainable option is biofortification, which is the practice of enhancing the nutritional value of food crops using either traditional breeding or contemporary biotechnology. In staple crops including rice, wheat, maize, and legumes, it increases the amount of vital vitamins and minerals. The idea, importance, and effects of biofortified crops in tackling hidden hunger and guaranteeing nutrition security for current and future generations are covered in the article.

Introduction

Traditionally, the availability of enough calories has been used to define food security. But having enough calories does not always translate into being healthy. Many people around the world experience "hidden hunger," a type of malnutrition brought on by insufficiencies in micronutrients including iron, zinc, and vitamin A. The Food and Agriculture Organization (FAO) estimates that micronutrient deficiencies impact more than 2 billion people globally. Iron-deficiency anaemia, vitamin A deficiency, and stunted growth brought on by inadequate nutrition are all ongoing problems in India. In order to solve these problems, nutrition security as well as food security are necessary. Biofortification has been introduced as a low-cost, sustainable approach to deliver essential nutrients through staple crops that people consume daily. Unlike food fortification (adding nutrients during food processing) or supplementation (providing pills or syrups), biofortification integrates nutrition into the crop itself.

Concept and Methods of Biofortification

Biofortification involves increasing the concentration of essential vitamins and minerals in crops. This can be achieved through three main approaches:

Conventional Plant Breeding

- ✓ Scientists cross high-yielding varieties with naturally nutrient-rich varieties.
- ✓ Example: Iron-rich pearl millet (Dhanashakti) developed in India.

Biotechnology / Genetic Engineering

- ✓ Specific genes responsible for nutrient accumulation are introduced.
- ✓ Example: *Golden Rice*, engineered to produce beta-carotene (Vitamin A).

Agronomic Biofortification

- ✓ Application of micronutrient fertilizers like zinc and selenium to soil or crops.
- ✓ Example: Zinc-enriched wheat through soil application in India.

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Importance of Biofortified Crops

Addressing Hidden Hunger: Staple crops like rice and wheat are widely consumed but poor in micronutrients. Biofortification enriches them with essential vitamins and minerals.

Cost-Effective: Once a biofortified variety is developed, seeds can be multiplied and distributed without recurring high costs.

Rural Reach: Unlike fortified foods available in markets, biofortified crops can be grown in villages and consumed directly.

Complementary Approach: It complements supplementation and fortification strategies.

Examples of Biofortified Crops Worldwide and in India

Vitamin A-rich Orange-fleshed Sweet Potato (OFSP): Helps prevent night blindness. Successfully adopted in Africa.

Golden Rice: Genetically modified rice enriched with beta-carotene.

Zinc-rich Rice and Wheat: Released in India under ICAR programs.

Iron-rich Pearl Millet (Dhanashakti): Reduces anemia prevalence.

High-Protein Maize / Quality Protein Maize (QPM): Contains balanced amino acids like lysine and tryptophan.

Biofortified Lentils and Beans: Enriched with iron and zinc to combat deficiencies in South Asia.

India has already released 100+ biofortified crop varieties including rice, wheat, maize, pearl millet, and mustard.

Health and Societal Benefits

Reduction in Anemia: Iron-rich crops reduce anemia in women and children.

Improved Growth in Children: Zinc-rich crops help prevent stunting.

Stronger Immunity: Vitamin A-rich crops improve immune response and reduce infections.

Better Productivity: Healthy farmers and workers contribute to economic development.

Intergenerational Benefits: Improved maternal nutrition reduces risks of low birth weight and child malnutrition.

Challenges in Adoption

Despite potential, biofortification faces barriers:

Low Awareness: Farmers and consumers often lack knowledge about nutrition-rich crops.

Market Acceptance: Biofortified crops sometimes look or taste different. For example, orange-coloured sweet potatoes or rice varieties may face resistance.

Yield Concerns: Farmers may prefer high-yield varieties over nutrient-rich ones unless biofortified crops also ensure productivity.

Policy and Regulatory Issues: Genetically modified crops like Golden Rice face public resistance and strict regulation.

Distribution System: Need to integrate biofortified seeds into government schemes like the Public Distribution System (PDS), Mid-Day Meal Scheme, and ICDS (Integrated Child Development Services).

Strategies for Promotion and Future Prospects

Government Support: Inclusion of biofortified crops in national nutrition and agriculture policies.

Research and Development: Strong collaboration between ICAR, ICRISAT, and HarvestPlus.

Farmer Incentives: Subsidies and support for adopting biofortified seeds.

Awareness Campaigns: Educating consumers about health benefits.

Integration with Food Security Programs: Using biofortified staples in schools, hospitals, and community kitchens.

Future research is also focusing on climate-resilient biofortified crops, ensuring that they provide both nutrition and resilience to stress conditions like drought, pests, and diseases.

Conclusion

In addition to being breakthroughs in agriculture, biofortified foods can also be used to benefit public health. They directly reach vulnerable populations by adding vital vitamins and minerals to basic crops. The success of biofortified cultivars in India and other nations indicates considerable promise, despite ongoing hurdles in awareness, acceptance, and scaling up. Biofortification should be used with complementing tactics including supplementation, fortification, and dietary diversification for long-term nutrition security. Biofortification has the potential to drastically lower hidden hunger and create a more productive, healthy society if it is supported by robust policy, adopted by farmers, and understood by consumers

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Revolutionizing the Fields: AI Cultivates a New Era for Indian Agriculture

Mayukh Saha

Government and startups roll out smart tools and advisory systems nationwide

The agricultural sector in India is being intensely industrially challenged by factors of unpredictable weather, rising costs of production and a massive shortage of labour despite the largely dependable nature of agriculture as the foundation of livelihood of a large proportion of the populace. As a reaction to these pressures, we are witnessing the emergence of artificial intelligence and data analytics as the key tools that reduce the severity of such adversities. Researchers and pundits argue that diseases and technologies driven by AI in agriculture are estimated to have a world-wide scale ranging between US1.7 billion in 2023 and a predicted US 4.7 billion in 2028, Offering farmers real-time information about the meteorological conditions, soil properties and plant health. Government institutions and individual innovators in India are rolling out new platforms including satellite-enabled yield prediction systems and smartphone-enabled crop-advisory platforms aimed at improving agricultural productivity and sustainability.

Government Initiatives: A recent Digital Agriculture Mission by the Union government is aimed at entrenching artificial intelligence and data analytics in the agricultural practice at the national level. The initiative was legislated in September 2024 and has allocated a budget of ₹2,817 crore to create a digital community infrastructure in which the farming community makes up. The backbone of this architecture is the AgriStack a digital registry that gives each farmer a unique identifier associated with a set of land and livestock footprint, and also creates geo-tagged cartographic representations of fields and type of crops (pib.gov.in). The proposal envisions that of a three-year period, about 1.1 crore individual farmer IDs will be granted; and amenity of an entire digital crop survey, with a scope of 400 districts during the 202425 rounds. As a result, a broad database of all the registered farmers and their areas is enshrined and the main goal is to enhance effectiveness and transparency of subsidy scheme, issuance of loans and insurance schemes.

Besides, the administration is using artificial-intelligence-based advisory tools to help in the day-to-day agricultural activities. Indicatively, a hosting voice chatbot such as the Kisan e-Mitra can reply to queries on topics like crop plans and the PM-Kisan subsidy in eleven regional dialects thus fulfilling more than twenty thousand queries daily among farmers. Also, the National Pest Surveillance System uses AI/ML to identify pest and disease threats on field photographs of up to 61 crops, so that over ten thousand extension workers can make early warnings to farmers. At the same time, with the

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support of fiscal incentives through the Sub-Mission on Agricultural Mechanization and a new bundle named Namo Drone Didi, authorities are promoting the use and adoption of drone technologies in agriculture in terms of application and monitoring. With these mechanisms, many farmer groups and women cooperatives can receive a state subsidy, usually half to three-quarters the price of drones bought out. The idea behind such interventions is to introduce new sophisticated tools to the traditional farming process, such as accurate sensors, flying drones, and Internet of Things systems.

Private-Sector Innovations: The current state of the agritech startup ecosystem in India is characterized by a propagation of solutions grounded in artificial intelligence (AI). Applications like AgroStar and DeHaat empower farmers by providing better access to quality inputs and offering agronomic advice tailored to their local language. Other ventures focus on data analytics. Bengaluru-based startups CropIn and Fasal utilize sensor networks and AI algorithms to deliver precise irrigation schedules and yield simulations based on meteorological, soil, and satellite data. Another significant trend is the emergence of digital marketplaces that leverage advanced technology. New services such as Ninjacart and WayCool establish direct connections between farmers and buyers, eliminating intermediaries and ensuring that farmers receive more favorable prices. Startups with specialized applications are employing computer vision techniques and machine learning (ML) to enhance the quality of produce. AgNext, based in Punjab, has developed vision systems capable of grading chili peppers and detecting defects directly in the field. Similarly, Intello Labs, located in Karnataka, uses AI to assess the quality of fruits and vegetables and reduce spoilage, enabling farmers to achieve higher prices. Additionally, there has been a rise in fintech activity, including digital underwriting by Jai Kisan, which provides rapid loans through technology, and "buy-now-pay-later" services that enable farmers to purchase superior seeds and equipment, thus facilitating investment in quality inventories. When all these developments are considered together, modern farming implements are becoming increasingly affordable for Indian farmers.

Field Deployments and Pilots: Artificial intelligence in agriculture can be developed as evidenced by pilot projects. The state of Telangana has the Saagu Baagu (Prosperity) program, a partnership between government and industry which used AI-based advisory systems and a WhatsApp chatbot in the Telugu language to assist about 7 000 chili farmers in the Kuramam district. In three consecutive years of growth, the participants grew their yield by an average of about 21 3/4 and multiplied their net earnings by a factor close to two with the income per season standing at approximately US 800/acre. Reduction in pesticide use (9 percent) and fertilizer usage (5 percent) were also factors of the trial. Improved grading process added price value of between 8-10%. A similar program has been in Maharashtra to the sugarcane farms of Baramati.

The initiative put up AI-enhanced weather sensors and soil sensors that sent information to the Agripilot.ai program. New daily alerts included the name of either water or spray pesticide, including real-time sensor values using sensors and satellite data, which allowed farmers to modify input application metrics to ensure superior-quality sugarcane. These examples help visualize the idea that the perspective of the support of language, using a combination of data analytics and remote sensing, but aimed on a local scale, can be satisfactory in adapting AI technologies to local needs of the Indian farming system.

Promise and Challenges: Conceptually, machine learning and artificial intelligence have the ability to directly improve operational efficiency gradually in small farms. Sensors which detect crop stress through drone or satellite images enable effective control of pesticides or irrigation hence low running costs and fewer environmental effects. Modern neural-network algorithms can identify plant diseases with great degrees of accuracy and makes it possible to conduct timely remedial measures before the outbreaks rapidly spread. The potential gains are immense; even 10-20 percent increase in yield/ input savings would significantly improve the income and fortitude of the farmers. In fact, empirical data conducted on pilot programs earlier prove that the net profits of participating farmers are great, which can be shown with regard to the SaaguBaagu chili example. However, analysts warn that the implement-ation is likely to be disproportionate.

Significant challenges arise from infrastructural shortages and insufficient digital literacy. According to a recent report compiled by MediaNama, it is estimated that only about 2% of Indian farmers currently utilize the potential of mobile applications or IoT services in their agricultural activities. Hundreds of millions of smallholders still lack access to smartphones or reliable internet services, and many are unable to obtain a digital identification record due to the absence of Aadhaar cards or unclear land ownership rights. Stakeholder issues have become even more pronounced: opponents argue that an engaging AgriStack database could infringe on farmer confidentiality and necessitates the building of trust to alleviate concerns about surveillance. Bridging such inequalities will require increased connectivity in rural communities, capacity building in farming, and high data protection standards. These challenges, as noted in one analytical study, can only be addressed through a collaborative effort among government, industry, and academia.

Despite these challenges, India's initiatives, through innovative digital projects in New Delhi and dynamic start-ups in rural towns, indicate a growing momentum. Should the promise of artificial intelligence be fully realized, even modest efficiency gains could enable Indian farmers to achieve greater production and income. The coming years will evaluate the pace at which these technologies grow for the millions of small farms.

Soil Degradation: Causes and Management

Shagun Kumari

Abstract

Soil degradation is a major environmental concern posing threats to food security, biodiversity, and climate control around the world. It is mainly attributed to the interplay between natural processes and anthropogenic drivers like unsustainable farming, deforestation, overgrazing, and industrialization. Successful management balancing sustainable agriculture practices, technological innovation, and strong policy support is essential to restore and protect this limited resource for future generations.

Introduction

Soil, a thin but very important layer of the Earth's crust, supports nearly all life on land through plant growth, water cycle management, and carbon sequestration. While essential to human health and ecosystem resilience, soil is far too often taken for granted and inadequately managed. Growing pressures from expanding populations, intensive agriculture, and industrialization have accelerated soil loss throughout the world, threatening human health and ecosystem resilience.

Reasons for Soil Degradation

Physical processes

- ✓ Water and wind erosion remove productive topsoil.
- ✓ Soil compaction caused by heavy machines reduces pore space, suppressing root growth and water infiltration.

Chemical factors

- ✓ Excessive use of chemical fertilizers and pesticides disrupt soil pH, nutrient balance, and kill good microorganisms.
- ✓ Salinization through unsound irrigation and drainage, and acidification through unsustainable crop/fertilizer choice reduce fertility.

Biological drivers

- ✓ Organic matter degradation (humus), soil diversity decline, and low microbial activity lower soil quality and structure.

Human drivers

- ✓ Deforestation removes cover vegetation, leaving soil vulnerable to erosion and nutrient loss. Overgrazing and monoculture reduce plant cover and soil cycle disturbances. Urbanization and land sealing eliminate productive land irreversibly.Industrial pollution unleashes heavy metals and toxic chemicals.

Management and Solutions Sustainable farming practices

Conservation tillage: Avoids or minimizes deep plowing to preserve soil structure and moisture.

Crop rotation and cover crops: Intersects pest life

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cycles, enhances nutrient cycling, and prevents soil loss.

Integrated nutrient management: Manages organic and inorganic materials to maintain soil fertility.

Efficient irrigation: Prevents overwatering and salinization.

Ecological restoration

Agroforestry and reforestation: Tree planting and involving crops in perennial plants fix soil, replenish organic matter, and enhance biodiversity.

Land reclamation: Reclaiming degraded lands and soils through organic matter and nutrient amendments.

Technological innovation

Precision agriculture: Employing remote sensing, GIS, and site-specific input applications to maximize soil management, minimize waste, and track the health of soils.

Digital soil mapping: Assisting farmers and planners in recognizing vulnerable areas and planning interventions.

Policy and community actions

- ✓ Implementing regulations to avoid deforest-ation, overgrazing, and pollution.
- ✓ Encouraging soil conservation by offering payments for ecosystem services, education, and infrastructure investment.

Benefits of Management

Long-term food production: Increased and more consistent crop yields enhance food security.

Improved ecosystem services: Better water filter-ing, nutrient cycling, and climate stabilization.

Greater resilience: Healthy soils withstand drought, floods, and other climate stresses better.

Conservation of biodiversity: Preserves micro-fauna and flora essential to ecosystem function.

Disadvantages

Cost and effort: Taking up new practices and technologies can be costly, particularly for small-scale farmers.

Short-term productivity decline: Moving away from traditional to sustainable practices can initially decrease output until soil vigor rebounds.

Policy implementation barriers: Poor governance or competing interests may restrict effectiveness.

Global Relevance

Soil degradation is a global crisis:33% of the world's soils are moderately to highly degraded, according to the United Nations, and 24 billion tonnes of arable land and 15 billion trees are lost each year, affecting food security and ecosystem stability for more than 1.5 billion people.Land degradation is a principal cause of biodiversity loss, more frequent and severe floods, forced migration, and in some instances, conflict.The connection between soil health and climate change is now well established, as soils contain more carbon than the atmosphere, and their degradation stimulates global warming.

Challenges

Awareness gap: Policymakers and the general public often underestimate the severity of soil degradation until the effects are severe.

Financial constraints: Small-scale farmers, particularly in developing countries, lack the financial means to make the switch to sustainable practices.

Fragmented policies: Inadequate or episodic policies have a limited impact on the large scale.

Climate change feedbacks: Increased wetter storms, warmer temperatures, and changing rainfall heighten the risk and severity of degradation.

Lack of data and monitoring: Unavailability of measuring the rate and amount of soil loss complicates focused action.

Conclusion

The prevention of soil degradation is vital for long-term food security, climate resilience, and conservation of biodiversity. It calls for holistic solutions: integrating sustainable agricultural practices, ecological rehabilitation, technological innovations and sound policy environments. Prioritizing the health of the soil will decide the resilience and prosperity of human civilization and the natural environment in the face of increasing environmental change.

Flood Hits Punjab: Farmers in Despair

Lakshana Rai

Abstract

Punjab, the biggest farming state in India, got hit by floods, one of the worst in decades. Farmers and folks in the rural are still suffering from the after effects. The heavy rains from the monsoon just kept coming, and too much water was let out from the dams. This made the Sutlej, Beas, and Ravi Rivers swell up and spill over everywhere. Huge parts of the state ended up underwater. Crops got wiped out completely. People had to leave their homes, livelihoods. These floods showed how shaky Punjab's whole farming setup is when the weather goes extreme like that. It makes you see the need for tougher ways to grow food, better handling of floods, and real help for the communities that keep the country fed.

Introduction

For Punjab's farmers, August 2025 is going to be the month of despair. This state that basically keeps India fed had its rich plains just totally swamped by the nonstop floods. Crops that were standing tall got wrecked in only a few days and homes got swept off. Families had to pack up and leave their villages and livelihoods behind. This place that's always been called India's breadbasket, the very same ground that holds the country together turned into a whole scene of destruction due to the floods.

A Flood Not Seen in Decades: People are calling this year's flood the worst ever since the flood back in 1988. Almost 1,400 villages in 13 different districts were flooded. The government went ahead and labeled all 23 districts as flood-affected. More than 30 people have lost their lives and three are still missing. Over 3.5 lakh people are out there trying to make amends and get their lives back on track. The districts that suffered the most include Gurdaspur, Amritsar, Hoshiarpur, and Ferozepur. Hundreds of villages there were completely cut off because of the water. It all started due to the excessive amounts of rainfall and cloudburst in Himachal Pradesh and Jammu and Kashmir. The catchments were all swelled up, pushing way too much water down into the Punjab region. There was extra water getting released from dams like Pong, Ranjit Sagar, and Bhakra, which just made everything worse. The Sutlej, Beas, and Ravi rivers overflowed and covered the banks. Huge areas of Punjab's rural areas vanished under the flood.

The Blow to Agriculture: The damage to farming has been huge, like staggeringly critical. Over 1.48 lakh hectares of fields got submerged. Rice crops that were only weeks from being harvested were ruined. Cotton fields and maize got wiped out. There's the

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heavy silt that has been piled up, plus the area has been waterlogged too long, making the areas prone to pest infestation and loss of good soil. Farmers are stressing about this season and worried about the upcoming one. For those small farmers who have small land holdings, losing a whole season of harvest can set them back years. All the money invested into seeds, fertilizer, diesel for pumps, has gone down the drain along with the flood. Livestock were lost which gives another hit as there is no alternative for the crop losses. Now they're looking at real financial crisis along, along with the emotional side of it all.

Relief and Rescue Efforts: The authorities managed to get nearly 20,000 people to safer camps. They've put together more than 170 relief camps for people to stay in. The National Disaster Response Force has sent out teams for relief and rescue. The Army, Navy, and Air Force have been called on for help too. Helicopters are flying, boats are out on the flooded water. Engineer units are trying to fix broken roads and the electricity to get connections back. Even after all the efforts plenty of areas are still isolated and hard to reach. In Kapurthala, families were paddling on rafts made from whatever they could find, along with their belongings. Villagers in Jalandhar were slogging through water up to their waists. Parents were lifting kids on their shoulders while hunting for dry ground. Schools and colleges all over Punjab were closed until September 7. That means the floods are hampering their day to day livelihoods.

Politics and Pleas for Support: This brings back what happened in 1988, when at least 600 people died. The death toll now isn't as high but the hit to the economy is massive. Chief Minister Bhagwant Mann came out and said the current relief sum is unrealistic. He wants at least ₹50,000 per acre to help farmers out, as the sum they're offering doesn't cover the real costs of dealing with the losses. Delhi's Chief Minister Arvind Kejriwal said he's standing with them and relief supplies are coming from the capital. Groups of citizens and political parties are sending aid urgently. Farmers though, they worry that when the water finally pulls back, it'll be them alone dealing with the havoc left behind.

Punjab's Fragile Breadbasket: These floods make you realize how Punjab's problems come from the way they farm as much as from the rain itself. For years, paddy has been planted that sucks up tons of water using traditional methods. Drainage systems are not upto the mark. Buildings keep getting constructed right on flood-prone land without much thought. Climate change is escalating it all, the monsoons can't be predicted, sudden cloudbursts and uncertain rain. If real changes are not made, Punjab could see this kind of thing happen more often.

Conclusion

The flood proves that even Punjab, the breadbasket of India, can be struck by such natural disaster. Relief work will ease the situation but the real issue is rebuilding trust in the land and the setups that are supposed to keep farmers safe. Without any quick action on this agenda, each monsoon season will bring the risk of more drowned fields, ruined harvest, and the aftermath of the disaster.

Locking Away Carbon: Pathways of Sequestration and their Environmental Impact

Chidanand Gowda M. R., Prajwala B., Manoj Gowda G. and V. Sahana Patil

Abstract

Carbon sequestration represents a vital frontier in the global effort to mitigate climate change, offering a means to capture and store atmospheric carbon dioxide (CO_2), the primary driver of global warming. It is broadly categorized into two types, natural sequestration and artificial or technological sequestration. While natural approaches harmonize with ecosystems enhancing biodiversity, improving soil health and supporting sustainable land use artificial methods offer greater precision and scalability, especially in industrial sectors. However, each pathway carries its own environmental implications, including energy consumption, cost, risk of leakage, and potential ecological disruption. Despite these concerns, carbon sequestration remains an indispensable tool in the climate toolbox. By reducing atmospheric CO_2 and complementing emission-reduction strategies, it plays a crucial role in achieving net-zero targets and stabilizing the climate. Ultimately, the success of carbon sequestration lies in its responsible integration where innovation meets ecology, and immediate action aligns with long-term sustainability.

Introduction

Carbon sequestration is the process of capturing and storing carbon dioxide (CO_2) from the atmosphere to mitigate its impact on climate change. This chapter aims to provide a comprehensive overview of carbon sequestration methods and their significance in combating global warming. The Earth's climate is rapidly changing due to increased greenhouse gas (GHG) emissions, necessitating urgent action to offset GHG releases. Soil carbon sequestration is a promising approach, with degraded and agricultural soils having significant potential to reduce CO_2 levels. Soils globally can retain twice as much carbon as the atmosphere and vegetation combined, influenced by climate and edaphic factors. Agricultural practices, such as land-use changes and residue management, impact soil carbon stocks and quality, enhancing food security and sustainable agriculture. Developing carbon sequestration technologies is crucial, including abiotic techniques like CO_2 injection into oceans, geological strata, mineral carbonation, and biotic techniques that provide cost-effective and immediate solutions. Both options are complementary and can mitigate climate change risks. Human activities, particularly fossil fuel combustion, have raised atmospheric CO_2

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concentrations, causing global warming and adverse impacts. Effective strategies are needed to reduce emissions and remove CO_2 from the atmosphere.

Natural Carbon Sequestration: Refers to the process by which carbon dioxide (CO_2) is removed from the atmosphere and stored in natural reservoirs, such as forests, grasslands, wetlands, and oceans. It is an important mechanism for mitigating climate change because it helps to offset the carbon emissions resulting from human activities.

Forests: Trees absorb CO_2 during photosynthesis and store it as carbon in their trunks, branches, and roots. Forests are one of the largest carbon sinks on earth, and deforestation contributes significantly to increased CO_2 levels in the atmosphere.

Soil carbon sequestration: Plants capture CO_2 from the air and convert it into organic matter through photosynthesis. When plant residues decompose, the carbon is stored in the soil. This process can be enhanced through sustainable agricultural practices like cover cropping, conservation tillage, and agroforestry.

Wetlands: Wetlands, such as marshes, swamps, and peatlands, can store large amounts of carbon. The waterlogged conditions slow down the decomposition of organic matter, allowing it to accumulate over time and sequester carbon.

Coastal ecosystems: Mangroves, seagrasses, and salt marshes are highly effective at sequestering carbon. These coastal ecosystems capture and store carbon in both their above-ground and below-ground biomass, as well as in the sediment and soils.

Ocean carbon sequestration: The ocean acts as a vast carbon sink, absorbing CO_2 from the atmosphere. Phytoplankton, microscopic plants in the ocean, absorb carbon during photosynthesis. When they die, they sink into the deep ocean, effectively sequestering carbon for long periods.

Promoting natural carbon sequestration is crucial for reducing greenhouse gas concentrations in the atmosphere. Protecting and restoring natural habitats, implementing sustainable land management practices, and conserving biodiversity are all important strategies to enhance natural carbon sequestration. However, it's important to note that while natural carbon sequestration is valuable, it should not be seen as a sole solution to climate change. Reduction of greenhouse gas emissions through transitioning to renewable energy sources and sustainable practices is still vital to mitigate the effects of climate change.

Artificial Carbon Sequestration: Artificial carbon sequestration, also known as engineered or technological carbon sequestration, refers to the deliberate and human-driven process of capturing and storing carbon dioxide (CO_2) from the atmosphere or other emission sources. It involves a range of technologies aimed at reducing the concentration of CO_2 in the atmosphere to mitigate climate change.

Carbon capture and storage (CCS): CCS involves capturing CO_2 emissions from large industrial sources, such as power plants and factories before they are released into the atmosphere. The captured

CO_2 is then transported and stored underground in geological formations, such as depleted oil and gas reservoirs or deep saline aquifers.

Direct air capture (DAC): DAC technologies capture CO_2 directly from the ambient air. These systems use sorbents or solvents to chemically absorb CO_2 which is then concentrated, separated, and stored. DAC can be useful for removing CO_2 from the atmosphere, even from dispersed sources like transportation or residential emissions.

Carbon mineralization: This method involves converting CO_2 into stable carbonate minerals through chemical reactions. For instance, CO_2 can react with certain types of rocks, such as basalt, to form solid carbonates that can be stored long-term. Carbon mineralization can occur naturally over geological timescales, but researchers are exploring ways to accelerate the process.

Bioenergy with carbon capture and storage (BECCS): BECCS combines biomass energy production with CCS. Biomass, such as agricultural waste or purpose-grown crops, is burned to generate energy. The resulting CO_2 emissions are then captured and stored using CCS technology. The idea behind BECCS is that the CO_2 emissions from biomass combustion are offset by the CO_2 removed from the atmosphere during the growth of the biomass feedstock.

Enhanced weathering: Enhanced weathering involves speeding up the natural process of rock weathering to absorb CO_2. Certain types of rocks, like olivine, can react with CO_2 when exposed to air and water, forming carbonates. Crushed rocks can be spread on the land or beaches, increasing their surface area for reaction with CO_2 and promoting carbon sequestration. Artificial carbon sequestration technologies have the potential to play a significant role in reducing greenhouse gas emissions and mitigating climate change. However, many of these methods are still in the early stages of development and face challenges such as cost, scalability, and environmental impacts. It is essential to continue research, development, and deployment efforts to improve these technologies and assess their viability as part of a comprehensive climate change mitigation strategy.

Environmental Implications of Carbon Sequestration: Carbon sequestration refers to the process of capturing and storing carbon dioxide (CO_2) from the atmosphere or other sources to mitigate climate change. While carbon sequestration technologies have the potential to help reduce greenhouse gas emissions, there are several environmental implications that need to be considered.

Some important key points are:

Land Use: Many carbon sequestration methods, such as afforestation (planting trees) and reforestation, require significant land area. This can lead to competition for land, particularly in regions with high population density or valuable ecosystems. Large-scale land use changes can have impacts on biodiversity, habitat loss, and the displacement of local communities.

Soil Health: Certain carbon sequestration techniques

like carbon farming or biochar application, involve modifying agricultural practices or soil management. While these methods can enhance carbon storage in the soil, they may also affect soil fertility, nutrient cycling, and microbial diversity. It is essential to carefully manage these practices to ensure long-term soil health.

Leakage and Long-term Stability: Carbon sequestration projects should ensure that the stored carbon remains locked away for an extended period. Leakage refers to the release of stored carbon back into the atmosphere or other carbon sinks over time. Leakage can occur due to natural processes, inadequate monitoring, or unforeseen events such as wildfires or disturbances. Ensuring long-term stability and minimizing leakage is critical to the effectiveness of carbon sequestration efforts.

Environmental Trade-offs: Some carbon capture technologies, such as direct air capture or carbon capture and storage (CCS), require significant energy inputs and infrastructure. These processes may result in increased energy consumption, emissions from the capture or storage infrastructure, or other environmental impacts associated with energy production. It is crucial to consider the overall life cycle emissions and environmental trade-offs associated with different carbon sequestration methods.

Ecosystem Impacts: Implementing large-scale carbon sequestration projects, such as afforestation or ocean fertilization, can have unintended consequences on ecosystems. The introduction of non-native plant species, alteration of natural hydrological cycles, and disruption of marine ecosystems are potential risks. Careful planning, environmental impact assessments, and adherence to sustainability principles are necessary to minimize adverse effects.

Equity and Social Implications: Carbon sequestration projects should be designed and implemented in a manner that considers social equity and community engagement. Local communities, particularly indigenous peoples and marginalized groups should be involved in decision-making processes to ensure their rights, livelihoods, and traditional knowledge are respected. To ensure the effectiveness and sustainability of carbon sequestration, it is essential to conduct thorough assessments, consider the potential environmental implications, and implement appropriate safeguards and monitoring systems. Integrating carbon sequestration with broader climate change mitigation and adaptation strategies can help achieve a balanced and holistic approach to environmental management.

Conclusion

Carbon sequestration has emerged as a powerful climate mitigation strategy, offering the potential to reduce atmospheric carbon dioxide and slow the pace of global warming. Its successful implementation, however, depends on a holistic understanding of environmental systems, technological capabilities, and long-term sustainability. As the world seeks pathways to climate stability, carbon sequestration represents not just a technical solution, but a commitment to restoring balance between human activity and the planet's natural systems.

Its true value will be realized only when used responsibly, transparently, and in harmony with wider goals of ecological resilience and intergenerational equity.

Farmers' Suicides in Telangana: Missing Issues

Gedam Kamalakar

Farmer suicides in Telangana are not just statistics they are a signal that multiple structural, institutional and social supports for agriculture are weak or misaligned. While official figures suggest fluctuations and declines over particular periods, on-the-ground reports, civil-society compilations and district-level incidents show persistent and, at times, sharply increased distress. The tragedy repeatedly exposes missing elements in policy and public debate: accurate data and transparency, attention to tenant and wage farmers, procurement and input-supply failures, gendered impacts, linked mental-health and poison-control responses, and real debt-relief pathways.

What the numbers say and why they can mislead

There are multiple sources for farmer-suicide data: the National Crime Records Bureau (NCRB), state compilations, civil-society tallies, and academic studies. Different definitions (farmer vs. agricultural labourer vs. tenant farmer), different denominators (per 100,000 cultivators vs. absolute counts), and delays or changes in classification mean that single-year comparisons can be misleading. For example, analyses of NCRB numbers show a sharp spike around 2014-2015 across India and Telangana linked to drought and crop failure followed by declines in later years in some official releases. But civil-society compilations and media-tracked lists show continuing high counts in recent years and point to under-reporting or delayed reporting in official series.

- ✓ A range of reporting indicates thousands of farming-related suicides across Telangana in the 2014-2023 decade; one civil-society factsheet cites a ten-year total (2014-23) of about 7,064 farmer suicides compiled from media/other sources.
- ✓ Some media summaries that use NCRB series report a big fall in suicides from very high counts in 2015 to much lower figures by 2022 but those trends depend on definitions and later data releases.

Because numbers are contested, one of the missing issues is transparent, real-time, disaggregated data: by district, by landholding class (marginal, small, and medium), by tenant vs. owner-cultivator, by gender, by crop and by cause (debt, crop failure, procurement delay, personal/family). Without this, policy responses will continue to be reactive and mis-targeted.

Root causes repeatedly identified but policy attention is incomplete

Academic and health-research studies make a critical point: the proximate act of suicide often masks deeper economic drivers. Recent empirical studies and reviews find that economic distress debt, crop failure, volatile markets, rising input costs is the

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dominant causal pathway; mental-health factors are typically downstream or interwoven with economic despair. In Telangana, common causes that recur across reports are:

Debt and credit distress: Informal loans, high-interest moneylenders, crop loans that cannot be serviced after failure. Debt chains and intergenerational liabilities play out in suicide clusters.

Crop failure and weather/climate shocks: Droughts, unseasonal rains and pest outbreaks (e.g., heavy rainfall damaging paddy crops) push incomes to zero. The 2014-2015 drought years are a clear example.

Market and procurement failures: Delayed procurement, price collapse at farm-gate, and the failure of timely MSP mechanisms (or access to them) leave farmers with unsold or unsalable produce; reports from procurement centers show instances where logistical failures and delays precipitated acute crises.

Input-cost and supply problems: Shortages in fertiliser or spikes in input costs increase the cost-risk ratio for cropping, sometimes tipping marginal farmers into negative returns. Recent protests and reporting in Telangana have flagged fertilizer shortages and supply-chain problems.

Pesticide access and method of suicide: Pesticide ingestion remains a common means of suicide among agricultural populations; healthcare and poison-control systems in many districts are underprepared for acute pesticide-poisoning emergencies. Hospital autopsy series and forensic studies show pesticides (including paraquat and other herbicides) as leading substances in intentional poisoning deaths in agrarian areas.

While these causes are frequently listed, the missing policy response is that solutions are rarely integrated. For example, loan-waiver rhetoric rarely pairs with improved procurement, extension services, and market access; poison-control and mental-health capacity building are separate from agricultural policy.

Missing issues that deserve urgent attention

Below I list the main gaps the "missing issues" that recur in Telangana but get insufficient attention.

Tenant farmers and the invisible landless: Tenant cultivators and sharecroppers are often excluded from official farmer registers and relief lists. They lack land titles required for many subsidy or relief schemes and hence do not receive ex-gratia payments or debt-relief easily. This invisibility leads to undercounting of distress and poor targeting of support.

Gendered impacts and widows' livelihoods: When a male head dies by suicide, the household's livelihood trajectory changes dramatically. Widow-hood, loss of tenancy rights, and difficulty accessing compensation or land redistribution are neglected. Few programmes systematically support widows to regain economic stability (land rights, training, and credit access). Media and NGO reports show many widows forced into precarious labor or migration.

Data transparency and classification: As noted earlier, conflicting datasets (NCRB, state police, civil society) confuse the public debate. There is a need for standard definitions (who counts as a farmer), timely district-wise dashboards, and an independent review mechanism. Civil society has accused governments of deliberate under-counting; whether intentional or not, opacity undermines remedial policy.

Procurement, storage and market access failures: Procurement delays at mandis and rice procurement centers especially during critical windows after harvest have precipitated acute crises when stock gets damaged by rains or when transport is absent. The link between procurement logistics and suicides is under-explored in policy design.

Agricultural price-risk management and crop insurance design: Crop insurance exists but suffers from low uptake, delayed claim settlements and basis risk (payouts that don't reflect small-holder losses). Insurance needs redesign for smallholders (quick assessment, easy claim, crop-wise tailored products) and to protect against post-harvest price crashes as well as production shocks.

Poison-control, emergency care and method-prevention: Because pesticide ingestion is a frequent method, restricting access to the most lethal pesticides, improving safe-storage practices, and strengthening rural emergency medical responses (antidotes, trained responders) are practical, life-saving measures that are often missing. Hospital studies show pesticides including highly toxic herbicides figure prominently in fatal cases.

Mental-health support anchored in economic relief: Mental-health interventions are necessary but cannot stand alone. Evidence indicates that economic insecurity is the principal driver. Crisis helplines, community counselling, and psychosocial services must be integrated with immediate economic relief e.g., rapid interim cash transfers, food support, or temporary wage work during lean months.

Political economy and accountability: There is frequent politicisation of farmer suicides blame-shifting between state and central governments. While political accountability is appropriate, the missing piece is institutionalized inquiry and remediation: rapid-response teams, independent inquiry into cluster suicides, and district-level corrective action plans.

Gaps in compensation and post-event support

Telangana's government documents show ex-gratia payments have been disbursed in specific periods (for example, government orders record ex-gratia payments for families). But gaps remain:

- ✓ Eligibility rules often exclude tenant and share-croppers.
- ✓ Amounts and timeliness vary; delays reduce efficacy.
- ✓ Post-compensation support for rehabilitation (land transfer, skill training, child education support) is patchy.

Civil society tallies indicate larger absolute numbers than official releases in certain years implying that compensation and rehabilitation may

not reach all affected families.

Recommendations closing the missing pieces (practical, actionable)

- ✓ Create a transparent, district-level suicide dashboard that disaggregates by farmer/tenant/ agricultural labourer, gender, age, crop, and proximate cause. This enables targeted interventions and independent scrutiny.
- ✓ Extend relief and registration to tenant and sharecroppers by creating easy proof mechanisms (affidavits, local panchayat certifications) so they can access ex-gratia, subsidies and rehabilitation.
- ✓ Fast-track procurement logistics and emergency purchase windows: allocate mobile procurement teams during harvest peaks; create contingency transport and cold-storage options to avoid loss of perishable crops. Ensure procurement delays are logged and remedied immediately.
- ✓ Revise crop insurance for fast claims and index-plus-loss assessment models that reduce basis risk plus mobile-based claim initiation and rapid assessment teams. Pilot quick-pay mechanisms for small claims. (Administrative design change.)
- ✓ Poison-control strategy: ban or restrict the most lethal pesticides; provide safe-storage kits; supply district hospitals with antidotes and train ER staff on poisoning management. Strengthen surveillance of pesticide sales and enforce safe-handling norms.
- ✓ Integrated crisis response teams at district level that combine agricultural extension, debtmediation cells, cash-transfer facilitation, and psychosocial counsellors deployable within 48-72 hours of a reported suicide to prevent contagion. (This closes the fragmentation between economic and mental-health responses.)
- ✓ Transparent debt-resolution and legal aid: set up legal-aid desks to renegotiate private loans, mediate with lenders and ensure members know their entitlements under government schemes.
- ✓ Gendered rehabilitation: prioritize widow support (livelihood trainings, direct cash transfers, priority for land allotments and subsidies) and ensure children of affected families get education stipends.

Conclusion why the missing issues matter

Farmer suicides in Telangana are not one-off tragedies; they are a symptom of multiple policy gaps interacting financial exclusion, poor market architecture, fragile procurement and public-health blind spots. Official numbers are important, but equally important is the detail behind the numbers: who is dying, why, and what safety nets failed. Closing the missing issues above would transform responses from episodic compensation to durable resilience-building: better data, inclusion of tenant cultivators, integrated economic and mental-health responses, and concrete measures to prevent lethal means of suicide (like pesticides). The cost of action improved procurement, faster insurance, and strengthened poison-control is far less than the social and human cost of continuing inaction.

Flowering Time in Dragon Fruit (*Hylocereus spp*.)

Rayapu Sai Theja, Nitu Kumari and Arathi Balan

Abstract

The climbing cactus known as dragon fruit (*Hylocereus spp*.), which grows in tropical and subtropical locations, has become a major commercial force globally because of its high nutritional content, appealing look, and capacity to grow on marginal ground. A crucial phenological stage in dragon fruit production, flowering time has a direct impact on fruit quality, market availability, and yield. Typically occurring in the summer to early fall, dragon fruit features huge, white, hermaphrodite, nocturnal blossoms that bloom for just one night. Flowering typically begins when there is warm weather, intense light, and enough moisture. The exact timing of flowering depends on the climate, cultivar, and management techniques. This article explains when dragon fruit flowers, what influences the initiation of flowers, and its importance in agriculture. The significance of flowering time is emphasized in connection with production regulation, pollination control, and climate change adaptation. This summarizes the consequences for academics and farmers, focusing on sustainable production methods.

Introduction

Dragon fruit is called pitaya or pitahaya, is indigenous to Mexico and Central America and is a member of the cactaceae family. Cultivated widely in South America and Southeast Asia, and increasingly in India and other tropical countries, it has become a fruit crop of economic value. With species like *H. undatus* (white-fleshed), *H. polyrhizus* (red-fleshed) and *H. megalanthus* (yellow-skinned with white flesh), the genus hylocereus is the most often grown. This perennial climbing cactus is suited to arid and semi-arid areas because of its succulent stems. It is prized for its visually appealing fruits that are high in vitamins, minerals, and antioxidants, as well as for its aesthetic value. Flowering and fruiting behaviour, which are impacted by crop management techniques, photoperiod, and climate, are crucial to dragon fruit production. Dragon fruit contains night-blooming flowers that open only once, usually in the evening or early morning, therefore knowing when to flower is crucial for successful production. Pollination success, fruit set, and yield are all impacted by timely flowering. Furthermore, flowering time is a critical factor in agronomic planning, particularly in nations where dragon fruit is a relatively recent arrival, as it differs by region and season.

Flowering time in dragon fruit

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Dragon fruit usually begins to flower 6-8 months after planting, while full commercial flowering may take place 12-18 months later. Warm months, high humidity, and sufficient rainfall typically correspond with the blossoming season. Dragon fruit blooms from May to October in tropical Asia and from June to November in subtropical regions. The enormous (20-30 cm long), tubular, and nocturnal flowers open between 6:00 and 8:00 PM and close early the next day. The bloom necessitates coordinated pollination, which is frequently done by bats, moths, and, in commercial production, hand pollination.

Fig. 1: Flowering in Dragon Fruit

Fig. 2. Reproductive whorls of the flower

Fig. 3: Bud swelling

Fig. 4: Bud emergence

Fig. 5: Bud development

Fig. 6: Floral tube elongation

Fig. 7: End of floral elongation

Fig. 8: Flowering stage

Fig. 9: Fruit formation

Fig. 10: Fruit development

Fig. 11: Fruit maturation

Location: Demonstration Orchard, Department of Fruit Science, RLBCAU, Jhansi

Seasonal Variations: During the summer and rainy season, flowering takes place several times in cycles, often from May to October in Tropical locations like Philippines, Malaysia, Thailand, and Vietnam. Depending on irrigation and weather, flowering may last until November in subtropical countries (India, southern China, and Israel), where it usually starts a little later in June or July. In South American locations (Colombia, Equator), tropical conditions with irrigation support can maintain flowering virtually all year round.

Factors affecting the time of flowering

Temperature: 18 to 26 °C is ideal for flowering. Flowering is suppressed by temperatures below 15 °C.

Photoperiod: High light levels and long days encourage the beginning of flowers.

Irrigation and moisture: While sufficient soil moisture is essential, waterlogging might prevent the commencement of flower buds.

Management of nutrients: Better flowering and fruit set are achieved with balanced nitrogen and increased phosphorus and potassium.

Pruning and training: Consistent flowering is encouraged by effective canopy management.

The significance of dragon fruit flowering time

Pollination Management: Because flowers are nocturnal and fleeting, pollination can be arranged by knowing when they bloom. In order to guarantee fruit set, certain Hylocereus species need to be cross-pollinated because they are self-incompatible. During the night time or early morning, farmers

frequently hand-pollinated.

Optimizing Yield: Multiple blooming flushes allow for longer harvest seasons, and flowering period determines fruiting cycles. Getting blossoming in sync increases output.

Market Supply: Farmers that are aware of flowering seasons can schedule harvests to coincide with the highest demand in the market, which guarantees higher prices and less gluts.

Response to Climate Change: Changes in the climate can affect when flowers bloom. By keeping an eye on phenology, one can anticipate changes brought on by warming climates and make timely adaptations.

Breeding and Research: In order to generate cultivars and facilitate hybridization, breeding programs need accurate flowering data. Improvement in genetics is supported by knowledge of the reproductive cycle.

Conclusion

In dragon fruit, flowering period is a crucial phenological characteristic that determines fruit production success. Flowering varies from place to place, highlighting the influence of regional climate, cultural customs, and cultivar genetic variations. By comprehending and controlling flowering time, farmers can maximize pollination, increase productivity, and satisfy consumer expectations. Furthermore, as dragon fruit farming spreads throughout the world, accurate understanding of its blossoming behaviour will be crucial for environmentally friendly production and adaptation. The development of cultivars with stable blooming features under various agroclimatic conditions and management strategies should be the main goals of future research.

From Soil to Sustainability: The Promise of Integrated Farming

Himani Sharma

Agriculture today faces immense challenges shrinking landholdings, rising input costs, soil degradation, and the urgent need to ensure food, nutritional, and livelihood security for a growing population. In this context, the Integrated Farming System (IFS) emerges as a promising solution. By blending multiple farming enterprises into a holistic system, IFS ensures sustainability, profitability, and resilience against environmental stresses.

What is Integrated Farming System (IFS)?

The Integrated Farming System is a synergistic approach to agriculture where various farming components such as crops, livestock, poultry, fisheries, horticulture, agroforestry, beekeeping, and value addition activities are combined in a mutually supportive manner. The central Idea is “recycling of resources” waste from one component becomes input for another. For example, livestock manure enriches the soil, crop residues feed animals, and pond silt nourishes fields.

Key Objectives of IFS

Sustainable Resource Utilization: Efficient use of land, water, labor, and capital.

Enhanced Farm Income: Multiple enterprises reduce dependence on a single source of income.

Employment Generation: Provides year-round work opportunities for rural households.

Nutritional Security: Ensures availability of diverse food products: cereals, pulses, milk, meat, fruits, vegetables, and honey.

Risk Minimization: Diversification reduces vulnerability to climate change, price fluctuations, and pest outbreaks.

Major Components of IFS

Crop Production: Cereals, pulses, oilseeds, vegetables, and fruits.

Livestock Rearing: Dairy, goatery, poultry, piggery, and sheep farming.

Fisheries and Aquaculture: Integration of fish farming with paddy fields or farm ponds.

Agroforestry and Horticulture: Fruit orchards, timber, and fuelwood plantations.

Beekeeping: Enhances pollination and provides honey and wax.

Advantages of Integrated Farming System

Higher Productivity: More output per unit of land.

Resource Recycling: Reduces cost of inputs and maintains soil fertility.

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Income Stability: Multi-enterprise setup cushions against losses in any single component.

Environmental Protection: Reduces dependence on chemical fertilizers and pesticides.

Food and Nutritional Security: Diverse products fulfill household needs.

Employment Generation: Reduces rural migration by engaging family labor throughout the year.

Challenges in IFS Implementation

- ✓ Requires proper planning and knowledge of multiple enterprises.
- ✓ Initial investment may be higher compared to monocropping.
- ✓ Limited awareness and extension support in some regions.
- ✓ Market access and infrastructure needed for perishable products.

Conclusion

The Integrated Farming System is more than just a farming model it is a way forward for sustainable agriculture. By integrating crops, livestock, fisheries, and other enterprises, farmers can maximize resource use, minimize risks, and achieve food, income, and environmental security. With proper training, policy support, and market linkages, IFS can transform small and marginal farms into prosperous, eco-friendly, and resilient enterprises.

Women in Agriculture: Invisible Backbone of India's Farming Sector

Debdipta Dolai

Abstract

Women play a vital role in India's agriculture, contributing to food security, household income, and biodiversity conservation. However, they face challenges like land ownership, limited resources, and lack of recognition. To fully utilize their potential, coordinated efforts are needed, including joint land titling, improved credit access, technology dissemination, and policy interventions acknow-ledging women as farmers.

Introduction

Women in Agriculture: The Unseen Foundation of India's Farming Sector Despite being the backbone of India's agrarian economy, women's contributions are frequently overlooked and underappreciated. Even though they perform a large amount of the agricultural labor, they encounter many obstacles that prevent them from advancing and becoming recognized. This article explores the many facets of women's roles in Indian agriculture, as well as their influence, challenges, and journey to empowerment.

The Diverse Roles of Women in Agriculture

Almost all facets of agricultural production and related activities involve women:

Crop Cultivation: Women actively participate in every step of crop production, from clearing the ground and planting seeds to weeding, transplanting, and harvesting.

Livestock Management: They are essential to the upkeep of poultry, dairy animals, and other livestock, which are vital for domestic sustenance.

Post-Harvest Operations: Women perform the majority of tasks related to threshing, winnowing, drying, storing, and processing agricultural products.

Seed Preservation and Traditional Knowledge: Women are frequently the keepers of traditional agricultural knowledge, such as knowledge of local agroclimatic conditions and seed preservation techniques.

Horticulture and Kitchen Gardens: They play a major role in the food security of households by being heavily involved in small-scale horticulture and kitchen gardens.

Challenges Faced by Women Farmers

Women farmers face a number of structural challenges in spite of their vital role:

Land Ownership and Access: A vast majority of women farmers do not own land, which limits their access to institutional credit, government schemes, and decision-making power.

Limited Access to Resources: They often face barriers in accessing quality seeds, fertilizers, mode-

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rn tools, and agricultural machinery.

Lack of Extension Services and Training: Extension services are often not adapted to the unique requirements and limitations of female farmers, resulting in a knowledge and skill development gap.

Drudgery and Health Issues: Women who work long hours in physically demanding jobs, frequently under challenging circumstances, may experience health problems.

Social and Cultural Barriers: Their freedom of movement, information access, and involvement in agricultural decision-making may be limited by patriarchal systems and societal norms.

Insufficient Recognition: Their work is frequently viewed as an extension of domestic duties rather than as productive labor, which results in a lack of support and acknowledgment.

Impact and Contributions

Women have made significant and wide-ranging contributions to Indian agriculture:

Food Security: Their persistent efforts guarantee food availability both nationally and in households.

Household Income: Their agricultural and related income greatly augments household income, raising living standards.

Rural Economy: The involvement of women is essential to the rural economy's viability and efficiency.

Conservation of Biodiversity: Their contribution to seed preservation aids in the preservation of agricultural biodiversity.

Going Forward: Giving Women More Power in Agriculture

In order to fully utilize women's potential in agriculture and guarantee their welfare, coordinated efforts are required:

Land Rights and Tenure Security: It is essential to implement policies that support joint land titling and make it simpler for women to obtain land.

Improved Access to Credit and Financial Services : Women can invest in their farms with the help of customized financial products and streamlined loan applications.

Technology dissemination and skill development: Increasing productivity can be achieved by offering training in climate-resilient agriculture, modern farming methods and the use of suitable technologies.

Strengthening Extension Services: It is crucial to make agricultural extension services more accessible to women and gender-sensitive.

Supporting Women Collectives: Women-led self-help groups (SHGs) and farmer producer organizations (FPOs) can gain more access to markets and bargaining power.

Policy Interventions: All agricultural programs must incorporate gender perspectives and specifically acknowledge women as farmers.

Conclusion

In addition to being participants, women are largely responsible for India's agricultural success. In addition to being issues of equity, acknowledging their critical role, resolving their difficulties, and

funding their empowerment are essential to attaining sustainable agricultural development and guaranteeing the country's food security. The transformation of India's agricultural landscape depends on empowering women farmers.

Biosensors for Plant Pathogen Detection: Fundamentals, Technological Innovations and Future Prospects

Ashish Singh Bisht, Sonam Bhatt, Monalisha Guru, Bijender Kumar and Rashmi Tewari

Introduction

Plant pathogens, including fungi, bacteria, and viruses, pose a significant threat to global food security and agriculture, causing an estimated 20% to 40% of annual crop production losses and financial costs exceeding $290 billion USD. Factors like climate change and global trade are accelerating the spread of these pathogens, necessitating a paradigm shift in plant pathology towards a new "mantra" of "early detection" in conjunction with "fast, accurate, and cheap" diagnostics. This is not just an economic issue; severe outbreaks can threaten human and animal health through poisonous mycotoxins and even lead to the extinction of plant species, making advanced diagnostic tools a public health and environmental imperative.

For years, conventional methods like Polymerase Chain Reaction (PCR) and Enzyme-Linked Immunosorbent Assay (ELISA) have been the standard for plant disease diagnosis, offering high accuracy and specificity. However, these traditional techniques are fraught with limitations that render them unsuitable for modern, large-scale surveillance. They are inherently time-consuming and labor-intensive, often requiring samples to be sent to a central laboratory for analysis, which can take days or weeks. This delay is catastrophic for rapidly spreading diseases, as it provides a crucial window for pathogens to multiply before intervention can be implemented. The complex and expensive equipment required for methods like PCR also makes them impractical for on-site use by farmers or non-specialists.

This trade-off between diagnostic accuracy and real-world applicability creates a significant diagnostic gap, particularly for small-scale farmers in resource-constrained settings where the costs and logistical complexities of traditional methods are prohibitive. Bridging this gap requires a new class of diagnostic tools that are rapid, accurate, and affordable, suitable for on-site, point-of-care (POC) use. Biosensor technology is uniquely positioned to address this critical need, driving the search for innovative solutions that enable real-time, on-site monitoring of crop health.

Core Principles of Biosensor Technology

Foundational Components: Bioreceptor, Transducer and Signal Processing: A biosensor is a device that converts a biological or chemical reaction into a measurable signal by using three main components: a bioreceptor, a transducer, and an electronic system. The bioreceptor, such as an antibody or nucleic acid, is the biological element that specifically interacts with the target substance

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(the analyte). The transducer then converts this bio-recognition event into a quantifiable signal, which can be electrical or optical. Finally, the electronic system processes this raw signal, making it interpretable for the user.

Key Performance Metrics in Biosensing: The performance of a biosensor is measured by three key metrics: selectivity, sensitivity, and the limit of detection (LOD). Selectivity is the device's ability to accurately identify a specific analyte within a complex sample, preventing false-positive results. Sensitivity and LOD are related to the biosensor's quantitative capabilities; sensitivity is the smallest change in concentration that can be measured, while LOD is the lowest concentration that can be detected. A low LOD is crucial for the early detection of plant pathogens, as it allows for diagnosis before the pathogen concentration becomes high enough to cause visible symptoms. A significant challenge in real-world application is that complex plant extracts can interfere with a biosensor's performance, reducing its accuracy and reliability.

Classification of Biosensors for Plant Pathogen Detection

Biosensors for plant pathogen detection can be broadly categorized based on the type of biorecognition element or the transduction mechanism they employ. This classification system provides a useful framework for understanding the diverse approaches being developed to address the diagnostic needs of agriculture.

Biorecognition-Based Systems

Nucleic Acid-Based Biosensors: Nucleic acid-based biosensors utilize DNA or RNA as the bioreceptor to detect the genetic material of the target pathogen. This approach offers exceptional specificity and sensitivity, particularly when integrated with nucleic acid amplification techniques. For example, DNA-based biosensors have been established as powerful tools for the rapid and sensitive identification of plant pathogens, often by coupling probe-functionalized electrodes with redox-active indicators to convert a recognition event into a quantifiable electrochemical signal. An innovative electrochemical nanobiosensor was developed for the detection of *Leifsonia xyli* subsp. *xyli* (*Lxx*) DNA in sugarcane sap, achieving an exceptional detection limit of 10 cells μL^{-1}. This method demonstrated high reproducibility and strong correlation with known disease resistance ratings in field trials, offering a cost-effective, equipment-free, and scalable solution for on-site deployment.

Recent advancements in this area have been propelled by the adaptation of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)-Cas systems for diagnostics. Platforms like SHERLOCK and DETECTR leverage the collateral cleavage activity of Cas enzymes to detect nucleic acids without the need for thermal cycling, offering high specificity and femtomolar-level sensitivity in a rapid (15-45 minute) and low-cost format. These systems represent a significant leap forward, as they address many of the practical limitations of conventional PCR while retaining high performance.

The shift from traditional bioreceptors to programmable and more stable elements like aptamers and CRISPR systems reflects a broader trend in the field. The desire for greater durability, broader applicability, and ease of manufacturing for portable devices is driving researchers towards these more advanced biorecognition elements, whose robust nature is better suited for the harsh and complex conditions of field use.

Immunobiosensors: Immunobiosensors are based on the highly specific and selective binding affinity between an antigen and its corresponding antibody. In this system, antibodies are immobilized on the transducer surface, and the subsequent binding of the target pathogen's antigen produces a measurable signal. This technology is particularly well-suited for the on-site, large-scale detection of plant pathogens, as demonstrated by their use in tissue print ELISA and lateral flow devices. However, the performance of immunobiosensors is fundamentally limited by the quality and storage conditions of the antibodies employed, as their stability can be affected over time and by environmental factors.

Phage and Aptamer-Based Biosensors: Beyond traditional bioreceptors, a number of emerging technologies are being explored. Phage-based biosensors utilize bacteriophages, which are viruses that specifically infect bacteria, as the recognition element. Aptamer-based biosensors, on the other hand, employ synthetic single-stranded DNA or RNA molecules that can be engineered to bind to a specific target with high affinity. These emerging bioreceptors are being developed to overcome some of the limitations of antibody-based systems, offering enhanced stability and specificity.

Transduction-Based Systems

Electrochemical Biosensors: Electrochemical biosensors are a highly promising class of diagnostic tools that measure changes in electrical properties caused by a bio-recognition event. They are characterized by their simple instrumentation, high specificity, and cost-effectiveness, making them particularly attractive for point-of-care applications. The core mechanisms of these sensors include:

- ✓ **Current-based (Amperometric) sensors:** These systems directly detect targets through redox reactions that cause a measurable change in current. An example is a sensor that detects oxalic acid secreted by pathogenic bacteria, where the intensity of the generated current signal is positively correlated with the acid's concentration.
- ✓ **Impedance-based sensors:** These monitor the change in charge transfer resistance at the electrode interface and are suitable for the quantitative analysis of molecules like DNA or proteins.
- ✓ **Potentiometric sensors:** These capture the target, causing a shift in the electrode potential, which is then measured. An immunosensor using a polyclonal antibody attached to gold electrodes was developed for the in-field detection of plant pathogens, demonstrating high specificity and rapid response.

Optical Biosensors: Optical biosensors leverage the properties of light to detect the presence of specific molecules. They operate by measuring changes in light characteristics such as absorption, reflection, and fluorescence.

- ✓ **Fluorescence Resonance Energy Biosensors (FREBs):** These systems use a fluorescent bioreceptor that emits a signal in the presence of an analyte. Green fluorescent proteins (GFPs) have been successfully employed in fluorescent biosensors to detect fungal pathogens such as *Phytophthora palmivora* and *Aspergillus nidulans*.
- ✓ **Chemiluminescence (CL) sensors:** These devices are based on the emission of light from a chemical reaction and are valued for their high sensitivity, broad dynamic range, and low cost. A DNA-based chemiluminescent optical fiber biosensor has been designed for the rapid diagnosis of *Brettanomyces bruxellensis*.
- ✓ **Surface Plasmon Resonance (SPR) biosensors :** This powerful optical technique measures a change in the refractive index that occurs when molecules bind to a metal surface, typically a thin film of gold. An SPR-based immunosensor was developed for the early detection of Asian rust in soybean leaf extracts, demonstrating a linear response by immobilizing an antibody on a gold plate.

Optical biosensors offer enhanced sensitivity and label-free detection, but they can be complicated, expensive, and less amenable to miniaturization compared to other methods. This suggests a clear trade-off: while optical methods can achieve superior performance in controlled settings, the practicality of on-site deployment often favors simpler, more economical transduction methods, such as electrochemical ones.

Mass-Based Biosensors: Mass-based biosensors detect analytes by measuring a change in mass. This principle is often applied using micro- or nano-scale oscillators, such as cantilever beams. When a target analyte, such as a bacterial cell, binds to the surface of the cantilever, it increases the overall mass of the structure, causing a measurable shift in its resonant frequency. This technique has shown significant potential for ultrasensitive detection, with the ability to detect bacteria at the single-cell level. By immobilizing specific antibodies on the cantilever, researchers have demonstrated the selective capture of bacterial cells, further enhancing the specificity of the system.

The Convergence of Enabling Technologies

The next generation of plant pathogen biosensors is defined not by a single technological breakthrough but by the convergence of several complementary fields. The integration of nano-technology, microfluidics, and artificial intelligence is creating a new class of diagnostic tools that address the limitations of their predecessors and pave the way for a more intelligent and sustainable agricultural future.

The Role of Nanotechnology, Microfluidics, and AI in Biosensors

Nanotechnology has transformed biosensors by using materials like metallic nanoparticles and carbon nanotubes to boost sensitivity and catalytic activity. Their high surface-area-to-volume ratio allows for more bioreceptors, leading to a lower limit of detection. For example, gold nanoparticles enhance the signals in optical and electrochemical biosensors, making them more accurate and sensitive. Microfluidics and "lab-on-a-chip"" systems are crucial for on-site diagnostics. These portable devices automate complex steps like sample preparation, eliminating the need for bulky lab equipment. One example is a microfluidic device that detects plant spores by measuring changes in electrical impedance, offering a selective and real-time solution for field-based analysis. The full potential of biosensors is realized through the integration of Artificial Intelligence (AI) and Machine Learning (ML). These technologies act as "analytical engines," turning raw sensor data into actionable insights. AI models can detect subtle signs of disease from images (image-based diagnostics), analyze complex genetic data (omics data analysis), and integrate information from multiple sensors into a comprehensive monitoring system (IoT).

Challenges and Future Directions

Despite their promise, several challenges hinder the widespread adoption of biosensors. Technical hurdles include interference from complex plant and environmental samples and the instability of biological components. Economic and regulatory barriers include high manufacturing costs and a lack of standardized regulations for agricultural diagnostics. The future of biosensing for plant pathogens is focused on technological convergence. This includes developing multi-pathogen detection platforms, using nanobiosensors for unparalleled sensitivity, and integrating these systems with IoT and drone technology. This will create an automated, data-driven ecosystem for precision agriculture, enabling farmers to make targeted, sustainable decisions.

Conclusion

The development of biosensors for plant pathogen detection represents a critical and transformative leap forward in modern agriculture. By offering a rapid, sensitive, and on-site alternative to traditional laboratory-based methods, these devices are poised to fundamentally change how plant diseases are managed. The core principles of biosensing, which rely on the synergistic integration of highly specific bioreceptors and versatile transducers, have given rise to a diverse array of innovative platforms, including electrochemical, optical, and mass-based systems. These platforms, in turn, are being propelled by the convergence of enabling technologies. Nanotechnology enhances biosensor performance by improving sensitivity and catalytic activity, while microfluidics enables the miniaturization and automation necessary for point-of-care diagnostics. Ultimately, the integration of these devices with AI and IoT systems promises to create a comprehensive data ecosystem that transforms raw data into actionable intelligence,

facilitating proactive disease surveillance and management. However, the field is not without its challenges. Issues related to sample matrix interference, reagent stability, and the economic and regulatory hurdles associated with commercialization must be addressed. Despite these limitations, the trajectory of research is clear: the future of plant disease diagnostics lies in the continued development of integrated, high-performance, and secure biosensing systems. By harnessing the power of these technologies, agricultural professionals can move beyond reactive disease control to a new era of precision agriculture, safeguarding crop yields, ensuring a stable food supply, and promoting a more sustainable agricultural legacy for generations to come.

Media Coverage on Food Security and Climate-Smart Agriculture

Shubham

Introduction

Food is the most basic need of every human, and farming is at the heart of food security. But today, agriculture faces big challenges due to climate change unpredictable rains, floods, droughts, and rising temperatures. To address these issues, experts promote Climate-Smart Agriculture (CSA), which includes methods like drip irrigation, drought-resistant seeds, and organic soil management.

But here's the important question: How does the media (newspapers, TV, radio, and online platforms) present these topics?

Aims of this Study

The main aim of this study is to look at how newspapers and other media talk about food security and climate-smart agriculture (CSA). Another goal is to find out the gaps and weak points in the way media covers these issues. Finally, I want to connect what I have learned in communication theories with real-life examples and fieldwork, so that the study feels both practical and meaningful.

Theories behind Media Coverage

When we look at how media covers agriculture, some theories help us understand the process better. The Agenda-Setting Theory shows that if media highlights issues like floods in Punjab (reported by The Guardian and AP News), people start paying attention to how climate change affects farmers. Finally, Development Communication explains the role of media as a connector. For example, initiatives like the "Viksit Krishi Sankalp Abhiyan" reported in Times Of India demonstrate how communication links government schemes, scientists, and farmers directly, making agricultural knowledge more accessible and useful in the real world.

Hot Global Issues

One of the biggest global challenges today is climate change, which directly threatens farming. Reports suggest that by 2050, yields of rice and wheat could fall by nearly 20% if farmers do not adopt climate-smart practices. This issue is also tied to the United Nations Sustainable Development Goals (SDGs), especially SDG 2 (Zero Hunger) and SDG 13 (Climate Action), which highlight the urgent need for sustainable farming methods. However, the role of media becomes critical here. Studies and news reports show that mainstream outlets often give more space to politics, entertainment, or cricket, while agriculture gets limited attention. For example, when floods hit Punjab in 2025, international outlets like The Guardian covered the crisis in detail, but local coverage was often delayed or short. This shows how farming and food security are hot global issues, but media priorities sometimes push them into the background.

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What the Media and Government Say

Recent reports from both media and government sources highlight the urgent need for Climate-Smart Agriculture (CSA) in India. For example, during the Punjab floods of 2025, AP News and The Guardian reported how thousands of acres of farmland were destroyed, showing how vulnerable farmers are to climate extremes. To address such risks, initiatives like the "Viksit Krishi Sankalp Abhiyan" (covered in Times of India) are spreading sustainable practices to rural villages, ensuring that even small farmers learn about water-saving techniques, organic inputs, and modern tools. Similarly, in Odisha, a climate project introduced mobile apps and weather stations, which helped around 7,000 farmers make better planting decisions an important example of how technology can empower communities (TOI report).

On the policy front, Reuters noted that the Indian government increased its agriculture budget by 15%, with more focus on improved seeds, irrigation, and food storage facilities. Meanwhile, opinion pieces in The Hindu and Indian Express emphasized that without faster adoption of CSA, India's long-term food security will remain at risk. Together, these reports suggest that while progress is being made through training programs, technology, and budgetary support, much more is needed to make agriculture resilient against climate change.

Case Studies India

- ✓ DD Kisan TV often covers new schemes but sometimes feels too technical.
- ✓ Community radio (FM Kisan Vani) works better since it uses local languages and shares farmer-to-farmer experiences.

Zimbabwe

A study of The Herald and The Chronicle showed that only 22.6% of agriculture articles linked farming with climate change. Many key issues like storage and poultry farming were neglected.

Farmers' Point of View

Interactions with farmers in Punjab and Haryana reveal that many feel neglected by mainstream media when it comes to agricultural issues. Farmers commonly mentioned that farming problems rarely appear in big newspapers and that they rely more on community radio because it communicates in their local dialect and addresses their daily concerns. While platforms like WhatsApp provide fast updates, farmers are cautious since not all information shared online is reliable. A fieldwork interview with Ramesh, a wheat farmer from Haryana, highlights these views. He explained that unexpected rains ruined half of his crop, and he only learned about watersaving methods through a community radio program, not newspapers. According to him, if mainstream media gave more coverage to farmers' problems, more farmers could prepare better against such risks. This example shows that while local media and community networks play a vital role in spreading practical agricultural knowledge, mainstream media still lags in giving adequate attention to rural challenges.

Problems in Media Coverage

- ✓ Farming often ignored in front-page news.
- ✓ Many journalists don't understand agri-science.
- ✓ Farmers in remote areas lack newspaper/internet access.
- ✓ Sensational politics and entertainment dominate over food issues.
- ✓ Wrong or half-information sometimes misguides farmers.

Conclusion

Media plays a crucial role in shaping public understanding of food security and climate-smart agriculture, but its coverage remains uneven. While disasters like floods or droughts gain headlines, everyday farming challenges often go unnoticed. Farmers rely more on community radio and local networks than mainstream outlets, as these provide practical and accessible information. To truly support climate resilience and sustainable food systems, the media must go beyond crisis reporting and give consistent, farmer-focused, and easy-to-understand coverage that connects science, policy, and ground realities.

You are What You Eat and What You Eat begins with the Soil

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Nutrients form the very foundation of both plant vitality and human well-being. For plants, a balanced supply of macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) and micronutrients such as iron (Fe), zinc (Zn), copper (Cu), boron (B), and molybdenum (Mo) is indispensable for growth, metabolism, and resilience to stress. When these nutrients are supplied in adequate balance, plants thrive with optimal yields and disease resistance. However, deficiencies or imbalances result in stunted growth, reduced productivity, and greater vulnerability to pests and environmental stressors. The effects extend beyond the farm. When humans consume nutrient-deficient crops, the outcome is often hidden hunger - a form of malnutrition where calories are sufficient but essential micronutrients are lacking. This translates into widespread public health challenges such as anemia, weakened immunity, impaired cognitive development, and chronic diseases (Varsha *et al.,* 2021; Global Nutrition Report, 2021). In this way, the soil-plant-human nutrition continuum makes clear that agricultural practices directly influence dietary quality and population health. The urgency is amplified by demographic trends. With the global population expected to surpass 10 billion by 2050, the challenge lies not only in producing more food but in producing nutrient-dense food in a manner that preserves environmental sustainability. Reliance on fertilizer-intensive, chemical-driven systems may deliver short-term yield gains, but they erode soil fertility, disrupt ecosystems, and compromise the nutrient value of crops.

Against this backdrop, the adoption of sustainable plant nutrition management becomes indispensable. By prioritizing soil health, nutrient cycling, and ecological balance, sustainable practices offer a pathway to secure agricultural productivity, environmental resilience, and improved human nutrition. This paradigm shift is not merely desirable, as it is essential for shaping the future of food security and human well-being.

Essential Nutrients in Plants and Their Roles

Macronutrients

Nitrogen (N): Crucial for chlorophyll production, protein synthesis, and vegetative growth.

Phosphorus (P): Supports root development, seed formation, and energy transfer (ATP).

Potassium (K): Regulates water balance, enzyme activation, and disease resistance.

Calcium (Ca): Strengthens cell walls and supports

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The Relationship between Plant Nutrition and Human Health

The nutrient composition of crops is the bridge between soil and society. Deficiencies in plants mirror deficiencies in humans:

	Role in Plants	Nutrients	Role in Humans	Deficiency Disease	Supplement Foods
Structural Elements	Fundamental component of organic molecules; forms carbohydrates, proteins, and lipids through photosynthesis.	**Carbon (C)**	Provides energy in the form of carbohydrates, fats, and proteins. Essential for cellular structure and metabolic functions.	Reduced energy production, fatigue	Carbohydrate-rich foods (grains, fruits, legumes)
	Vital for respiration and energy release; involved in photosynthesis (produced as a by-product).	**Oxygen (O)**	Essential for cellular respiration to produce energy (ATP). Crucial for all metabolic processes.	Hypoxia, reduced energy production	No direct supplement (oxygen therapy if needed)
	The integral part of water, carbohydrates, and other organic compounds; supports photosynthesis.	**Hydrogen (H)**	Key component of water and organic molecules; maintains acid-base balance and hydration.	Dehydration, pH imbalance	Water, fruits, and vegetables
Primary macro Nutrients	Component of chlorophyll, proteins, and enzymes; promotes leaf growth.	**Nitrogen (N)**	Essential for protein synthesis and amino acid formation.	Poor protein synthesis, muscle wasting	Protein-rich foods (meat, eggs, beans, dairy)
	Energy transfer (ATP), root development, and seed production.	**Phosphorus (P)**	Supports bone and teeth development, and energy metabolism.	Weak bones and teeth, fatigue	Dairy, fish, nuts, legumes
	Regulates water uptake, enzyme activation, and photosynthesis.	**Potassium (K)**	Maintains fluid balance, nerve function and heart health.	Muscle weakness, irregular heartbeat, cramps	Bananas, oranges, potatoes, spinach
Secondary macronutrients	Strengthens cell walls, and supports root and shoot development.	**Calcium (Ca)**	Crucial for strong bones, muscle function and nerve signaling.	Osteoporosis, muscle cramps	Dairy, leafy greens, fortified cereals
	The central component of chlorophyll aids photosynthesis.	**Magnesium (Mg)**	Important for energy production and muscle relaxation along with Disease resistance	Muscle spasms, fatigue, weak immunity	Nuts, seeds, whole grains, green vegetables
	Synthesizes proteins, and forms chlorophyll, and enzymes.	**Sulfur (S)**	Helps produce amino acids for skin, hair, and nails and muscle formation.	Brittle hair and nails, poor skin health	Protein-rich foods (meat, eggs, onions, garlic)
Micronutrients	Assists in chlorophyll synthesis and electron transport.	**Iron (Fe)**	Vital for oxygen transport via hemoglobin; prevents anemia.	Anemia, fatigue, pale skin	Red meat, beans, lentils, spinach
	Activates enzymes support growth and hormone production.	**Zinc (Zn)**	Boosts immune function, wound healing and DNA synthesis.	Impaired wound healing, reduced immunity	Meat, shellfish, seeds, nuts
	Enables photosynthesis, enzyme activation, and disease resistance.	**Copper (Cu)**	Involved in iron metabolism and brain development.	Anemia, neurological issues	Shellfish, nuts, seeds, organ meats
	Facilitates photosynthesis and nitrogen assimilation.	**Manganese (Mn)**	Supports bone formation and antioxidant defense.	Weak bones, poor metabolism	Whole grains, nuts, leafy vegetables
	Essential for cell wall formation and reproductive health.	**Boron (B)**	Supports bone health and brain function.	Weak bones, cognitive decline	Fruits (apples, oranges), leafy vegetables

Micronutrients	Required for nitrogen fixation and enzyme activation.	**Molybdenum (Mo)**	Helps metabolize sulfur-containing amino acids.	Sulfur metabolism issues	Legumes, whole grains, nuts
	Helps in Seed maturity	**Chlorine (Cl)**	Enhancement of the digestive process	Digestive disorders, dehydration	Table salt, seaweed, tomatoes
	Activates enzymes like urease; essential for nitrogen metabolism in legumes.	**Nickel (Ni)**	Required in trace amounts for enzyme activation and iron absorption. Supports lipid and DNA metabolism.	Poor enzyme activity, iron absorption issues	Legumes, nuts, grains
	Strengthens cell walls, improves drought resistance, and protects against diseases.	**Silicon (Si)**	Supports bone and connective tissue health. May enhance immune response and prevent bone-related disorders.	Weak bones, poor connective tissue health	Oats, bananas, green beans

root/shoot development.

Magnesium (Mg): Central atom in chlorophyll, essential for photosynthesis.

Sulfur (S): Integral for amino acid and protein synthesis.

Micronutrients

Iron (Fe): Vital for chlorophyll synthesis and respiration.

Zinc (Zn): Regulates enzyme function and hormone synthesis.

Copper (Cu): Supports chlorophyll production and respiration.

Manganese (Mn): Promotes photosynthesis and enzyme activity.

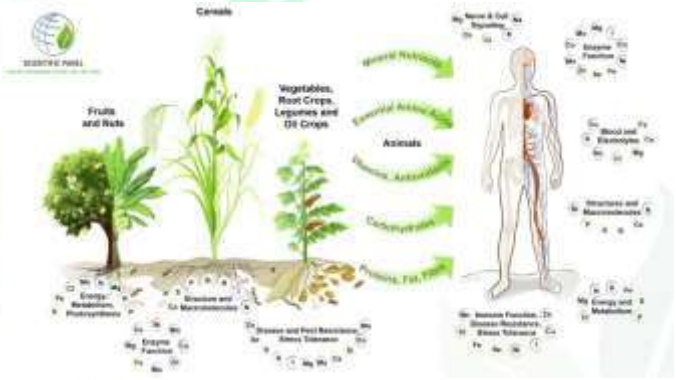
Boron (B): Essential for reproductive development and sugar transport.

Molybdenum (Mo): Required for nitrogen fixation.

Chlorine (Cl): Maintains ionic balance and aids photosynthesis.

Nickel (Ni) and Silicon (Si): Emerging essential elements for metabolism and stress tolerance.

When adequately supplied, these nutrients ensure higher yields, resilience to stress and improved food quality. Conversely, deficiencies lead to poor soil fertility and crops lacking vital nutrients, directly affecting human diets (FAO, 2015).



Source: Plant nutrients are essential for the alleviation of chronic and hidden hunger - SPRPN

Source: FAO

Sustainable Plant Nutrition and Human Health

The soil-plant-human continuum clearly

demonstrates that malnourished soils produce nutrient-poor plants, which in turn lead to malnourished people. Addressing soil fertility is not merely an agronomic challenge it is a public health intervention (Harvard Health, 2023). India's heavy dependence on chemical fertilizers particularly nitrogen (N), phosphorus (P), and potassium (K) has ensured short-term yield gains but also created long-term challenges, including soil degradation, nutrient imbalances, and declining productivity (Gummadala *et al*., 2023; Varsha *et al*., 2021). The overuse of subsidized urea has reduced soil organic carbon and microbial diversity, weakening the biological foundation of soils (Rajasekaran Murugan *et al*., 2011).

Dual Risks of Nutrient Imbalances

Toxicity (Selenium case, Buldhana, Maharashtra): Excess selenium accumulation in wheat entered the food chain. Communities consuming this wheat reported hair loss, skin damage, and other health disorders (Times of India, 2025).

Deficiency (Zinc & Iron in cereals): Cereal-based diets lacking zinc and iron led to widespread hidden hunger, weakened immunity and chronic under-nutrition in millions across India and other developing regions (Global Nutrition Report, 2021).

Pathways to Sustainable Nutrition

Organic Manures (farmyard manure, vermi-compost, Panchgavya): Improve soil structure, enrich organic matter, and stimulate beneficial microbes.

Biofertilizers: Mobilize nutrients naturally by fixing nitrogen, solubilizing phosphorus, and enhancing micronutrient uptake (Prajapati, 2014).

Agroecological Practices: Diversified cropping, mulching, intercropping, and residue recycling enhance nutrient cycling, resilience, and food quality.

When integrated, these approaches revitalize soils, produce nutrient-dense crops, and ensure healthier diets a holistic win-win model for agricultural and nutritional security.

A Note on Fortification and Modification

Emerging strategies like biofortification and genetic modification attempt to enhance specific nutrients in plants. While they can help address targeted deficiencies, they often overlook the risk of over-accumulation or imbalance. For instance, selenium is beneficial only in trace amounts; excessive uptake, often triggered by chemical fertilizer misuse, can be toxic to humans. Nutrients should always be balanced; excess and deficiency both cause problems in humans as well as in plants

By contrast, organic amendments and biofertilizers maintain nutrients at optimum, balanced levels, enabling plants to absorb what they need without creating harmful excesses. This balance is key to ensuring both soil sustainability and safe, nutrient-rich diets.

Looking Ahead

Sustainable nutrient management is not merely an agronomic practice but a strategic pathway for food security, public health, and climate resilience. To achieve this, the biomass produced

from the soil must be returned to it in the form of manure, compost, or crop residues; otherwise, continuous extraction of nutrients combined with dependence on chemical fertilizers leads to soil degradation and nutrient depletion. Restoring soil health requires building soil organic carbon, adopting diversified cropping, mulching, inter-cropping, and recycling residues to strengthen nutrient cycling and long-term productivity. Healthy soils grow nutrient-rich crops, and nutrient-rich crops ensure healthy people demonstrating that soil health and human health are inseparable. By embracing organic farming and restoring natural nutrient cycles, we can secure safe, nutrient-dense food and a healthier future. Eat organic, live healthy.

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Nutritional Value and Medicinal Benefits of Monkey Jack Fruit

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Abstract

Monkey Jack is a tropical fruit widely found in South and Southeast Asia. The fruit is rich in carbohydrates, dietary fiber, vitamins such as vitamin C, and minerals like calcium, iron, potassium and phosphorus. Along with these nutrients, it contains antioxidants and bioactive compounds that help in protecting the body against harmful free radicals and improving overall health. From a medicinal point of view, Monkey Jack has been used in traditional practices for centuries. The fruit pulp supports digestion, acts as a natural remedy for intestinal worms, and is useful in liver and stomach disorders. Overall, Monkey Jack is a nutrient-rich fruit with multiple health benefits.

Introduction

Monkey jack fruit (*Artocarpus lakoocha* Roxb.) is a tropical fruit originating from India. Asian countries including Bangladesh, Bhutan, Nepal, Myanmar, Sri Lanka, Thailand, Maylasia, and Laos produce this fruit.

Artocarpus is part of the Moraceae family, which includes over 60 genera and over 1000 species. These species have multiple uses, including food and traditional medicine. The Artocarpus genus produces enormous, nutritious edible fruits. This genus includes *Artocarpus heterophyllus, Artocarpus altilis, Artocarpus hirsutus, Artocarpus lakoocha,* and *Artocarpus camansi* etc. This plant's many components and chemical extracts have been explored as potential medicinal sources.

Several studies have found that eating tropical fruits can lower the risk of noncommunicable diseases such as diabetes, cancer, coronary heart disease, and neurological disorders. Medicinal plants have antioxidant, anti-inflamm-atory, antibacterial, and cytotoxic properties, making them potential thera-peutic ingredients. This article explores the nutritional profile, bioactive compounds, and health-promoting properties of Monkey Jack fruit.

Nutritional Value

A single fruit that weighs between 250 and 300 grams contains 10 to 30 irregularly shaped and sized seeds. Fresh fruits and seeds are rich in nutrients and offer therapeutic benefits. Pickles, sauces, and chutneys are made from the male flower spike and unripe fruit, which are also used as vegetables. The fruits have a sweet-sour flavour.

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The edible pulp is regarded as a liver tonic and is said to possess hepatoprotective qualities because of the antioxidants it contains. It has anti-aging and anti-inflammatory properties. The powdered bark is applied as a paste to treat skin issues such as boils, pimples, and ulcers. Furthermore, the tree is used for food and timber. It is commonly used in heavy construction, poles, furniture, and plywood due to its durability and termite resistance. This diet is also suitable for breastfeeding animals, resulting in increased milk production. Monkey Jack Fruit leaves contain 16% crude protein, and a mature tree can yield 60-200 kg of fresh feed each year. This tree's fruits and male flowers can be consumed fresh, cooked, steamed, or roasted. A tree's sticky latex is a valuable source of fuel and can be used for several purposes.

Nutrient Composition

Nutrient	Amount
Energy	79 Kcal
Moisture	90 g
Fat	1 g
Protein	2 g
Fiber	3 g
Mineral	1 g
Calcium	67 mg
Phosphorous	25 g

Monkey jack fruit contains high levels of ascorbic acid (171.07 mg/100 g), β-carotene (3718.16 µg/100 g), Na (46 mg/100 g), K (785 mg/100 g), Fe (15.09 mg/100 g), Cu (1.31 mg/100), Mn (3.76 mg/100), and P (66.06 mg/100). This fruit has multiple uses, both as a nutritive food and a raw material for pharmaceuticals due to its pharmacological qualities. The nutrient value of Monkey Jack fruit should be explored further to raise awareness about its benefits for a healthier lifestyle.

Traditional Importance

Monkey Jack is a useful fruit in village life. People eat its sour-sweet pulp fresh, or make chutney, pickles, and cool summer drinks from it. It is tasty and refreshing.

Vegetable of its flowers: Male flowers are washed and fried with oil, cumin seeds, salt, pepper, turmeric, and onion. And is served with paratha.

Fresh Consumption: Ripe fruit pulp is eaten raw or slightly cooked.

Pickle: Unripe fruit is picked, cleaned in warm water, chopped into little pieces, and sun dried for 2-3 hours. To create pickle, combine oil, turmeric, fenugreek seeds, fennel seed, salt, red chili powder, and garam masala mix thoroughly. Keep them for one month to get them ready; in the meantime, sun drying is important.

Sauce: The fruit and spike of male flower are used to produce a tasty sauce.

Phytochemicals and Bioactive Compounds

Monkey Jack is rich in bioactive compounds that contribute to its medicinal and functional food potential.

Polyphenols: Including flavonoids and phenolic acids that have antioxidant, anti-inflammatory, and cardioprotective effects.

Tannins: Provide antimicrobial activity and aid in digestion.

Saponins: Exhibit cholesterol-lowering and immune modulatory properties.

Anthocyanins: Present in some varieties, providing additional antioxidant activity.

Medicinal Properties

It contains antioxidant**,** anti-inflammatory, anti-diabetic potential, anticancer, and anti-HIV effects. The bark of this tree contains 8.5% tannin, which has been used to treat skin lesions. Consuming the fruit pulp of fruit refreshes the liver. The seeds and milky latex of this fruit can be used as a purgative. Powdered bark can effectively treat wounds. The seed and bark of this fruit can help treat stomach and liver disorders. Unripe fruit can produce tridosa impotency and lack of appetite due to its spicy, sweet, and sour flavours.

Antioxidant Activity: The fruit contains high levels of vitamin C, polyphenols, and flavonoids, which scavenge free radicals and reduce oxidative stress. This helps prevent chronic diseases such as heart disease, diabetes, and cancer.

Immune System Support: Vitamin C, along with minerals like zinc, enhances immune defines. Regular consumption of fruit can help reduce susceptibility to infections.

Digestive Health

- ✓ **Dietary Fiber:** Promotes bowel regularity, prevents constipation, and supports healthy gut microbiota.
- ✓ **Tannins:** Provide mild astringent properties that can protect against diarrhea.

Heart Health: Potassium and polyphenols in Monkey Jack help in maintaining blood pressure, reducing LDL cholesterol, and improving overall cardiovascular function.

Bone and Muscle Health: The combination of calcium, magnesium, and phosphorus contributes to strong bones and teeth, while protein content supports muscle growth and repair.

Weight Management: Low-calorie content and high fiber make Monkey Jack fruit a healthy snack for weight management, helping to maintain satiety while providing essential nutrients.

Anti-Diabetic Potential: Some studies suggest that bioactive compounds in Monkey Jack may help in regulating blood glucose levels, making it beneficial for diabetic patients.

Antimicrobial and Anti-Inflammatory: Tannins, flavonoids, and saponins contribute to antimicrobial properties, which can help prevent infections. Anti-inflammatory properties aid in reducing chronic inflammation and associated disorders.

Conclusion

Fruit pulp is rich in carbohydrates, dietary fibre, vitamins such as vitamin C, and essential minerals like calcium, iron, phosphorus and potassium. Along with these, it contains valuable bioactive compounds, including antioxidants and phytochemicals, which play a significant role in supporting overall health and preventing lifestyle-related disorders. From a health perspective, Monkey Jack fruit provides multiple benefits. Its antioxidant properties protect the body against free radicals, thereby reducing the risk of chronic diseases such as heart disease, diabetes, and certain cancers. The dietary fibre content improves digestion, prevents

constipation, and promotes gut health. In traditional medicine, it has been used for centuries to treat intestinal worms, skin problems, liver disorders, and throat infections, proving its long-standing therapeutic importance.

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Unattended Herbs Underfoot

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Abstract

In our modern world, where the pace of life often overshadows the rhythms of nature, the humble weeds that peek through pavement cracks or carpet untended gardens are frequently overlooked. Yet, these "unattended herbs underfoot" hold a wealth of medicinal properties that have been cherished by various cultures for centuries. Medicinal plants have been integral to human health and well-being for millennia, forming the foundation of traditional healing systems around the world. Often, these valuable resources are closer than we realize thriving in our own backyards, gardens, and local environments. Nature has an uncanny ability to thrive in the least expected places. Weeds, or "wild herbs," are often dismissed as nuisances. Still, they exemplify a remarkable resilience, often sprouting in hostile environments where cultivated plants may struggle. This adaptability is mirrored in their medicinal properties; these plants have evolved complex biochemical pathways that produce compounds beneficial for human health. As global interest in natural remedies rises, rural traditions advocating the use of wild herbs are resurfacing, shedding light on their potential. With a growing body of scientific research validating the efficacy of these plants, there is an urgent need to rediscover our connection with the green world around us.

Introduction

In contemporary societies, where the tempo of daily life often disconnects people from natural cycles, common weeds and untended garden herbs are frequently neglected. Yet these "unattended herbs underfoot" possess a range of bioactive properties that have been used in traditional medical systems for centuries. Often classified as ruderal or wild species, these plants demonstrate notable ecological resilience, thriving in compacted soils, pavement edges, and other marginal habitats. That resilience is accompanied by complex secondary metabolism: many produce diverse phytochemicals with therapeutic potential, including alkaloids, flavonoids, terpenoids, and phenolics.

It is true that most of urban, semi-urban and rural populations are unaware about the importance of this hidden treasure of medicinal herbs but at the same time it is also true that many tribal communities are well aware of these herbs. This has resulted in development of new branch called Ethnobotany. Ethnobotanical knowledge of medicinal herbs "under foot" refers to the traditional wisdom concerning common, often overlooked plants that grow in abundance. This includes weedy species found in yards, along roadsides, and in disturbed areas. Ethnobotany studies the relationship between people and plants, focusing on how communities use

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local flora for medicine, food, and other cultural purposes, particularly regarding wild, uncultivated medicinal herbs. These studies document traditional knowledge, often held by elders, about the uses and properties of wild plants, which can be crucial for discovering new drugs, supporting community healthcare, preserving biodiversity and understanding the cultural context of plant use. For indigenous and rural communities, these medicinal herbs are easily accessible to everyone, including those in urban or suburban areas. This makes them particularly valuable for household and community-level healthcare. Before the advent of modern medicine, these ubiquitous herbs were often the first line of defence against minor illnesses and injuries. This knowledge was passed down through generations, often within family lines. Documenting the use of these plants is a crucial aspect of ethnobotany. It helps preserve traditional knowledge that is at risk of being lost due to urbanization and technology. Many of today's pharmaceuticals have roots in traditional knowledge of medicinal plants. This chapter reviews a selection of such plants, summarizing their historical applications, documented pharmacological effects, and practical avenues for incorporation into everyday health practices.

Some Common Unattended Medicial Herbs

In recent years, rising demand for foods rich in antioxidants, vitamins, minerals, and therapeutic compounds has intensified pressure on major agricultural and medicinal species. This burden can be eased by more effective use of underutilized plants that offer nutritional and medicinal benefits. Often neglected and undervalued as “minor” crops, these species are nonetheless rich sources of phytochemicals and bioactive secondary metabolites. The wild herbs considered in this review have received little attention from both commercial and scientific communities. Expanding research and development on these plants could foster wider recognition of their value to human health and society.

Gokhru, Puncture vine (*Tribulus terrestris Family Zygophyllaceae*): It grows as a common weed in dry, sandy, or waste areas, roadsides, and even desert climates, thriving in warm temperatures and requiring low rainfall. It grows prostrate along roadsides and waste places and often crushed under feet. It is widely known as a noxious weed because of its small woody fruit the bur having long sharp and strong spines which easily penetrate surfaces, such as bare feet or thin shoes of crop workers and other pedestrians, the rubber of bicycle tires, and the mouths and skin of grazing animals. It has been used for a long time in both the Indian and Chinese systems of medicine for treatment of various kinds of diseases. People use tribulus for sexual disorders, chest pain, enlarged prostate, kidney stones and many other conditions, but there is no good scientific evidence to support most of these uses.

Punarnava (Boerhavia diffusa, Family Nyctaginaceae): It is a creeping, perennial, much-branched herb, found in grasslands, agricultural fields, wastelands, and disturbed habitats like roadsides and

abandoned areas. It is used in traditional and homeopathic medicine for its diuretic, anti-inflammatory, and blood-purifying properties. It's applied to treat liver and kidney disorders, jaundice, skin infestation, asthma, and high blood pressure. Its name "Punarnava" refers to the plant's rejuvenating and restorative properties for the body, symbolizing its role in bringing vitality and youthfulness back to the system.

Biskhapra, Horse Purslane (*Trianthema portulacastrum*, Family Aizoaceae): This plant is used extensively in Indian traditional medicines and is also consumed as a vegetable throughout Asia for its perceived health benefits. It is a widespread herbaceous weed found in a diverse range of habitats, including roadsides, disturbed areas, wastelands, gardens, and especially irrigated croplands. It is used in traditional medicine for its potential benefits, including acting as a laxative, diuretic, and anti-inflammatory agent. It is also used to treat anemia, liver diseases, kidney ailments, and eye problems like night blindness. The plant has shown potential in experimental studies for liver and kidney protection.

Dudhi, Dugdhika (*Euphorbia prostrate*, Family Euphorbiaceae): It is most common prostrate weed, growing in disturbed, open, and sun-exposed areas such as fields, gardens, lawns, pavements, and sandy soils. *Euphorbia Prostrata* extract has anti-hemorrhoidal properties, i.e., stops bleeding by shrinkage of blood vessels. It also acts as an anti-oxidant, an anti-inflammatory as well as an analgesic. This promotes healing and relieves any pain or inflammation associated with hemorrhoids (piles).

Gotu Kola, Indian Pennywort *(Centella asiatica*, Family Apiaceae): Gotu kola thrives in shady, wet, and marshy habitats, such as near water, paddy fields, and grassy thickets. Pegged as the "herb of longevity," gotu kola is a staple in traditional Chinese, Indonesian, and Ayurvedic medicine. Practitioners claim the medicinal plant has the power to boost brainpower, heal skin issues, and promote liver and kidney health and some studies seem to agree.

Brahmi (*Bacopa monnieri*, Family Plantaginaceae): Its name Brahmi, is after the Hindu deity Brahma, and is used in Ayurvedic medicine for its memory-enhancing properties. It is an aquatic or semi-aquatic herb that thrives in wet, marshy areas, and along the banks of rivers and streams. *Bacopa monnieri* possesses high-value medicinal properties such as neuroprotection against dementia, amnesia, Parkinson's disease (PD), schizophrenia, Alzheimer's disease (AD), and epileptic seizures. Apart from being an excellent memory and intelligence promoter, Brahmi benefits also encompass anti fever, anti-diabetes and anti-oxidant.

Latjira, Puthkanda (*Achyranthes aspera*, Family Amaranthaceae): The latjira plant, also known as Apamarg or *Achyranthes aspera*, is a versatile weed found globally and extensively used in traditional medicine for its anti-inflammatory, antioxidant, antimicrobial, diuretic and digestive properties with benefits ranging from healing skin

disorders and wounds to treating respiratory issues, piles, and kidney stones. Its habitat is wide-ranging, growing as an annual or perennial herb throughout India and other parts of the world.

Tandla, False Amaranth (*Digera muricata*, Family Amaranthaceae): It is a widespread annual herb found as a weed in tropical and subtropical regions, including India and Africa. It thrives in seasonally dry tropical climates and is known for its rich medicinal value. All parts of the plant are used in traditional medicine for a wide range of ailments, including treating urinary tract issues, kidney stones, digestive disorders, and inflammation. It also possesses antibacterial, antifungal, and antioxidant properties and is consumed as a nutritious green vegetable.

PITPAPRA (*Fumaria Parviflora*, Family Fumariaceae): It is a neglected herb, common in the plains of the Indian subcontinent, growing in light, well-drained soils. Medicinally, they are used for liver complaints, skin diseases, fever, diarrhoea and as a general tonic. It is used in Ayurvedic and Unani medicine for its hepato-protective, anti-inflammatory, antioxidant, laxative and diuretic properties.

Ashwagandha, Indian Ginseng (*Withania somnifera*, Family Solanaceae): It is found growing as a wide herb along roadsides and neglected places but it is also cultivated in India's dry, subtropical regions, with major producing states including Rajasthan, Madhya Pradesh, Gujarat, Haryana, Uttar Pradesh, Maharashtra, and Punjab. Ashwagandha has been in use as a medicinal plant for thousands of years, especially in traditional Ayurvedic medicine. Currently, ashwagandha supplements are often promoted for stress and anxiety, sleep, male infertility, and athletic performance. The raw material used in medicine is the root, and the name "Ashwagandha" is derived from the word "ashwa", meaning horse. It is believed that after consuming the root, one gains powers similar to that of a horse. The second part of the name "gandha," means fragrance and refers to the characteristic smell of the fresh root of the plant.

Patha, Velvet Leaf (*Cicampelos pareiera*, Family Menispermaceae): Cissampelos pareira grows as a slender, grooved, and hairy climber or a slender climbing shrub on roadsides and neglected places. It is a traditional medicinal plant with uses for treating ulcers, wounds, rheumatism, fever, and various skin conditions like acne. Modern research indicates its anti-inflammatory, antioxidant, antimicrobial, and anticancer properties, which support its historical applications and suggest potential in treating chronic diseases and purifying the blood.

Scarlet Pimpernel (*Anagallis arvensis*, Family Primulaceae): It thrives in various disturbed habitats, especially in well-drained, sandy soils, and is commonly found in arable fields, pastures, grasslands, gardens, roadsides, and other human-modified sites worldwide. It has diverse potential medicinal values, including antimicrobial, anti-inflammatory, antioxidant and anti-parasitic properties. In traditional medicine, it's used for skin ailments like scabies and eczema, as a diuretic for

oedema, and for mood support. Modern researchers are exploring its cytotoxic, antiviral and enzyme inhibitory capabilities.

Shankhpushpi (*Convolvulus pluricaulis*, Family Convolvulaceae): It is a perennial herb found throughout India, particularly in the sandy and rocky areas of Northern India, including the upper Gangetic plains, and is cultivated as an ornamental and medicinal plant. Shankhapushpi is a very famous Ayurvedic medicine used to improve memory, intelligence etc. It is also used in other conditions like vomiting and toxic conditions. It helps to manage digestion and constipation due to its mild laxative property. It improves mental health and help in managing depression due to its anti-depressant activity. According to Ayurveda, Shankhpushpi helps to calm down the brain and relieve stress as well as anxiety.

Spiny Amaranth (*Amaranthus spinosus*, Family Amrathaceae): *Amaranthus spinosus* thrives in a variety of human-disturbed environments, including agricultural fields, waste areas, roadsides, and gardens in tropical and subtropical regions worldwide. It has various traditional medicinal uses, such as a diuretic, laxative, and anti-pyretic. It is also used for digestive disorders to treat excessive menstral bleeding, inflammation, wounds and burns and as a traditional antidote to snake bites. It also has antioxidant, anti-inflammatory and hepatoprotective properties.

Mulethi, Liquorice (*Glycirhiza glabra*, Family Fabaceaea): Mulethi Powder, also known as licorice root powder, is a versatile and revered herbal remedy in Ayurvedic medicine. Derived from the root of the *Glycyrrhiza glabra* plant, mulethi powder has been used for centuries due to its numerous therapeutic properties and health benefits such as Soothes Digestive Issues, Supports Respiratory Health, Anti-Inflammatory Effects, Enhances Skin Health and Balances Hormones.

Giloy, Guduchi (*Tinospora cordifolia*, Family Menispermaceae): Giloy is an anti-inflammatory, antipyretic herb and is useful in building up the immune system and the body's defence against infections. It enhances the activity of macrophages (the cells responsible for fighting foreign bodies as well as microorganisms) and thus helps in early recovery. As per modern science view point, Giloy is useful in managing dengue fever. Regular intake of Giloy during dengue helps in improving the immune system. It also helps in increasing platelet count.

Goat Weed (*Ageratum conyzoides*, Family Asteraceae): Goat weed thrives in any garden and agricultural soils and is very common in disturbed sites and degraded areas.It is used as traditional medicine for the treatment of numerous ailments such as analgesic, antifungal, wound healing, anti-inflammatory, and hemostatic, smooth muscle relaxant, and anticoagulant activity.

Kanghi, Atibala (*Abutilon indicum*, Family Malvaceae): It is often found in disturbed areas like roadsides, wastelands, and along forest edges. Atibala, is a plant in traditional medicine with numerous applications including treating fever, coughs,

diarrhoea, and urinary issues. Its leaves and roots possess anti-inflammatory and analgesic properties, while the whole plant is used as a diuretic, laxative, and expectorant. It is also an aphrodisiac and is used for blood disorders, ulcers, and as a uterine tonic.

Aloe, Ghee Kunwar (Aloe vera, Family Liliaceae): Aloe vera originated in Africa and the Arabian Peninsula and grows in hot, dry climates, often found in the southern U.S. and parts of India. As a xerophytic succulent, it thrives in sandy, well-draining soils but has also become naturalized in various subtropical and temperate regions worldwide due to its widespread cultivation. Aloe vera is a medicinal plant used to promote wound healing, soothe burns, and treat various skin conditions like acne and psoriasis. The medicinal value is due to its anti-inflammatory, antimicrobial, and antioxidant properties. The gel of the leaf (In fact modified stem called phylloclade) is applied topically, while the plant's compounds are used in oral supplements.

Tulsi, Holy Basil (*Ocimum sanctum*, Family Lamiaceae): It is an annual delicate herb cultivated extensively in tropical climate of the country. It is also planted in kitchen garden and as an indoor plant since it is kept sacred in Hindu philosophy. Medicinally the leaves are used for various kind of classical and health benefits. Tulsi, also known as holy basil, holds a revered place in Ayurveda. Tulsi has been treasured for centuries for its numerous health benefits. Revered as the “Queen of Herbs” in the Ayurvedic tradition, Tulsi has not only medicinal value but also cultural and religious significance in India. The medicinal properties of tulsi have been studied in hundreds of scientific studies. These studies reveal that tulsi has a unique combination of actions that include: Antimicrobial, mosquito repellent, anti-diarrheal anti-oxidant, anti-cataract, anti-inflammatory, chemo preventive, hepato-protective, neuro-protective, cardio-protective, anti-diabetic, anti-hypertensive, anti-carcinogenic, anti-pyretic, analgesic, anti-allergic etc.

How Herbs are used as Medicine

Traditional practitioners utilize various parts of the plant, including leaves, stems, flowers, fruits, roots, bark, rhizomes, and seeds. Some of the herbs are taken orally as teas, powders, tablets, or concentrated liquid extracts and some are applied externally as pastes, gels, or lotions for local treatment. The most used part of the plant in the preparation of herbal medications is the leaves, followed by roots and flowers and other aerial parts. The medicinal herbs are used for the treatment of a disease in following forms:

Decoctions and Infusions

Decoction: Involves crushing or boiling plant parts in water to create a liquid extract. Infusion is Similar to decoction but typically uses gentle steeping of plant material in hot water, as in a tea.

Powdered Form: Herbs are dried and ground into a fine powder, which can then be swallowed as such or compressed into tablets.

Paste/Ointment: Plant materials are processed into a thick paste or mixture, sometimes combined with a base, for external application to the skin.

Tinctures/Extracts: Liquid extracts are created through processes like fluid extraction, where alcohol or another solvent is used to draw out the medicinal compounds.

Conclusions

India is endowed with a rich diversity of medicinal plants, yet many species remain underutilized, overlooked, or neglected. "Neglected" or "unattended" herbs are those that have been used locally for health care but have received little scientific study, commercial development, or conservation attention. These species can provide affordable, culturally appropriate treatments for local communities and also represent valuable leads for new pharmaceuticals. Why these herbs are neglected? There can be many reasons. Many traditional remedies are known only within specific communities or regions, so they remain invisible on a national or international scale. Moreover traditional use does not always translate into comprehensive phytochemical, pharmacological, or toxicological research, which limits broader adoption and commercialization.

It is true that there is a vast list of unattended, underutilized medicinal herbs but some key safety considerations must be adopted:

- ✓ Accurate botanical identification is essential; misidentification can produce harmful or even fatal outcomes.
- ✓ Wild-harvested material may be contaminated with pesticides, heavy metals, or adulterants, so quality control and standardization are required.
- ✓ Traditional dosing practices vary widely; self-treatment for serious conditions based on unverified claims should be avoided.
- ✓ Potential drug-herb interactions must be assessed before recommending use alongside conventional therapies.

Neglected herbs can be developed into medicines through Ethno botanical documentation i.e. recording traditional uses, local names, preparation methods and safety knowledge and by identifying active compounds, testing biological activity in vitro and in animal models. Standardization, Safety testing and drug-interaction studies, dose finding etc. through Clinical trials are also needed. Adopting a systematic, multidisciplinary approach that integrates traditional knowledge, rigorous scientific evaluation, quality assurance, and conservation will maximize the potential of India's neglected medicinal herbs while minimizing risks to human health and biodiversity.

Cultivating Climate Resilience: The New Face of Rice Farming

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Rice feeds more than half the world's population, yet its traditional flooded paddies are under siege from rising temperatures, erratic rainfall, and dwindling resources. Continuously flooded systems emit methane, deplete water tables, and trap millions of smallholder farmers in cycles of low returns. As demand for rice climbs by an estimated 30 percent by 2050, Asia's scientists, governments, and communities are forging new pathways integrating precision irrigation, diversified rotations, resilient varieties, and digital tools to turn vulnerability into opportunity.

Facing the Climate Crisis in Rice Cultivation

Rice paddies contribute roughly 11 percent of agricultural greenhouse gases, mainly as methane released under anaerobic, waterlogged conditions. Higher air and soil temperatures accelerate crop stress and pest outbreaks, while unpredictable monsoons strain irrigation networks. In low-lying deltas, sea-level rise drives saltwater intrusion; inland, droughts and heatwaves sap yields. Nearly 144 million smallholder households face these threats, and slowing yield growth jeopardizes food security for billions. Incremental tweaks cannot solve this complex crisis what's needed is systemic change in how rice is grown, managed and governed.

Regional Innovations in Sustainable Rice Systems

Across Asia, five pillars of innovation are reshaping rice landscapes alternate wetting and drying, governance-driven irrigation, mechanization with rotation, direct seeding and soil health, and targeted pilots in Kerala.

Vietnam: The "One Million Hectares of High-Quality Rice" program trains over 155,000 households in alternate wetting and drying (AWD). By draining paddies at critical stages rather than continuous flooding, farmers cut irrigation and input costs by 30-35 percent, lift profits by the same margin, and boost yields from the national average of 6 t ha^{-1} to 8 t ha^{-1}. Methane emissions drop by up to 48 percent.

Indonesia: Facing aging canals and patchy water access, the Ministry of Agriculture brokered irrigations service agreements between water authorities and farmer groups. Modernized canals and scheduled deliveries now reach 350,000 households, aligning flows with rice's growth stages, trimming water use by 20 percent, and reducing diesel pumping costs.

Bangladesh: To overcome land and water constraints, the national strategy layers mechanization with

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legume-rice rotations. Winter crops such as mung bean or lentil follow the wet-season rice harvest, breaking pest cycles, fixing nitrogen, and spreading labor peaks. Mechanized transplanters and combines compress fallow from three months to weeks, raising system productivity and nutritional diversity.

India: Under the World Bank's Scaling Next Generation Rice Impact Program, extension services promote direct-seeded rice (DSR) in place of puddled transplanting. DSR cuts labor and water requirements by nearly 25 percent; mid-season drainage adds a further 40 percent reduction in methane. Incorporating composted rice straw and green manures builds soil carbon and heat tolerance, enabling two-crop systems when short-duration pulses or oilseeds follow rice.

Kerala: The Climate Resilient Agri-Value Chain Modernization Project (KERA) and Kerala Agricultural University are piloting AWD across 22,000 ha, targeting 45,000 farmers. In partnership with IRRI, they're developing Low Emission Packages (LEPs) and digital water-management tools tailored to Palakkad's uplands and Thrissur's kole wetlands. By 2026, Kerala Climate-Resilient Agriculture Innovation Labs (K-CRAIL) in Alappuzha, Palakkad, and Wayanad will evaluate bio-inputs, micro-irrigation technologies, and stress-tolerant varieties. Concurrent investments in soil testing, solar pumps, biogas units, and community seed banks aim to slash on-farm energy demand by 40 percent and safeguard indigenous germplasm for climate extremes.

Diversified Cropping Sequences for Ecosystem Balance

Transforming monocultures into dynamic rotations tackles multiple challenges at once. Key sequences include:

Rice-Azolla rotations: Floating Azolla ferns fix 50-60 kg N ha^{-1} $season^{-1}$ and suppress weeds, cutting synthetic fertilizer needs by up to 30 percent.

Rice-Maize relay cropping: Sowing maize into maturing rice reduces fallow to days, boosting annual output by 20-25 percent in trial plots.

System of Rice Intensification (SRI): Wider spacing, AWD, and organic amendments encourage robust root systems, lifting yields by 20-30 percent while saving 30 percent of irrigation water.

Rice-Legume-Oilseed sequences: Short-duration pulses or sunflower following rice enhance soil fertility, diversify household diets, and open new market channels.

By weaving cereals, legumes, and cover crops into the calendar, farmers enrich soil, break pest cycles, and distribute labor, water, and input demands more evenly across the year.

Scaling Up: Policy, Market Incentives, and Collaboration

Widespread adoption hinges on enabling policies, viable markets, and shared learning, with critical enablers such as carbon and water credits that reward methane reductions and irrigation savings to make AWD and DSR financially attractive; service-fee models where community contributions fund canal maintenance and scheduling; input-output link-

ages guaranteeing procurement support for diversified crops pulses, specialty rice, by-products; digital platforms and on-farm demonstrations delivering mobile advisories with weather forecasts, satellite imagery, and planting windows for timely decisions; and regional networks under the Next Generation Rice program facilitating cross-country exchanges of best practices from Java's canals to Kerala's kole lands. When policy frameworks reward resource efficiency and ecosystem services, farmers gain both resilience and profit.

Conclusion: A Blueprint for Resilient Rice Landscapes

Rice farming's next chapter will be written in mosaic paddies where precision irrigation meets diversified rotations, resilient varieties, and community stewardship. From Vietnam's AWD fields to Kerala's Low Emission Packages, farmers are already architecting agroecosystems that deliver food, income, and environmental services in the face of climate uncertainty. Scaling these innovations through policy incentives, market linkages, and collaborative research will transform paddy fields into regenerative landscapes ready to nourish a growing population under changing skies.

Coconut Cultivation in Kerala

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Abstract

Coconut cultivation in Kerala is a fundamental part of the state's economy, culture, and daily life. The very name "Kerala" is derived from "Kera," meaning coconut tree, showing how deeply this crop is rooted in the region's identity. Known as the "Kalpavriksha" or "tree of life," the coconut palm offers food, oil, fiber, shelter, and a multitude of by-products, making it indispensable to human life. Kerala is among the largest producers of coconut in India, and its agricultural system depends significantly on the crop. This article provides a detailed discussion on the importance of coconut cultivation in Kerala, the different varieties grown, the major diseases affecting palms and their remedial measures, the role of coconuts in Kerala's economy, suitable soil conditions, and the diverse uses of coconuts. By examining these aspects in detail, this article highlights how coconut cultivation remains the backbone of Kerala's agrarian landscape.

Introduction

The coconut palm (*Cocos nucifera*) is one of the most valuable crops in tropical agriculture. In Kerala, it is not only a source of food and raw material but also a symbol of prosperity and tradition. Coconut farming occupies nearly one-third of the cultivated land in Kerala and directly influences the livelihood of millions of farmers and workers. The humid tropical climate, fertile soil, and high rainfall make Kerala ideal for coconut farming. Historically, coconuts have played a central role in shaping Kerala's culture, cuisine, and economy. Today, industries such as coir, oil production, and handicrafts are heavily dependent on coconut as their raw material. Although coconut farming faces challenges like diseases, declining productivity, and competition, it continues to be Kerala's most important crop.

Why Coconut Cultivation is Important in Kerala

Coconut cultivation is important for Kerala due to the following reasons:

Economic role: Coconut contributes significantly to the state's GDP and provides raw material for multiple industries.

Employment: Millions of people are employed in farming, coir factories, toddy tapping, and oil production.

Cultural role: Coconuts are used in religious ceremonies, festivals, and traditional food, making them part of Kerala's cultural identity.

Food and nutrition: Coconut oil and kernel are important parts of Kerala's diet, while tender coconuts are consumed as natural health drinks.

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Exports: Processed coconut products, such as coir mats and virgin coconut oil, contribute to Kerala's foreign exchange earnings.

Varieties of Coconut

Kerala grows tall, dwarf, and hybrid varieties of coconut.

Tall Varieties: West Coast Tall, East Coast Tall, and Lakshadweep Ordinary are hardy and long-living (80-100 years).

Dwarf Varieties: Chowghat Dwarf Orange, Chowghat Dwarf Yellow, and Malayan Dwarf begin yielding early and are ideal for tender nuts.

Hybrid Varieties: Hybrids such as Kera Sankara and Chandra Sankara combine the high yield of dwarfs and the longevity of tall varieties. These hybrids are increasingly promoted for higher farmer income.

Diseases of Coconut and Its Remedial Measures

Coconut palms suffer from various diseases:

Root Wilt Disease: Characterized by yellowing leaves and reduced yield. Managed through nutrient application and removal of infected trees.

Bud Rot: Caused by fungus; controlled by removing affected palms and applying Bordeaux mixture.

Stem Bleeding: Oozing of fluid from cracks; treated by chiseling affected areas and using fungicides.

Leaf Rot: Affects young leaves; controlled by copper fungicides and sanitation. Proper disease management is necessary to maintain yields and secure farmer livelihoods.

How Coconut Cultivation Helps in Kerala's Economic Growth

Coconut contributes heavily to Kerala's economic growth. The coir industry, one of the largest cottage industries in the state, employs lakhs of rural women. Coconut oil, copra, and value-added products like coconut milk, chips, and virgin coconut oil have strong domestic and export markets. Coconut shells support activated carbon and handicraft industries, while leaves and timber are used in construction and crafts. Coconut cultivation not only sustains agriculture but also fuels trade, industry, and tourism, strengthening Kerala's economic foundation.

Soil Composition for Coconut Cultivation

Coconut palms grow best in sandy loam, laterite, and coastal alluvial soils. The soil should be well-drained and fertile, with a pH between 5.2 and 8.0. Waterlogging is harmful to palms. Organic manuring, mulching, and irrigation improve soil fertility and productivity. Intercropping with pepper, banana, and pineapple enhances farm income and maintains soil health. Kerala's soil types and climate provide an ideal environment for coconut farming.

How Coconut is Useful

Every part of the coconut palm is useful:

Water: Refreshing drink rich in electrolytes.

Kernel: Used for cooking and oil extraction.

Oil: Used in food, cosmetics, and industry.

Coir (husk): Used in ropes, mats, mattresses, and

geo-textiles.

Shell: Used for handicrafts and activated carbon.

Leaves: Used for thatching and making brooms.

Timber: Used for furniture and house construction.

This holistic utility justifies its name “tree of life.”

Conclusion

Coconut cultivation is deeply woven into Kerala’s agricultural, economic, and cultural identity. It provides food, employment, and industrial raw materials while also shaping Kerala’s traditions. Although challenges like diseases and declining productivity exist, advancements in hybrids, disease management, and value addition ensure coconut remains central to Kerala’s prosperity. Thus, the coconut palm will continue to symbolize life, culture, and growth in the state.

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Post-Harvest Management and Processing of Cocoon

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Abstract

Sericulture, the art of rearing silkworms for silk production, is a centuries-old practice that transforms the humble cocoon into a luxurious fabric. The most critical phase of this process is the post-harvest management and processing of the cocoons. This stage begins immediately after the silkworms have finished spinning and involves a series of scientific and meticulous steps. These include stifling to prevent moth emergence, drying for preservation, and the elaborate process of reeling, which unwinds the continuous silk filament. Proper post-harvest handling is paramount to ensuring the quality, strength, and commercial value of the final silk thread. This study provides a popular overview of these essential steps, highlighting the transfer from a protective shell to a high-quality silk thread.

Introduction

The adult larva will spin a cocoon by expelling a silk thread from its silk gland through a spinneret when it is placed in the mountage (Fig. 1). The protein that makes up silk filament solidifies when it comes into touch with air. It takes three to four days for a mature silkworm larva to spin a cocoon, as you are aware. Metamorphosis occurs and the larva becomes a pupa following the full ejection of silk and the construction of the cocoon. The pre-pupal stage is in between. This is a really fragile period. Within ten days, the pupa typically transforms once again and pierces the cocoon to emerge as a moth.

Fig. 1: Mountage

Cocoon Harvesting and Initial Sorting: The harvest of cocoons is the first step in the post-harvest chain. The timing is crucial: it's done about 5-7 days after the larva has pupated, before the moth is ready to emerge (Lounibos, 1976). A late harvest allows the moth to cut through the cocoon, rendering the silk useless for reeling a continuous thread. Farmers carefully pluck the cocoons from their mountages (the frames where the silkworms spin) and then perform an initial sorting (Fig. 2). They separate out damaged, flimsy, or double cocoons (where two silkworms have spun together), as these have different reeling requirements or are unsuitable for quality silk production. This early quality control is

Fig. 2: Harvesting and sorting

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a vital first step.

Post-Harvest Management

Once the cocoons are harvested and sorted, two critical processes must happen immediately: stifling and drying.

Stifling (Pupa Killing): Stifling is the process of killing the pupa inside the cocoon. Because if the pupa is allowed to mature into a moth, it will secrete an alkaline fluid that dissolves the silk filament at one end to escape, thereby breaking the single, long thread. This is the single biggest threat to the integrity of the silk filament. The most common methods for stifling are:

Sun Drying: The simplest and oldest method, where cocoons are spread on mats and exposed to scorching sun for several days (Fig. 3). While cheap, it can damage the silk and is highly dependent on weather conditions.

Fig. 3: Sun drying

Steam Stifling: Cocoons are placed in a chamber and subjected to hot steam. The cocoons are cooked first in hot water at 95-100°C for 10-15 minutes to soften the adhesion of silk threads among themselves, loosening of the threads to separate freely and to facilitate the unbinding of silk threads (Manjunath, 2022). This is a quick and effective method that kills the pupa without damaging the silk, and is often used by small-scale reelers (Fig. 4).

Fig. 4: Steam Stifling

Hot Air Drying: The most advanced and preferred method for large-scale operations (Singh, 2011). Cocoons are dried in a controlled environment with hot air, which not only kills the pupa but also uniformly hardens the sericin gum (Fig. 5). This method ensures better reelability and quality of the final silk.

Fig. 5: Hot air drying

Drying and Storage

After stifling, the cocoons must be thoroughly dried (Fig. 6). A fresh cocoon contains a significant amount of moisture from the pupa. If not dried properly, it can become susceptible to mold and fungal growth, which ruins the silk. Cocoons are dried to a specific moisture content and then stored in a cool, dry, and well-ventilated space. Proper storage is essential for preserving the cocoons until they are ready for reeling, which can be weeks or months later.

Fig. 6: Drying and storage

Cocoon Processing: Reeling the Golden Thread

This is where the magic truly happens. Reeling is the process of unwinding the silk filament from the cocoon. It's an intricate dance of heat, water, and tension.

Cocoon Cooking (Boiling): Before reeling, cocoons are cooked by immersing them in hot water (Fig. 7). This step is crucial for softening the sericin, the

natural protein gum that binds the silk filament layers together. The right temperature and duration are vital too hot, and the silk becomes weak, too cool and the sericin won't soften enough to allow for smooth unwinding (Naik *et al*., 2005). In cooking process 7 to 8 per cent of sericin is dissolved.

Fig. 7: Cocoon cooking

Deflossing/Brushing: Once cooked, the cocoons are brushed to find the free, outer end of the silk filament (Javali *et al.*, 2018). Floss is the unreelable, tangled mass of silk that is present on the exterior of cocoons. The process of deflossing involves removing the floss in order to identify the cocoon real reeling ends that are capable of continuous reeling (Fig. 8). Deflossing is typically accomplished in India by hand-peeling off the floss layer. To save time and effort, a basic tool like a brush or broom made of bamboo root sticks might be used instead.

Fig. 8: Deflossing of cocoons

Reeling: Filaments from multiple (generally 4 to 8, depending on the required thickness) cocoons are typically joined and put onto a reeling or spinning machine, which simultaneously produces a single strand of silk from the cocoons and automatically unravels the cocoons (Lee, 1999). Different reeling methods exist, from the traditional hand operated *charkha* to modern multi-end reeling machines that automate much of the process (Fig. 9). The quality of the raw silk depends on the denier (thread thickness), uniformity and cleanness of the reeled thread. Quality control is maintained throughout the process to ensure the final product meets international standards.

Fig. 9: Charkha reeling

Conclusion

The process of turning a silkworm cocoon into a usable silk thread is a very important. It begins with the crucial step of harvesting the cocoons at the right time to ensure the continuous silk filament remains unbroken. After harvesting, the cocoons go through stifling to kill the pupa inside, preventing it from damaging the silk. This is followed by drying to remove moisture and allow for long-term storage. The final and most crucial part of the process is reeling. First, the cocoons are cooked in hot water to soften the natural gum, and then they are de-flossed to find the correct reeling end. Finally, multiple filaments are combined and unwound onto a machine to create a single, strong silk thread. Every one of these steps is essential for producing high-quality, clean and uniform silk that is valued around the world.

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Changing Pest Dynamics in Indian Agriculture: Field and Storage Losses and their Sustainable Solutions

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Abstract

Indian agriculture, which is vital for food security and rural livelihoods, faces growing challenges from pests in both field crops and stored grains. Traditionally, pest issues occurred seasonally and varied by region. However, in recent decades, their behavior has changed dramatically due to climate change, intensive farming, pesticide overuse, and global trade. In field crops, invasive species like *Spodoptera frugiperda* (fall armyworm) in maize, the resurgence of brown planthopper in rice, and the bollworm complex in cotton have caused major yield losses. In storage, pests such as rice weevil (*Sitophilus oryzae*), khapra beetle (*Trogoderma granarium*) and lesser grain borer (*Rhyzopertha Dominica*) continue to cause post-harvest losses of about 5 to 10% of India's stored grains every year. The changing pest dynamics not only threaten crop yields and grain quality but also increase pressure on farmers, markets, and national food reserves. Tackling these challenges requires sustainable and integrated solutions. Overusing chemical pesticides has led to resistance, pest resurgence, and environmental issues. It is essential to shift towards eco-friendly methods. Integrated Pest Management (IPM), using resistant crop varieties, conserving natural enemies, applying biopesticides, utilizing hermetic storage technologies, and following traditional practices offer promising alternatives. Additionally, digital pest monitoring, climate-resilient pest forecasting, and effective policy measures are key to reducing losses in both fields and storage. This article looks at the changing nature of pest dynamics in Indian agriculture, measures their economic impact and effects on food security, and points out sustainable solutions that support long-term goals for environmental safety, farmer welfare, and national food security.

Introduction

Agriculture in India is crucial for the rural economy and for national food and nutrition security. However, pest damage in fields and storage systems is a major issue that undermines agricultural productivity. Traditionally, pest infestations followed predictable seasonal patterns and were managed with conventional control methods.

In recent decades, pests have changed significantly. Climate change, global trade, continuous mono-cropping, and careless use of pesticides have altered pest behavior, distribution, and intensity. New pests like the fall armyworm in maize, the return of the brown planthopper in rice, and bollworms in cotton have resulted in serious yield losses, putting farmers' livelihoods at risk. Storage pests like the rice weevil,

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khapra beetle, and grain borers also cause significant post-harvest losses, impacting food reserves and market stability. With India's growing population and rising food demand, these pest issues threaten both productivity and food security. Therefore, it is important to study the changing pest dynamics in both fields and storage, assess their effects, and create sustainable, eco-friendly management strategies.

Key roles of Pest Dynamics, Field & Storage loss

Changing Pest Dynamics in Field Crops: In recent decades, India has experienced a noticeable change in the types of pests, their spread, and the severity of their attacks on major crops. Various factors, such as climate change, globalization, and intensive farming practices, have led to these shifts.

Invasive Alien Pests: The arrival of invasive insects has created major challenges. A notable example is the Spodoptera frugiperda, or fall armyworm, which was first reported in India in 2018. Within a year, it spread throughout most maize-growing states, causing yield losses of up to 30%. Its ability to feed on different crops, high reproductive rate, and resistance to common insecticides made it a tough pest. Similarly, the papaya mealybug and rugose spiraling whitefly have invaded horticultural systems, damaging papaya, banana, and coconut farms.

Resurgence of Native Pests: Some pests that were once under control have come back strong. The brown planthopper in rice has become more damaging due to the widespread use of pesticides, which eliminated its natural predators. Cotton bollworms have also returned in *Bt* cotton, showing how pests can adapt and overcome resistance methods.

Climate-Driven Changes: Rising temperatures, unpredictable monsoons, and long dry spells have changed pest life cycles. Warmer winters allow many insects to survive longer and produce more generations. For example, rice stem borer infestations have increased in warmer conditions, while thrips and mites thrive in hot, dry weather. Extreme rainfall and flooding often lead to outbreaks of planthoppers in rice and sucking pests in pulses.

Impact on Yields: Together, these pests cause 15 to 25% crop yield losses every year in India. Such losses affect farmer incomes, increase pesticide costs, reduce soil biodiversity, and lead to fluctuations in food prices.

Storage Pest Challenges

While losses in the field are clear, losses in post-harvest storage often go unnoticed but are equally harmful. India, the second-largest producer of cereals, faces significant challenges in safely storing its grain reserves.

Major Storage Pests: The rice weevil (*Sitophilus oryzae*), lesser grain borer (*Rhyzopertha dominica*), khapra beetle (*Trogoderma granarium*) and Angoumois grain moth (*Sitotroga cerealella*) are some of the most destructive storage insects. They lead to both quantitative losses, where grain weight decreases and qualitative losses, including contamination, reduced nutritional value & poor germination.

Extent of Damage: Studies show that 5 to 10% of stored grains in India are lost each year due to pest infestations. In wheat and rice, this totals nearly 15 to 20 million tonnes annually, enough to feed millions of people. Insects often infest the grain as well as storage structures, sacks, and warehouses, making control more challenging.

Favourable Conditions: Poor storage facilities, high humidity, and improper handling create ideal conditions for pest growth. Smallholder farmers, who typically store grains at home in traditional structures, face the greatest risk. Large warehouses, if not properly cleaned, can also become hotspots for infestations.

Economic and Food Security Impact: These post-harvest losses reduce the amount of grain available for sale, lower the quality of grains for consumption and trade, and weaken national food reserves. For a country like India, where food security is essential, such losses represent not just an economic issue but also a social challenge.

Limitations of Chemical Control

The traditional response to pest problems in India has been the heavy use of chemical pesticides. While these offered short-term fixes, the long-term consequences have been serious.

Resistance Development: Pests like cotton boll-worms, rice planthoppers, and aphids have gained resistance to many types of insecticides, making several chemicals ineffective.

Pest Resurgence: Overusing pesticides often kills helpful predators and parasitoids, allowing second-ary pests like whiteflies and mites to grow uncontrollably.

Residue and Safety Concerns: Too many chemical applications leave residues in food grains, posing health risks to consumers and impacting export quality.

Environmental Pollution: Runoff from pesticide use pollutes water bodies, harms pollinators like bees, and disrupts soil ecosystems.

Thus, relying solely on chemical control is unsustainable and counterproductive.

Sustainable and Integrated Solutions

To protect agriculture, India must move toward holistic and eco-friendly pest management strategies.

Integrated Pest Management (IPM): This science-based approach combines biological, cultural, mechanical, and need-based chemical methods. For example, farmers can practice timely sowing, crop rotation, use pheromone traps, release natural enemies, and apply targeted sprays when pest populations exceed specific levels.

Resistant Varieties: Developing crop varieties that can withstand major pests reduces reliance on chemicals. For instance, rice varieties that tolerate the brown planthopper and maize hybrids that show some resistance to the fall armyworm are promising options.

Biological Control: Encouraging natural enemies such as Trichogramma wasps, ladybird beetles, and fungi that affect insects can help lower pest populations. Successful releases of parasitoids in

sugarcane and cotton demonstrate the effectiveness of this method.

Biopesticides: Neem-based products, microbial pesticides like *Bacillus thuringiensis* (Bt), and viral biocontrol agents provide safe alternatives. These options minimize ecological harm while effectively controlling pests.

Hermetic and Improved Storage: Airtight bags, such as PICS bags, metal silos, and fumigation-free storage methods protect grains from pests. Solar disinfestation and inert dusts like diatomaceous earth are useful tools for smallholder farmers.

Digital Pest Monitoring: Mobile apps, drone surveillance, and AI-powered pest forecasting models are being tested in India. Early-warning systems enable farmers to take preventive measures instead of relying on reactive sprays.

Policy and Farmer Training: Government programs promoting IPM, subsidies for biocontrol agents, and awareness campaigns are crucial. Improving warehouse infrastructure, supporting farmer producer organizations (FPOs), and enhancing cooperative storage systems will help lower post-harvest losses.

Conclusion

The changing pest dynamics in Indian agriculture pose a serious challenge to food security, farmer welfare, and environmental sustainability. Field and storage pests are rapidly evolving due to climate change, global trade, and intensive farming practices. While chemical pesticides have offered temporary relief, they have also led to resistance and ecological imbalances. The solution lies in adopting integrated and sustainable pest management strategies that reduce losses, conserve biodiversity, and ensure safe food production. Strengthening research, promoting resistant varieties, improving storage infrastructure, and raising farmer awareness will be crucial to overcoming these challenges. By implementing these measures, India can protect its agricultural productivity and secure long-term food and nutritional security.

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Digital Safety is Not an Option, it's a Necessity Protect Your Data as You Protect Your Crops

Vijaya Tiwari

With digital Empowerment and technological advancements our India's farming sector is changing a lot. Digital India has empowered our farmers and the growing technology now helps farmers in many ways, such as giving them weather updates, information on crop prices, and digital tools to improve farming. But along with these benefits, new challenges have come and keeping farmers ditally safe is a new challenge in itself.

Digital safety seems to be nation's biggest priority and it is important that farmers know how to use these digital tools safely and protect themselves from online problems.

Why Digital Empowerment is important for Farmers?

Digital empwerement has made farmers life easier and technical. Overall productivity of farmers has increased. We can understand this better by and example by using app like Farmout farmers can recieve satellite images to help them understand their fields better. Not only this there are numerous apps that provide farmers with important information like weather updates, market prices, and farming tips.

The government is supporting this digital change too. One big plan is the Digital Agriculture Mission, with a huge investment of ₹2,817 crore. The main aim of government is to create a system where farmers can easily use digital services. These services include Agristack and Krishi Decision support System

AgriStack: A digital database that keeps farmers' records, maps of villages, and crop information.

Krishi Decision Support System: A tool that helps farmers take smart decisions using data.

How digital Literacy has made Farmers Life better

Even though digital services are available, many farmers don't know how to use them. A survey in 2022 showed that 23.4% of adults in rural India don't have basic digital knowledge. This makes it hard for them to use online services for things like checking market prices, applying for government help, or making payments.

Learning digital skills farmers can get better and quick advice about crops and weather, digitally sound farmer can make use of UPI for digital payments hence monetization becomes easier (but and sell online giving them better options).

How to make Farmers Digitally Safe

Always use strong, Unique Passwords: Avoid using simple or common passwords like "123456" or your name, birthday. Combination of letters, numbers and special character makes the password stronger and cannot be hacked easily.

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Secondly never use same passwords for multiple apps and sites.

Stay alert of Phishing Attempts: Never click on suspicious links in SMS, emails, or WhatsApp messages, unknown links can drop you in big trouble One must avoid sharing personal information like bank account numbers or Aadhaar numbers over messages or calls. Always remember Official government messages usually come from verified sources (e.g., digitalindia.gov.in).

Security updates must be regularly updated: Always keep mobile apps, operating systems, and antivirus software up to date. Your updated mobile can patch vulnerabilities and attack effectively and keep you safe from potential risk of hacking

Always use Official Apps and Portals: Prefer government-recommended apps like mKisan, PM-Kisan, and official agricultural advisory apps. Avoid downloading third party apps or unknown links.

Download apps only from trusted sources like Google Play Store or official websites after reading reviews

Strengthening Mobile Devices: You can secure your mobile phones by settings up a PIN, fingerprint, or pattern lock for your phone. Avoid sharing your phone or unlock codes with others. In case your phone is lost you can find your phone using a feature "Find My Device". This device enables to find your phone and erase your valuable data just with a single click.

Avoid public Wi-Fi as secure wifi strengthens your digital safety. A secure network is of utmost importance when we talk about our data, photos, information and sensitive transactions (e.g., accessing bank accounts). We encourage people to Use mobile data or trusted Wi-Fi connections when possible.

Be Careful with Digital Payments: Use trusted payment apps like UPI (BHIM App) or Paytm and make sure the app is official. Verifying the recipient details before making payments protects you from getting scammed. Always keep your passwords and PINs confidential.

Backup Important Data: Regularly back up important agricultural records and photos (e.g., crop damage reports) to cloud services or physical storage. This protects your valuable data and prevents data loss in case of device theft or malfunction.

Stay Informed: Government is prioritizing digital safety of farmers and keeping this in mind to protect farmers and make digital services easier, several initiatives have been taken by Government like E-Panchnama System: In Maharashtra, farmers can report crop damage online to get faster compensation and reduce fraud.

Digitizing PACS: NABARD is making credit societies digital in Jharkhand, helping farmers access loans and services easily and transparently. Not only this Model Digital Villages has been set up in Prayagraj, where 23 villages are becoming digital hubs with high-speed internet, helping farmers access education, healthcare, and government services.

Report Cyber Crimes: In case of cyber frauds don't panic if cyber fraud is suspected it must be reported as soon as possible to local cybercrime cells or visit cybercrime.gov.in. Our awareness and quick response is our greatest weapon and can help defeating cyber crime and win over cyber frauds.

Way Forward

Apart from this government needs to focus on better internet access, improved connectivity, good policies and more awareness programs that can reach the farmers. Creating safe environment for farmers and making farmers digitally empowered is need of an hour.

Digital empowerment can greatly help Indian farmers, but only if they use it safely. The government, local organizations, and communities must work together to teach farmers how to use digital tools securely. Digital safety is nation's foremost priority and will help farmers benefit from modern technology and lead to a stronger farming sector in India. Together we can and we will make the difference. Farmers should use strong passwords, trusted apps, and stay alert to avoid online scams. Safe digital practices help them grow smarter and secure their future.

Greener Rice Fields: Tackling Methane for a Sustainable Future

P. Sangameshwari

Abstract

Rice is the lifeline for billions of people across Asia and Africa, yet its cultivation is a major contributor to global methane emissions. Flooded rice fields create oxygen-free conditions where microbes break down organic matter, releasing methane a greenhouse gas nearly 28 times more potent than carbon dioxide. Globally, paddy cultivation accounts for 8-12% of total methane emissions, making it both a food security necessity and a climate challenge. This article explores climate-smart strategies to mitigate methane from rice fields without compromising productivity. Water-saving approaches such as Alternate Wetting and Drying (AWD) and mid-season drainage have been shown to reduce emissions by 30-70% while conserving up to 30% irrigation water. Improved management of organic residues, use of well-decomposed compost instead of fresh straw, and balanced fertilizer application further suppress methane release. Emerging innovations such as low-methane rice varieties**,** biochar application, and diversified cropping systems offer promising long-term solutions. Beyond environmental gains, these practices provide co-benefits including lower input costs, improved soil health, and opportunities for farmers to access carbon credits. However, widespread adoption faces challenges such as limited awareness, lack of infrastructure for precise water control, and socio-economic barriers. Addressing these gaps through training, supportive policies, and farmer incentives is essential. By aligning food security goals with environmental stewardship, methane mitigation in rice farming can transform paddy cultivation into a climate-smart enterprise. Greener rice fields, managed with innovation and responsibility, hold the key to both feeding people and protecting the planet.

Introduction

Rice is the staple food for more than half of the world's population. Yet, its cultivation under flooded conditions is a major contributor to greenhouse gas emissions. Waterlogged soils create oxygen-free environments that favor methane (CH_4) production. Methane is nearly 28 times more effective than carbon dioxide in trapping heat, making it a serious contributor to climate change (FAO, 2020).

Global estimates suggest that rice paddies contribute nearly 10% of all agricultural methane emissions (Wassmann *et al.*, 2019). The challenge is to continue feeding billions of people while reducing the environmental footprint of rice farming. Fortunately, climate-smart farming practices provide pathways to lower methane emissions without reducing yields.

How Methane Forms in Rice Fields

Methane emissions arise when anaerobic

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microbes break down organic matter in flooded soils. Fresh residues such as rice straw accelerate this process. The gas then escapes into the atmosphere either through bubbling or via rice plant stems (Yagi & Minami, 1990). Thus, continuous flooding and fresh organic inputs increase methane release, while improved water and residue management can significantly reduce it.

Practical Strategies for Reducing Methane Emissions

Smarter Water Use

Alternate Wetting and Drying (AWD): Fields are allowed to dry for short periods before being irrigated again. This reduces anaerobic conditions and methane production. Studies have shown AWD can reduce methane by 30-70% while saving irrigation water (IRRI, 2013).

Mid-Season Drainage: Temporarily draining fields during the growing season also helps in cutting emissions without reducing yields (Pathak & Jain, 2012).

Better Residue and Organic Matter Handling

- ✓ Incorporating large amounts of fresh straw just before planting can boost methane emissions. Composting residues or using them as fodder instead reduces methane release (Yagi and& Minami, 1990).
- ✓ Application of well-decomposed manure instead of raw organic matter also lowers emission risk (Wassmann *et al*., 2019).

Balanced Nutrient Management

- ✓ Proper timing and application of urea improve nitrogen use efficiency, reducing excess biomass that adds to methane formation.
- ✓ Neem-coated urea and other inhibitors have been reported to cut both methane and nitrous oxide emissions from rice soils (Pathak and Jain, 2012).

Climate-Smart Rice Varieties

Low-methane rice varieties with fewer aerenchyma channels (gas-conducting tissues) are being developed. These cultivars have shown up to 40% lower emissions compared to traditional varieties (IRRI, 2018).

Diversified Cropping Systems

- ✓ Switching from continuous rice-rice cropping to rice-wheat or rice-maize rotations reduces the period of waterlogging, thereby lowering annual methane emissions (FAO, 2020).
- ✓ The System of Rice Intensification (SRI), which involves wider spacing, younger seedlings, and intermittent irrigation, has also demonstrated methane reduction benefits (Wassmann *et al*., 2019).

Soil Amendments and Innovations

- ✓ Adding biochar enhances soil health and suppresses methane-producing microbes by changing soil microbial activity (Pathak and Jain, 2012).
- ✓ Application of iron and gypsum-based amendments has also been found to discourage methane release (Wassmann *et al*., 2019).

Benefits beyond Methane Reduction

The adoption of methane mitigation practices not only addresses climate change but also brings

multiple co-benefits:

- ✓ Water savings of 20-30% with AWD and SRI (IRRI, 2013).
- ✓ Lower input costs and possible carbon credit opportunities, improving farmer incomes (FAO, 2020).
- ✓ Improved soil aeration encourages beneficial microorganisms, enhancing soil fertility (Wassmann *et al*., 2019)

Challenges in Practice

Despite proven benefits, adoption remains slow. Farmers often lack awareness, and rural areas may not have the infrastructure for precise water control. In addition, farmers may hesitate to adopt new practices without assurance of stable yields or financial incentives (Pathak and Jain, 2012).

The Way Forward

Future efforts should combine research, extension, and supportive policies. Large-scale promotion of AWD, SRI, residue management technologies, and biochar can make rice farming more climate-smart. Developing locally adapted low-methane rice varieties and linking farmers to carbon markets could further accelerate adoption (Wassmann *et al.*, 2019).

Conclusion

Rice farming will remain central to global food security, but its environmental cost can be reduced. Through water-smart irrigation, residue management, balanced fertilization, and innovative soil and varietal strategies, farmers can significantly cut methane emissions. By embracing these climate-smart practices, rice cultivation can move toward a greener and more sustainable future.

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Good Agricultural Practices: Concept and Strategies

Kaushik Gogoi, Pompy Deka, Mrinal Choudhury and Britan Rahman

Introduction

Agriculture remains the backbone of the global food supply, supporting the livelihoods of billions and ensuring food and nutritional security. However, the challenges faced by modern agriculture such as climate change, food safety concerns, degradation of natural resources, and market competitiveness necessitate the adoption of sustainable and responsible farming systems. In this context, Good Agricultural Practices (GAP) have emerged as a globally recognized standard that ensures agricultural production is environmentally sustainable, socially acceptable, and economically viable.

The concept of GAP covers a range of on-farm practices aimed at improving the quality and safety of agricultural products while maintaining ecological balance and promoting the well-being of farmers and rural communities. This assignment explores the detailed concept of GAP, its principles, objectives, benefits, and the strategic framework needed for successful implementation.

Concept of Good Agricultural Practices (GAP)

Good Agricultural Practices (GAP) refer to "practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products." This definition has been widely supported by the Food and Agriculture Organization (FAO) and other international bodies.

Historical Background

The GAP movement gained momentum in the 1990s, particularly in Europe and the US, due to increasing concerns about food safety, traceability, pesticide residues, and environmental degradation. The Eurep GAP (now GLOBALG.A.P) certification system was one of the early global standards that set protocols for producers to comply with.

Core Principles

Food Safety: Production of safe and healthy food free from harmful residues or contaminants.

Environmental Sustainability: Conservation of soil, water, air, and biodiversity.

Economic Viability: Enhancing farm productivity and profitability.

Social Responsibility: Ensuring labor rights, gender equity, and welfare of farming communities.

Animal Welfare: Ethical treatment of animals in livestock production.

Objectives of GAP

- ✓ To ensure food safety and quality from farm to table.
- ✓ To protect natural resources including soil, water, and biodiversity.
- ✓ To promote efficient use of inputs such as water, fertilizers, and pesticides.

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- ✓ To provide traceability and transparency in agricultural supply chains.
- ✓ To increase farm productivity and profitability in a sustainable manner.
- ✓ To create market access opportunities for smallholder and commercial farmers.
- ✓ To improve working conditions and promote fair labor practices in agriculture.

Components of GAP

GAP practices are generally divided into the following components:

Soil Management: Good Agricultural Practices (GAP) place high value on proper soil management as a pillar for sustainable agriculture. Soil mapping and testing assist in the determination of soil fertility level and nutrient needs, facilitating accurate application of inputs. Adding organic materials like compost or farmyard manure enhances soil structure, fertility, and microbial life. Practices such as cover cropping and crop rotation are important for the health of the soil through the replenishment of nutrients, disruption of pest and disease cycles, and increase in biodiversity. Also, conservation tillage and contour farming are implemented to reduce soil erosion, retain water, and increase long-term productivity. These practices, collectively, provide healthier soils, sustainable crop yields, and conservation of the environment.

Water Management: Water management under GAP is designed to make optimal use of available water resources in an efficient and sustainable manner. Modern irrigation systems like drip and sprinkler irrigation help apply water accurately, minimize wastage and enhance crop yields. Rain-water collection and water recycling are encouraged to save water, recharge aquifers, and make agriculture more drought-resistant. Concurrently, waterlogging and salinity are prevented from reducing soil fertility and retarding plant growth. Introducing these practices together optimizes the use of water resources and ensures soil and crop sustainability.

Crop Production: Crop production under Good Agricultural Practices (GAP) focuses on the utilization of certified seeds and quality planting materials to promote healthy crop establishment and increased yields. Nutrient management in an optimal ratio, based on soil test recommendations, is practiced to satisfy crop needs effectively while preventing nutrient imbalance and environmental degradation. Integrated Pest and Disease Management (IPM) is practiced to minimize the dependency on chemical pesticides by utilizing biological, cultural, and mechanical methods of control. In addition to this, the following adoption of better agronomic techniques like appropriate spacing, timely planting, and effective weed control also raises productivity and sustainability. These steps combined ensure safe, efficient, and environmentally friendly crop production.

Post-Harvest Handling: Post-harvest care in Good Agricultural Practices (GAP) emphasizes quality preservation and minimizing losses from farm to market. Clean and hygienic harvesting equipment

and containers are utilized to avoid contamination and maintain food safety. Sifting, sorting, packaging, and storage properly assist in preserving uniformity, improving market value, and minimizing spoilage. In addition, the implementation of cold chain systems is also crucial in maintaining freshness, enhancing shelf life, and delivering produce to consumers in optimal conditions. All these practices collectively protect not only the nutritional integrity but also the economic value of agricultural produce.

Agrochemical Use: Agrochemical management within Good Agricultural Practices (GAP) guarantees the safe and prudent use of inputs to safeguard human health and the environment. Pesticides and fertilizers are used wisely, closely adhering to prescribed dosage and timing in order to avoid adverse effects. Handlers are obliged to wear personal protective equipment (PPE) to lessen health hazards during spraying and handling. Farmers also keep accurate records of agrochemical application for transparency, traceability, and regulatory compliance. Additionally, strict compliance with pre-harvest intervals and maximum residue levels (MRLs) ensures that the produce is safe for consumption while adhering to food safety requirements.

Animal Husbandry (if applicable): Livestock under Good Agricultural Practices (GAP) focuses on animal health, wellbeing, and safety of food. Supply of clean shelter in addition to safe water and healthy diet guarantees optimum growth and productivity of the animals. Periodic veterinary checkup, vaccine-ation, and disease control activities are key factors in protecting herd health and minimizing the chances of infection. In addition, the use of antibiotic and alternative drugs is strictly controlled to avoid drug resistance and maintain the safety of animal-derived products. All these practices combine to promote sustainable livestock production while protecting consumers' health.

Worker Health and Safety: The health, safety, and well-being of farm workers are significant aspects of Good Agricultural Practices (GAP). Training sessions and awareness programs provide workers with information about safe farming practices, chemical handling, and hygiene. Ensuring access to safety equipment and sanitary facilities helps protect workers from workplace hazards as well as foster their general well-being. Furthermore, adequate compensation and reasonable working conditions are also required to ensure worker motivation, dignity, and social sustainability. These collective measures form a secure, ethical, and conducive working environment for agriculture.

Waste Management: Waste disposal within Good Agricultural Practices (GAP) is aimed at minimizing environmental contamination and ensuring resource efficiency. Composting of organic waste reduces farm waste to the minimum while building soil fertility and structure by recycling nutrient-rich waste back into the soil. On the other hand, safe disposal of chemical containers and toxic waste is strictly adhered to ensure that soil, water, and ecosystems are not contaminated.

These habits maintain a cleaner world while promoting sustainable and responsible agriculture.

Benefits of GAP

For Farmers: GAP enables farmers to enhance productivity and profitability and decrease input costs by utilizing resources optimally. It also decreases risks by encouraging diversification and sustainable methods, and facilitates greater access to domestic and export markets.

For Consumers: GAP guarantees safe and quality food with traceability and transparency in the production process. It also guarantees that consumers are provided with ethically produced and environment-friendly products.

For the Environment: GAP promotes conservation of biodiversity, limits chemical and waste pollution, and improves soil and water health, making the ecosystem more sustainable.

For National and Global Economies: GAP enhances agricultural exports, generates rural jobs, and supports the attainment of Sustainable Development Goals (SDGs).

Certification and Standards

Several national and international standards guide the certification of GAP:

Certification: GAP certification is a process whereby farmers and producer associations are formally certified for the adoption of safe and sustainable agriculture. For certification, they are required to adhere to set standards and be inspected by accredited certification organizations. Certification ensures that agriculture practices are up to standards in terms of food safety, environmental stewardship, and labor rights. It further enhances farmers' credibility and increases their access to high-value domestic and foreign markets, particularly in export-oriented commodities.

Standards: Both at a national and international level, GAP standards are established for consistent safe and sustainable food production. The most extensively used international standard is GLOBALG.A.P., which has in-depth guidelines for crops, livestock, aquaculture, and supply chains. In addition to this, most nations have also established national GAP standards, which are tailored to local farm conditions and market requirements. Such standards typically promote soil and water management, safe and effective utilization of fertilizers and pesticides, proper handling after harvest, record keeping, worker safety and health, and conservation of the environment. By ensuring compliance with such standards, farmers not only maintain consumer confidence but also ensure long-term sustainability of agriculture.

Conclusion

Good Agricultural Practices are not just a set of technical recommendations they represent a holistic approach to farming that balances productivity, food safety, and environmental stewardship. For countries like India with a large agricultural base, embracing GAP can significantly contribute to sustainable development, enhance farmer incomes, and ensure consumer health. Successful implementation of GAP requires a comb-

ination of policy support, stakeholder collaboration, farmer training, and consumer awareness. As agriculture moves into a more regulated and quality-driven era, GAP will be a cornerstone for future-ready and resilient farming systems.

Enhancing Pigeonpea Productivity: A Comprehensive Guide to Modern Management Practices for Sustainable High Yields

Kamsali Pruthvi Raju, G. Balraj, Manaswini Govindu and Aman Tigga

Abstract

Pigeon pea (*Cajanus cajan*) is a major legume crop grown in tropical and subtropical regions, valued for its high protein content and its role in improving soil health through nitrogen fixation. It's especially important in drought-prone and low-input farming areas. However, the crop's yield potential is often not fully realized due to challenges like pests, diseases, poor soil conditions, and limited access to proper farming techniques. This review highlights the key practices needed to boost pigeon pea production, including choosing the right varieties, treating seeds, using proper sowing time and spacing, and managing nutrients and water effectively. It also covers pest and disease control, weed management, and timely harvesting can help close the yield gap and make pigeon pea farming more productive and resilient, particularly in rain fed and resource-limited regions.

Introduction

Pigeon pea (*Cajanus cajan*), commonly known as Tur, Arhar, or Red Gram, is a vital part of Indian agriculture and kitchens. Second only to gram in pulse production, this ancient legume is a staple in Indian meals, mostly consumed in the form of split dal. Beyond taste, it's packed with nutrition and offers great potential for farmers when cultivated smartly.Tur dal is rich in protein (22.3%), loaded with essential minerals like iron (5.8 mg/100 g) and phosphorus (304 mg/100 g), and contains amino acids like lysine, cystine, and threonine, which are crucial for body function.

Management Practices for Yield improvement

Climate and Soil Preferences: Pigeon pea thrives in semi-arid tropical zones and needs warm temperatures between 26°C to 30°C during the rainy season and 17°C to 22°C post-monsoon. It prefers well-drained black cotton soils with a pH between 7.0 and 8.5.

Field Preparation: Deep ploughing during summer helps aerate the soil.

Fig. Pigeon pea crop (IIPR, Kanpur)

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Raised beds, broad-bed furrows, or ridge planting work best in areas with poor drainage.

Fig: Pigeon pea pod stage (crop overview)

Varieties and Sowing measures: Early varieties ICPL 88039, ICPL 87, UPAS 120, ICPL 84023, Pusa Ageti, and ICPL 20325, mature within 120 to 140 days. Sowing done in the First fortnight of June. Late maturing varieties like BSMR 736, Asha (ICPL 87119), Maruti, BDN 711, TAT 10, and C-11 require a longer growing period of around 210 to 230 days.Sowing done at the Second fortnight of June.

Table 1: Seed Treatment chemicals and their dosage

Category	Chemical/Bio-agent	Dosage	Purpose
Fungicide (Chemical)	Thiram	2–3 g kg^{-1} seed	Controls fungal pathogens like wilt and root rot
	Carbendazim	1 g kg^{-1} seed	Effective against internal seed-borne fungi
	Thiram + Carbendazim	2 g + 1 g kg^{-1} seed	Broad-spectrum disease control
Bio-fungicide	*Trichoderma viride*	5-10 g kg^{-1} seed	Eco-friendly control of fungal diseases
Biofertilizer	*Rhizobium* culture	7-10 g kg^{-1} seed	Enhances nodulation and nitrogen fixation
	Phosphate Solubilizing Bacteria (PSB)	7-10 g kg^{-1} seed	Improves phosphorus uptake

Seed Rate and Spacing: Early varieties require 20-25 kg ha^{-1} and 45-60 cm row spacing while late varieties require 15-20 kg ha^{-1} and 60-75 cm row spacing.

Cropping & Intercropping Systems: Pigeonpea makes an excellent partner in the field with cereals like sorghum, maize and pearl millet or with legumes like mung bean, black gram and soybean or with annuals like cotton, sugarcane and castor. Common crop rotations include pigeon pea-urd-wheat, mung + pigeon pea-wheat, and early pigeon pea-potato-urd bean, which improve soil fertility, break pest cycles, and enhance overall productivity.

NPK requirement: NPK (ha^{-1}): 25-30 kg N, 40-50 kg P_2O_5, 30 kg K_2O.

Micronutrient management involves applying sulphur at 20-40 kg ha^{-1}, zinc at 3 kg ha^{-1} or as a spray if deficient, and spraying $FeSO_4$ (0.5%) at 60, 90 and 120 DAS to maintain healthy crop growth. Though tur is drought-hardy, yield can be enhanced with three timely irrigations at 30 DAS (branching), 70 DAS (flowering), and 110 DAS (podding).

Table 2: Key Insect Pests of Pigeon pea and their Management

Pest	Chemical/ Insecticide	Dosage	Application Stage
Pod Borer (*Helicoverpa armigera*)	Emamectin benzoate 5% SG	220 g ha^{-1} in 500 L water	At flowering/pod formation
	H. armigera Pheromone Traps	10-12 traps ha^{-1}	For monitoring and mass trapping
Pod Fly	Monocrotophos 36 SL	1 L ha^{-1} in 800-1000 L water	At 50% flowering stage
	Neem Seed Kernel Extract (NSKE) 5%	50 g L^{-1} water	Eco-friendly, effective during flowering
Plume Moth	Azadirachtin 0.03% WSP	2500-5000 g ha^{-1}	Spray during flowering
	Neem Oil	2% solution	Repeated application if needed
Pod-Sucking Bugs	Carbofuran 3G	15 kg ha^{-1}	Soil application at sowing

Weed Management: Weeds seriously affect yields

during the first 60 days, so management is crucial. Manual weeding at 20-25 and 45-50 DAS is effective, while pre-emergence application of pendimethalin @ 0.75-1 kg a.i. ha^{-1} helps control early weed growth.

Table 3: Key Diseases of Pigeon pea and their Management

Disease	Fungicide/ Chemical	Dosage	Application Stage
Wilt (Fusarium)	Thiram + Carbendazim	2 g + 1 g kg^{-1} seed	Seed treatment
	T. viride soil application	2.5 kg ha^{-1} + 50 kg FYM/sand	At 30 DAS
Sterility Mosaic Disease (SMD)	Fenazaquin 10 EC	1 ml L^{-1} water	Spray at 45 and 60 DAS
Phytophthora Blight	Metalaxyl 35 WS	3 g kg^{-1} seed	Seed treatment
Alternaria Blight	Mancozeb 75 WP	2 g L^{-1} water	Foliar spray during early symptom appearance

Harvesting and Storage: Harvest when 2/3 of pods turn brown. Dry plants under the sun for 3-6 days before threshing. Dry seeds to 9-10% moisture and fumigate or treat with neem leaf powder to protect against storage pests.

Yield: Irrigated: 25-30 q ha^{-1}; Rainfed: 15-20 q ha^{-1}

Conclusion

Pigeonpea (*Cajanus cajan*) is one of India's most important pulse crops, valued for both its nutritional benefits and its role in sustainable farming. Known for its resilience, it grows well in dry and semi-arid areas, enriching the soil by fixing nitrogen and thriving even with limited water. Its high protein content and essential nutrients make it a key part of many diets, while also providing a steady source of income for farmers.With the right farming pigeonpea can give better yields and help farmers make the most of their land.

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Terminal Heat Stress in Wheat Crop: Challenges and Management Strategies

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Abstract

Wheat, often called the "golden grain," feeds over a third of the world's population, providing essential calories and protein. Yet, rising global temperatures are threatening wheat production, especially during its most sensitive growth stages. Terminal heat stress occurs when wheat faces high temperatures during flowering and grain filling can severely reduce both yield and grain quality. This stress speeds up leaf aging, disrupts water and nutrient use, damages key enzymes, and shrinks grains, making them less nutritious and less valuable. Even a small rise in temperature during this period can cut yields by 6-10%, highlighting the vulnerability of wheat to climate change. Scientists and farmers are tackling this challenge through a mix of smart farming and breeding strategies. Early sowing, timely irrigation, balanced fertilization, and soil-conserving practices help reduce stress, while new heat-tolerant wheat varieties are being developed using advanced breeding and biotechnology tools. Cutting-edge technologies, including remote sensing and high-throughput screening, allow rapid identification of resilient wheat lines. By combining these approaches, it is possible to maintain wheat yield and quality even as climates warm. Tackling terminal heat stress is crucial not only for farmers but for global food security, ensuring that this vital crop continues to nourish billions in a changing world.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important staple crops worldwide, providing nearly 20% of the total dietary calories and protein for the global population (Kundu *et al*., 2024; Shiferaw *et al*., 2013). However, wheat productivity is increasingly constrained by climatic variability, especially rising temperatures. Among the major abiotic stresses, terminal heat stress, characterized by high temperature during the grain-filling stage, is one of the most significant yield-reducing factors (Dhillon *et al*., 2024). Wheat (*Triticum aestivum* L.), known as the "golden grain," plays an indispensable role in global food security, providing approximately 20% of the world's protein and caloric intake. As a dietary staple for over 35% of the global population, wheat's high-yielding and disease-resistant varieties introduced during the Asian Green Revolution significantly transformed agricultural productivity (Sharma and Sharma, 2025).

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In South Asia, particularly India, wheat contributes substantially to food security and rural livelihoods. However, the sustainability of wheat production is increasingly threatened by climate change and rising temperatures, especially during critical growth phases. According to recent climate projections, global mean temperatures are expected to rise by 1.5-2.0 °C by mid-century, with even higher increases in South Asia's wheat belts (IPCC, 2021). Among the abiotic stresses faced by wheat, terminal heat stress during the reproductive and grain-filling stages is one of the most detrimental. Unlike episodic heat waves earlier in the season, terminal heat occurs toward the end of the crop cycle, when plants have limited capacity to recover. This stress shortens the grain-filling period, reduces dry matter partitioning to grains, and accelerates senescence, ultimately leading to yield and quality losses (Joshi *et al*., 2009; Dhillon *et al*., 2024).The frequency and intensity of terminal heat episodes are projected to increase due to shifts in sowing windows, late planting, and unseasonal warming trends in major wheat-producing regions of Asia, Africa, and the Mediterranean (Behera *et al*., 2024; Reynolds *et al*., 2021). For instance, in the Indo-Gangetic Plains, a 1 °C rise in mean temperature during grain filling can reduce wheat yield by 6-10% (Kalra *et al*., 2008; Kaur *et al*., 2019). Moreover, the nutritional quality of wheat**,** particularly grain iron, zinc, and protein composition is also negatively affected under terminal heat stress (Panigrahi *et al*., 2022).

Terminal Heat Stress in Wheat: Terminal heat stress refers to the exposure of wheat plants to temperatures exceeding 30-32 °C during their reproductive and grain-filling stages (Yadav *et al.*, 2022). This phenomenon is particularly prevalent in late-sown wheat and in regions that experience sudden increases in temperature during the spring. Since wheat is highly sensitive during anthesis and grain filling, heat stress at this stage can drastically impair yield potential and grain quality (Joshi *et al*., 2009).

Impacts and responses of plant to heat stress

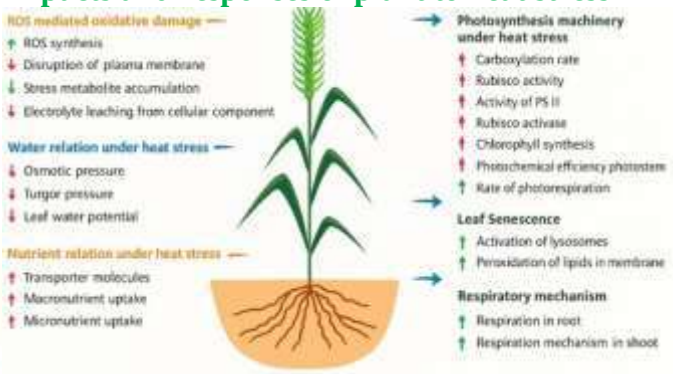

Fig. 1: Impacts and responses of plant to heat stress (Yadav *et al*., 2022)

Impacts of Terminal Heat Stress on Wheat: Terminal heat stress (THS) triggers a cascade of physiological and biochemical disruptions that significantly reduce wheat productivity. A primary effect is oxidative stress, where excessive reactive oxygen species (ROS) damage membranes, cause electrolyte leakage, and lead to harmful metabolite accumulation (Dos *et al*., 2022). Heat also disrupts water relations by reducing osmotic and turgor pressure, lowering leaf water potential, and making plants more prone to wilting. Nutrient uptake efficiency declines as transporter activity weakens, while photosynthesis is severely impaired. Damage

to chlorophyll, reduced Rubisco activity, and loss of photosystem II efficiency decrease carbon fixation, while photorespiration and photo-oxidation intensify (Lal *et al*., 2022). Physiologically, THS shortens the grain-filling period as high temperatures accelerate leaf senescence and crop maturity (Murmu *et al*., 2025; Kumar *et al*., 2024). Reproductive processes are also vulnerable heat during anthesis reduces pollen viability, spikelet fertility, and fertilization success (Choudhary *et al*., 2022). Key metabolic enzymes, including Rubisco and amylases, are inactivated, lowering starch biosynthesis and assimilate supply to grains (Chen *et al*., 2022). Meanwhile, respiration rates in roots and shoots increase, depleting carbohydrate reserves and reducing energy availability for grain development (Ullah *et al*., 2022; Sivakumar *et al*., 2024). The culmination of these stresses results in major yield and quality losses. Wheat yield typically declines by 15-25%, and up to 40% under severe terminal heat stress (Yadav *et al*., 2022). Thousand-grain weight, grain size, and test weight are reduced due to poor starch deposition and premature grain filling (Prasad *et al*., 2023). Grains often appear shrivelled, diminishing both yield and market value. While crude protein concentration may increase under heat stress, end-use quality often declines as gluten strength and processing properties deteriorate (Han *et al*., 2025; Panigrahi *et al*., 2022).

Management and Mitigation Strategies: Addressing terminal heat stress requires a combination of agronomic management and genetic improvement. Among agronomic practices, early sowing remains one of the most effective measures, as it allows crops to complete their reproductive stages before the onset of extreme temperatures (Kalra *et al*., 2008). Supplemental irrigation during grain filling also helps reduce canopy temperature while maintaining photosynthesis and grain filling (Gulino *et al*., 2024). Balanced nutrient management, especially with nitrogen, potassium, and micronutrients, further enhances stress resilience by supporting metabolic activity under adverse conditions (Farooq *et al*., 2011). Conservation agriculture practices such as mulching and residue retention also play an important role in lowering canopy temperature and conserving soil moisture (Demo and Bogale, 2020).

From a genetic perspective, breeding heat-tolerant varieties has been a central focus of wheat improvement programs. Traits such as stay-green, canopy temperature depression, and membrane thermostability are being used as key selection criteria for developing resilient lines (Reynolds *et al*., 2021). Molecular breeding has facilitated the identification of quantitative trait loci (QTLs) associated with grain filling and canopy cooling, enabling marker-assisted selection for heat tolerance (Kim *et al*., 2024). In addition, biotechnological interventions, including the overexpression of heat shock proteins and antioxidant enzymes, have shown promise in conferring thermotolerance to wheat plants (Sertse *et al*., 2023).

Recent Advances: Recent years have witnessed significant technological and methodological advan-

ces aimed at managing terminal heat stress more effectively. High-throughput phenotyping, often employing remote sensing and imaging tools, has allowed rapid screening of large germplasm collections for heat tolerance traits (Araus and Cairns, 2014). Furthermore, climate-smart agricultural practices that integrate stress-tolerant varieties with improved agronomic strategies are emerging as sustainable solutions for ensuring stable wheat production under warming climates (Behera *et al*., 2024). Together, these approaches offer a multifaceted framework for mitigating the adverse effects of terminal heat stress and securing wheat productivity in the face of global climate change.

Conclusion

Terminal heat stress is a major challenge for wheat production under climate change, significantly reducing yield and grain quality. A combination of early sowing, heat-tolerant cultivars, precise irrigation and conservation agriculture can mitigate its effects. Future research should integrate molecular breeding, biotechnology, and precision agriculture to enhance resilience. Developing climate-resilient wheat varieties remains critical to ensuring global food security in warming environments.

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Commodity Exchange in Agriculture: A Game Changer for Indian

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Abstract

This article explores the role of commodity exchanges in transforming Indian agriculture by providing a transparent, efficient, and accessible marketing platform for farmers. It explains how these exchanges facilitate real-time price discovery, risk management through futures contracts, and direct market access ultimately leading to better income stability. The article also highlights key challenges such as lack of awareness and digital barriers, while suggesting practical steps for wider farmer participation. Commodity exchanges hold the potential to empower farmers and modernize India's agricultural economy.

Introduction

Agriculture forms the backbone of the Indian economy, yet farmers often face unpredictable prices and limited market access. Traditional selling systems through mandis and middlemen frequently result in low returns for their hard work. In this scenario, commodity exchanges offer a modern, transparent, and efficient platform for trading agricultural produce. By connecting farmers to national markets and providing tools like futures contracts, these exchanges help in better price realization and risk management, paving the way for a more profitable and secure farming future.

Commodity Exchange: A commodity exchange is a centralized, electronic platform where buyers and sellers trade standardized agricultural and non-agricultural goods. Unlike a traditional mandi (local market), where price discovery depends on negotiation or local demand, a commodity exchange reflects real-time national and global prices.

There are two main types of trading in commodity exchanges:

Spot Trading: Immediate buying and selling of goods.

Futures Trading: A contract to buy or sell a commodity at a future date at a pre-agreed price.

Farmers Benefit

Better Price Realization: Farmers can sell produce at the best available price in the country.

Eliminates Middlemen: Direct access to buyers means higher profits.

Scientific Storage: Farmers can store produce in accredited warehouses and sell when prices are favorable.

Access to Credit: Warehouse Receipts can be used to get loans from banks.

Price Hedging: Futures contracts help lock in prices in advance, minimizing losses from price crashes.

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Major Commodity Exchanges in India

Exchange	Focus Commodities
NCDEX (National Commodity and Derivatives Exchange)	Wheat, Soybean, Chana, Mustard, Guar, etc.
MCX (Multi Commodity Exchange)	Primarily non-agricultural (Gold, Silver, Crude Oil), but also some agri commodities
ICEX (Indian Commodity Exchange)	Rubber, Diamond
e-NAM (Electronic National Agriculture Market)	Government-supported agri trading platform integrating APMC mandis

Understanding Futures Contracts with an Example

Consider a cotton farmer who anticipates a drop in market prices by the time of harvest. To safeguard his income, he enters into a futures contract on the National Commodity and Derivatives Exchange (NCDEX) to sell his cotton at a fixed price of ₹7,000 per quintal, with delivery scheduled in three months. When the harvest period arrives, if the market price has indeed dropped to ₹6,000 per quintal, the farmer is protected he still receives the agreed price of ₹7,000. This mechanism helps him avoid potential losses and ensures price stability, making futures trading a valuable risk management tool in agriculture.

Challenges in Adoption

Despite the benefits, many Indian farmers are not yet part of this system. Why?

Lack of Awareness: Many farmers don't know what a commodity exchange is.

Digital Divide: Poor internet access in rural areas restricts participation.

Quality Standards: Commodity exchanges require standardized, graded produce, which small farmers may not be able to meet.

Volume Requirements: Small landholders may not produce in sufficient quantity to trade.

Risk of Speculation: Improper understanding of futures trading may lead to losses.

Steps to Promote Commodity Exchange in Agriculture

To make the system farmer-friendly, the following steps are needed:

Training and Capacity Building

- ✓ Conduct awareness programs in villages via Krishi Vigyan Kendras (KVKs), Agri-Universities, and FPOs.
- ✓ Include commodity market education in school and college curricula.

Promote FPO Participation

- ✓ Farmer Producer Organizations can aggregate produce and trade on behalf of smallholders.
- ✓ FPOs can also provide storage, quality grading, and credit support.

Government Role

- ✓ Link APMC mandis with e-NAM and promote interoperability.
- ✓ Provide subsidized warehousing and grading infrastructure.
- ✓ Offer insurance schemes for futures trading participants.

Technological Interventions

- ✓ Develop mobile apps with local language interfaces showing real-time prices.
- ✓ Introduce SMS alerts for commodity price changes.

Global Perspective

Countries like the USA, Brazil, and China have well-developed commodity exchange systems. In the USA, platforms like Chicago Board of Trade (CBOT) have helped stabilize prices for farmers for decades. India is slowly catching up and with the right push, we can create a farmer-first exchange system.

Conclusion

Commodity exchanges represent a revolutionary change in Indian agriculture. By making markets more transparent, efficient, and farmer-friendly, they can ensure that agriculture is not just a livelihood but a profitable venture. As we move towards a Digital India, let us also aim for a Digitally Empowered Farmer. With commodity exchanges, Indian farmers can finally break free from age-old market chains and enter the world of smart, secure, and scientific agriculture.

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Baby Corn (*Zea mays* L.): The Wonder Crop to Increase the Farmer's Income

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Abstract

After rice and wheat, corn (*Zea mays* L.) is the third most important crop in the world. Between 8 and 25 percent of the land and cereal production is devoted to it. The dehusked corn ear, known as baby corn, is harvested two to three days after silk emergence but before fertilization. Because of its sweet flavor, baby corn is eaten as a vegetable. It was a unique choice for cultivation in non-traditional corn-growing areas because of its short duration, adaptability to various cropping systems, suitability for all seasons, and environmentally benign farming methods. A tasty and nutritious vegetable that is becoming more and more well-liked in urban and suburban settings is baby corn. For crop diversification, maize value addition, and the expansion of the food processing sectors, baby corn is a preferable choice.

Introduction

Baby corn (also known as young corn, cornlettes, child corn or baby sweet corn) is a cereal grain taken from corn (maize) harvested early while the stalks are still small and immature. It typically is eaten whole including the cob, which is otherwise too tough for human consumption in mature corn in raw, pickled, and cooked forms. Baby corn is common in stir fry dishes. Maize occupies third position as cereal crop after rice and wheat. Maize is also known as "Queen of Cereals". Maize provides nutrition to human and as a fodder crop to animals. Growing of maize as vegetable crop increases its value in cropping system along with its applications in industries with different range of products.

Among all the cereals, maize has the highest production potential. Young corn has a small growth period. Hence farmers can cultivate 3 or more than 3 crops in a year. Due to more crop cycle farmers economy can be improved (Das *et al*., 2008). Amongst the cultivated maize crops, the most promising one is baby corn. It is the most exquisite one as it provides the increased range of production, value addition as well as increased income. It belongs to the family Gramineae and originated from Central America. The grains are used as food, feed as well as industrial raw materials. It contains carbohydrate in the form of starch (up to 80%) and crude protein (up to 10%). According to Thava Prakash *et al*. (2005), 100 gm of baby corn contains

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required moisture (89.0%) moisture, fats (0.2 gm), protein (1.9 gm), carbohydrate (8.2 mg), ash (0.06 gm), calcium (28.0 mg), potassium (86.0 mg). Despite of human nutrition the other benefits of baby corn are the utilization of its husk, silk and stover as green fodder.

In China, Baby corn was used as vegetables crop and further it was gradually spread to all over the world to accept it for cultivation. Now baby corn is cultivated all over the world. Thailand is the highest producer of baby corn and the production value is nearly $64 million US (Stone *et al*., 2018). Baby corn cultivation has already started in India and major states are going for its cultivation at larger scale. In India, it is cultivated on 9.43 m ha land. In India total production is 24.35 m t and productivity is 2583 kg ha^{-1} (FAO 2015). Consideration by different group of researchers is currently more focussed towards investigating its potential in India for acquiring outside trade other than higher financial incomes to the farmers. The cultivation of baby corn is higher in many parts of India including Meghalaya, Uttar Pradesh, Haryana, Maharashtra, Karnataka and Andhra Pradesh (Kheibari *et al*., 2012).

Nutritional value of baby corn

Baby corn has nutritional value very related to vegetables like cauliflower, cabbage and tomatoes etc. (Baby corn nutritional value per 100 grams). Besides all of these nutrients, it also contains iron, vitamin A, B and folic acid in very less quantity. Studies have showed that its one cup meets about of recommended daily intake of Fe and vitamin A and 4% of recommended daily intake of vitamin C.

S. No.	Nutrients	Quantity
1.	Energy	26 calories
2.	Carbohydrates	3.1 g
3.	Fibre	1.7 g
4.	Protein	2.5 g
5.	Sodium (Na)	300 mg
6.	Calcium	95 mg
7.	Magnesium	345 mg
8.	Phosphorous	898.62 mg

Health benefits

- ✓ Reduction in body weight
- ✓ Maintain blood sugar level
- ✓ Improve digestion
- ✓ Source of nutrients
- ✓ Improve vision
- ✓ Prevention of neural-tube birth defects

Uses of baby born

- ✓ The entire short ear of baby corn is edible. Baby corn can be eaten raw or cooked.
- ✓ It is used in variety of traditional and continental dishes besides being canned.
- ✓ It is used as decorative, crispy vegetable in salad, soup, pickles, pakoras, vegetable biryani, mixed vegetable, pasta, chutney, cutlets chat, dry vegetable, kofta curry, Manchurian, raita, candy, jam, murabba, burfi, halwa, kheer, deep fried baby corn with meat and rice and other favorite dishes (Asaduzzaman *et al*., 2014).
- ✓ It can also be used after boiling and blanching. Except corn, its whole plant can also be used as fodder for cattle, which is nutritious. Moreover straw, dry leaves and cob covering can be used as good fuel.

Attributes of maize genotypes for baby corn

selection

- ✓ The main attributes related to baby corn are early maturity, prolificacy, synchronized ear emergence and yellow kernels (Kumar and Kalloo, 1998).
- ✓ Early maturity (>55 days) baby corn takes as a catch crop and helps the crop to gateway from biotic and abiotic stresses which shows after the flowering stage.
- ✓ Prolificacy- An ideal plant bears three ears per plant without losing quality, size and shape of young ears.
- ✓ Synchronized ear emergence lowers the harvesting and storage cost of ears gradually.
- ✓ Yellow immature kernel with uniform row arrangement is one of the criterions for baby corn breeders.

Challenges of Baby Corn in India

Perishability and Short Shelf Life

- ✓ Baby corn has a very short harvest window (1-2 days for optimum quality) and spoils quickly without proper cold storage.
- ✓ Limited cold chain infrastructure in rural areas leads to post-harvest losses.

Labour-Intensive Cultivation

- ✓ Requires frequent harvesting (every 2-3 days), which increases labour requirements and cost.
- ✓ Skilled labour is needed to harvest at the correct maturity stage.

Market Awareness and Demand Fluctuations

- ✓ Consumer awareness about baby corn's nutritional value and culinary uses is still low in many regions.
- ✓ Seasonal demand from hotels, restaurants, and export markets can be unstable.

Lack of Standardized Varieties: Many farmers grow baby corn from normal maize hybrids rather than specialized baby corn hybrids, leading to inconsistent yield and quality.

Infrastructure and Processing Gaps

- ✓ Limited facilities for processing (blanching, canning, freezing) restrict expansion into processed food markets.
- ✓ Poor packaging leads to damage during transportation.

Price Instability: Farmers often face fluctuating prices due to oversupply during peak seasons and lack of organized procurement.

Pest and Disease Management: Baby corn is susceptible to maize pests like stem borers, armyworms, and fungal diseases, requiring careful management.

Scope of Baby Corn in India

High-Value Crop for Diversification

- ✓ Can be cultivated throughout the year in many parts of India, providing an additional income source for farmers.
- ✓ Short duration (60-70 days) allows it to fit well into multiple cropping systems.

Export Potential

- ✓ Growing international demand for baby corn in South-East Asia, Middle East, and Europe for fresh and processed forms.
- ✓ India's climatic diversity allows off-season

production, giving a competitive advantage.

Value Addition Opportunities

- ✓ Baby corn can be processed into canned, frozen, and pickled products for retail and export.
- ✓ Potential for integration with food processing industries and ready-to-eat food segments.

Nutritional and Culinary Appeal

- ✓ Low calorie, high fibre, and rich in vitamins and minerals.
- ✓ Increasing health-conscious consumer base and demand from restaurants, hotels, and fast-food chains.

Employment Generation: Labour-intensive cultivation offers employment opportunities in rural areas for harvesting, grading, packaging, and processing.

Government and Institutional Support

- ✓ Inclusion in horticulture development programs under MIDH, NHM, and state horticulture missions.
- ✓ Potential for contract farming with organized buyers and food processing companies.

Agro-Industrial Linkages

- ✓ Can be integrated with dairy farms (as the stalks are excellent fodder) and poultry feed production.
- ✓ By-products have economic value, reducing waste.

Production method of baby corn

Crop Selection and Varieties

Special Baby Corn Hybrids: 'VL Baby Corn 1', 'HM 4', 'PAC 792', 'G-5414', and some sweet corn hybrids also work. Choose short-duration, high-yielding hybrids with small ear size and uniform maturity.

Climate and Soil Requirements

Climate: Warm, humid climate; optimum temperature 20-30°C.

Soil: Well-drained loam or sandy loam with pH 5.5-7.5. Avoid waterlogged soils.

Season: Can be grown year-round, but best sowing seasons are February-March, June-July, and October-November (varies by region).

Land Preparation

Ploughing: 2-3 deep ploughings to get a fine tilth.

- ✓ Add 20-25 t ha^{-1} of well-decomposed FYM (farmyard manure) during final ploughing.
- ✓ Ensure proper drainage channels.

Sowing

Spacing

Row-to-row: 60 cm

Plant-to-plant: 20 cm

Seed Rate: 20-25 kg ha^{-1}

Sowing Method: Dibbling or seed drill. Seeds are sown 3-4 cm deep. Treat seeds with fungicides (Carbendazim 2 g kg^{-1}) to prevent seed-borne diseases.

Nutrient Management

Basal Dose: NPK @ 60:60:40 kg ha^{-1}.

Top Dressing: 60 kg N ha^{-1} in 2-3 splits at 20 DAS (days after sowing) and 40 DAS. Foliar spray of micronutrients (Zn, B) enhances ear quality.

Irrigation

- ✓ Maintain moisture at germination and silking stage.

- ✓ Irrigate immediately after sowing, then at 7-10 day intervals.
- ✓ Avoid water stress, especially during ear formation.

Intercultural Operations

Weeding: 2 manual weedings at 20 DAS and 40 DAS.

Mulching: Can conserve soil moisture and reduce weeds. Earthing up around 30 DAS improves plant support.

Pest and Disease Management

Common Pests: Stem borers, fall armyworm, shoot fly.

Control: Spray Emamectin benzoate 5 SG @ 0.4 g litre^{-1} or Spinosad 45 SC @ 0.3 ml litre^{-1}.

Common Diseases: Leaf blight, downy mildew.

Control: Spray Mancozeb 0.2% or Metalaxyl-Mancozeb 0.2%.

Harvesting

First harvest: 45-50 DAS (variety-dependent).

- ✓ Harvest cobs 1-3 days after silk emergence, before fertilization.
- ✓ Harvest interval: Every 2-3 days for continuous picking.
- ✓ Handle gently to avoid damage.

Post-Harvest Handling

- ✓ Dehusk immediately to prevent heat build-up.
- ✓ Sort and grade based on size and tenderness.
- ✓ For fresh market: Pack in perforated polythene bags and store at 4-6°C.
- ✓ For processing: Blanch in hot water (90-95°C for 1-2 minutes) before freezing or canning.

Yield

Fresh cob yield: 800-1200 kg ha^{-1} (husked baby corn).

Green fodder (stalks/leaves): 40-50 t ha^{-1} valuable for livestock.

Important varieties and hybrids of baby corn

The important varieties/hybrids cultivated in India, along with their key traits are given in the following table.

Name of varieties	Institute of Release	Characteristics
Public Sector Varieties		
VL Baby Corn 1	VPKAS, Almora	Short duration (60-65 days), uniform cobs, good tenderness.
HM 4	IARI, New Delhi	High yield potential, good cob size, suitable for spring and kharif seasons.
G-5414	PAU, Ludhiana	High number of cobs per plant, good sweetness, suitable for fresh and processing.
PEHM 2	IARI, Pusa	Medium duration, good for both baby corn and fodder.
African Tall		Mainly a fodder maize variety, sometimes used for baby corn in dual-purpose systems.
Private Sector / Hybrid Varieties		
PAC 792	Advanta	Uniform small cobs, good market acceptance.
Sweet Gold	Advanta	Attractive colour, tender texture, sweet taste.
Prakash	Private hybrid	High yield, uniform maturity, disease tolerant.
Golden Baby	Private hybrid	Suited for fresh market, good sweetness, high recovery after husking.
Sweet Corn Hybrids Used as Baby Corn: Some sweet corn hybrids viz., Sugar 75, Madhuri, and Priya are harvested early for baby corn. **Note** ✓ Many baby corn growers use normal maize hybrids (grain maize) harvested at 1-3 days after silk emergence. ✓ Specialized baby corn hybrids are preferred for uniform ear size, tenderness, and higher number of ears per plant.		

The future prospects of baby corn in India

Expanding Domestic Market

- ✓ Urban lifestyle changes are driving demand for

exotic and health-focused vegetables.

- ✓ Hotels, restaurants, and fast-food chains (HORECA sector) increasingly use baby corn in salads, stir-fries, soups, and snacks.
- ✓ Rising health-conscious consumer base is pushing baby corn into supermarkets and online grocery platforms.

Export Opportunities

- ✓ India has a climatic advantage to produce baby corn year-round for fresh and processed export.
- ✓ Major importing countries: Thailand, Vietnam, UAE, UK, and other European markets.
- ✓ Processed baby corn (canned, frozen, pickled) has growing demand in Middle East and EU due to long shelf life and convenience.

Integration with Food Processing Industry

Baby corn has high value addition potential:

- ✓ Canning, freezing, vacuum-packing, pickling.
- ✓ Ready-to-eat and ready-to-cook packaged products.
- ✓ Government's PLI Scheme for food processing and Operation Greens can promote processing units.

Role in Crop Diversification

- ✓ Fits into short-duration cropping systems (60-70 days) and can be grown between major crops.
- ✓ Suitable for peri-urban agriculture where proximity to markets reduces transport and storage costs.
- ✓ By-products (stalks, husks, tassels) provide quality green fodder and enhancing farm profitability.

Technology and Research Potential

- ✓ Development of specialized high-yielding baby corn hybrids with uniform cobs and pest/disease resistance.
- ✓ Protected cultivation (polyhouse/net house) for premium off-season production.
- ✓ Cold chain and logistics improvement to reduce post-harvest losses.

Government and Policy Support

- ✓ Inclusion under National Horticulture Mission (NHM) and Mission for Integrated Development of Horticulture (MIDH).
- ✓ Subsidies for drip irrigation, seed production, and cold storage.
- ✓ Opportunities for contract farming with food processors and exporters.

Challenges to Address for Future Growth

- ✓ Need for organized marketing systems and price stabilization.
- ✓ Development of cold chain infrastructure in rural belts.
- ✓ Farmer training on harvesting window, quality standards, and post-harvest handling.

Conclusion

Baby corn in India has strong future potential as a niche, high-value, short-duration crop especially if linked with processing industries, export chains, and modern retail. With research backed varieties,

organized marketing, and cold chain development, India can emerge as a major global supplier. Further, for grab baby corn industry, regional co-operation for swap of information and germplasm, regional testing of selected hybrids and varieties, joint meetings and visits, human resource growth, collaborative efforts for research, development and sensitization of policy makers for reaching at adoption of appropriate baby corn output and processing technology would be highly desirable.

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Digital Minimalism: Reclaiming Focus and Mental Well-being in a Hyper-connected World

Kumari Pallavi, Hari Charan Kalita, H. Kalita and A. K. Mohanty

Introduction

Technology has undoubtedly given us extraordinary gifts such as instant access to information, seamless communication across continents, and conveniences that our ancestors could never have imagined. The very tools designed to keep us connected have left us feeling increasingly scattered, restless, and detached from the present moment. The more we immerse ourselves in the digital noise, the harder it becomes to be truly grounded in our own lives. We now find ourselves living in an era where our phones seem to vibrate more often than our very own hearts beat. From the moment we wake up until the time we fall asleep, the digital world constantly competes for our attention. Research suggests that the average individual checks their smartphone well over 150 times a day a habit that slowly but steadily chips away at our focus. Entire mornings, which could once have been devoted to quiet reflection, meaningful conversations, or productive work, are now effortlessly consumed by endless scrolling through feeds, replying to a barrage of pings, and engaging with fleeting snippets of content that vanish almost as quickly as they appear. It is precisely here that digital minimalism steps in not as a harsh rejection of modern technology, but as a thoughtful and conscious philosophy for reclaiming our time, attention and mental well-being in a hyper-connected world. Digital minimalism does not demand that we throw away our smartphones or erase every social media account. Instead, it calls for a mindful alignment between technology and our deepest values. It urges us to ensure that our devices work in service of our goals, growth, and happiness rather than allowing them to dictate our behavior and shape our lives.

The Hidden Costs of Constant Connectivity

Digital technologies were designed to make our lives easier, yet the very platforms meant to connect us often leave us more distracted, anxious, and fatigued. Consider a few examples:

Attention fragmentation: Studies show that after being interrupted by a notification, it can take up to 25 minutes to fully regain focus. Multiply that by dozens of notifications a day, and you realize how much productivity evaporates unnoticed.

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The illusion of connection: Social media fosters a sense of closeness but often replaces deep, meaningful interaction with surface-level engagement likes, shares, and emoji's. Many people report feeling lonelier after spending extended time online.

Mental health drain: Research links excessive screen time and social media use with higher rates of anxiety, depression, and sleep disruption.

Lost presence: Instead of being fully engaged with family, friends, or even our own thoughts, our attention is divided between the physical moment and the digital one buzzing in our pockets.

Criticisms and Misconceptions

Some critics argue that digital minimalism is impractical, even unrealistic, in a world where technology has become deeply woven into the fabric of daily life. They point out that smartphones, social media, and instant messaging are no longer luxuries but necessities for work, communication, and even access to basic services. To them, the idea of stepping back from screens seems naive, as though it ignores the realities of modern existence. Others raise a different concern that digital minimalism carries a certain privilege. They suggest that it is easier for academics, writers, or creative professionals, who often have more control over their schedules, than for employees in fast-paced industries who are expected to be "always on." For workers whose livelihoods depend on constant emails, updates, and online coordination, the concept can appear out of reach or even elitist. However, these criticisms often misinterpret what digital minimalism is asking of us. It is not a call to quit the internet, abandon modern tools, or retreat to a cabin in the woods. Rather, it is about conscious engagement approaching technology with intentionality instead of falling into default, addictive patterns of use. Digital minimalism recognizes that technology is here to stay, but it urges us to reclaim the power to decide how, when, and why we use it.

The Benefits of Living with Less Digital Clutter

Adopting digital minimalism is far more than just cutting down on screen time it is about reclaiming attention, clarity, and purpose in a world overloaded with digital noise. By intentionally choosing what technologies to keep in your life and how to use them, create space for what truly matters. The rewards of this shift extend across personal well-being, productivity, and relationships.

Sharper focus: This allows us to engage in deep work reading, problem-solving, or creating without being pulled in multiple directions. The ability to focus deeply not only improves the quality of work but also leads to greater satisfaction in what we accomplish.

Improved mental health: Continuous exposure to social media feeds, breaking news alerts, and endless scrolling often fuels stress, comparison, and anxiety. Stepping back from these digital triggers even for short breaks can reduce feelings of overwhelm and restore mental calm.

Stronger relationships: True connection requires presence, and presence is difficult when attention is constantly divided between a conversation and the

pull of a buzzing phone. By putting devices aside during meals, meetings, or quality time, we show others that they matter. This simple act of being fully engaged strengthens bonds, fosters trust, and nurtures more meaningful interactions.

Rediscovered joys: Life is full of simple pleasures that often go unnoticed when we are glued to screens. Reading a physical book without checking messages in between, spending an afternoon gardening, sketching, or even savoring quiet moments of stillness can feel more rewarding and enriching. By clearing away digital clutter, we create room for hobbies, creativity, and real-world experiences that add depth and joy to everyday living.

Enhanced productivity and energy: With fewer digital interruptions, we conserve mental energy that would otherwise be drained by constant multi-tasking. This allows us to work more efficiently, finish tasks faster, and still have time and energy left for personal growth and relaxation.

Greater Sense of Control: Digital minimalism reminds us that technology should serve us not control us. Instead of being at the mercy of endless notifications and algorithm-driven feeds, we learn to decide when and how to engage. This shift restores a sense of agency and empowerment in daily life.

Digital Minimalism in the Workplace

- ✓ Emphasizing deep work blocks free of inter-ruptions.
- ✓ Replacing constant chats with structured communication.
- ✓ Digital minimalism promotes intentional use of technology at work.
- ✓ It helps reduce constant digital distractions like emails, chats, and notifications.
- ✓ Encourages prioritizing deep, focused work over multitasking.
- ✓ Employees learn to check emails at set times instead of continuously.
- ✓ Promotes the use of digital tools that add value, not overwhelm.
- ✓ Reduces digital fatigue caused by excessive screen time.
- ✓ Encourages "digital decluttering" by removing unused apps and tools.
- ✓ Helps in creating boundaries between work and personal digital life.
- ✓ Supports mental well-being by reducing information overload.
- ✓ Encourages mindful breaks away from screens during work hours.
- ✓ Promotes face-to-face or phone conversations over endless chat threads.
- ✓ Reduces stress caused by constant notifications and multitasking.
- ✓ Boosts productivity by focusing on essential tasks only.
- ✓ Encourages minimal but effective digital communication.
- ✓ Increases job satisfaction by lowering digital burnout.
- ✓ Helps teams streamline tools to avoid duplication and confusion.
- ✓ Promotes sustainable work habits by balancing

digital and offline work.

- ✓ Creates a healthier, more focused, and productive work culture.

Practical steps toward digital minimalism

- ✓ Audit Your Digital Life
- ✓ Define Your Core Values
- ✓ Declutter Your Devices
- ✓ Control Notifications
- ✓ Set Tech-Free Boundaries
- ✓ Batch Digital Tasks
- ✓ Practice Intentional Consumption
- ✓ Reclaim Idle Moments
- ✓ Prioritize Human Connection
- ✓ Experiment with Digital Sabbaths

Conclusion

In many ways, digital minimalism is less about the tools we use and more about the values we choose to live by. It is a philosophy that reminds us that our attention is one of the most valuable resources we possess finite, fragile, and deeply tied to the quality of our lives. Every moment spent in shallow distractions mindlessly scrolling, tapping, or swiping is not neutral; it is a trade-off. It is time that could have been invested in nurturing creativity, building meaningful relationships, pursuing personal growth, or simply allowing ourselves the rest our minds and bodies crave. Importantly, digital minimalism does not call for the complete abandonment of technology. Technology is not the enemy; it is a tool with extraordinary potential. What it asks of us is to reframe the relationship we have with our devices.

Instead of being passive consumers, endlessly reacting to notifications and algorithm-driven feeds, we become intentional users choosing what serves us and discarding what drains us. This shift is not about rejection but about alignment: ensuring that technology amplifies our values rather than undermines them. Ultimately, digital minimalism is not just a strategy for managing screens or decluttering devices. It is a pathway back to clarity in a noisy world, to balance in a culture of constant urgency, and to meaning in a society that often mistakes busyness for fulfillment. It teaches us that less digital clutter creates more space for the things that matter most presence, purpose, and peace.

Heat Waves and their Impacts on Fisheries: Challenges and Adaptation Strategies

Sneha Chaudhury, Ayushi Pandey and Krishan Kumar Yadav

Abstract

Heat waves defined as prolonged periods of unusually high air and water temperatures are becoming more frequent and intense under the influence of climate change. Fisheries, which form the backbone of food security, nutrition, and livelihoods for millions worldwide, are highly sensitive to thermal stress. Elevated water temperatures affect fish physiology, growth, reproduction, and survival, while also altering aquatic ecosystem dynamics, species distribution, and pathogen prevalence. This article examines the ecological and socio-economic consequences of heat waves on fisheries, and explores adaptation strategies ranging from ecological management to policy-level interventions. Strengthening climate resilience in fisheries is crucial for ensuring long-term sustainability and safeguarding the livelihoods of vulnerable communities.

Introduction

Climate change has emerged as one of the most pressing global challenges of the 21st century, and among its many consequences, heat waves stand out as an increasingly frequent and severe threat. Traditionally, heat waves have been studied in terms of terrestrial ecosystems and human health, but recent scientific attention has highlighted their profound impacts on aquatic environments, particularly fisheries. Heat waves in aquatic systems often referred to as marine heat waves (MHWs) or freshwater temperature extremes are characterized by sustained periods of unusually high-water temperatures. These events disrupt the delicate thermal balance required for the survival and productivity of fish species, aquatic plants and micro organisms which form the foundation of aquatic food webs. Fisheries, both capture and aquaculture, are highly vulnerable to such thermal anomalies. Fish are ectothermic organisms, meaning their physiology, growth, reproduction, and behaviour are directly regulated by the surrounding water temperature. Even minor deviations from their optimal thermal range can lead to increased metabolic stress, reduced oxygen availability, impaired immune responses, and in severe cases, mass mortality. Beyond the ecological conseq-uences, heat waves pose significant socio-economic risks. Globally, fisheries contribute not only to biodiversity and ecosystem services but also to livelihoods, nutrition, and food security for millions of people. According to the Food and Agriculture

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Organization (FAO, 2024), more than 3.3 billion people depend on fish as a primary source of animal protein, making the stability of fisheries under climate extremes a critical concern. Recent studies reinforce these concerns. For example, marine heat waves in the northeast Pacific Ocean have disrupted food webs favouring gelatinous zooplankton and altering energy flows, which threatens commercially important fish and marine mammal populations (Gomes *et al.,* 2024). In the Gulf of Alaska, heat waves have shifted hatch dates for Pacific cod by two to three weeks, with higher larval mortality and fewer juveniles surviving past their first year (Almeida *et al.,* 2024). In the Lakshadweep Sea, elevated heat stress has led to intense coral bleaching and risks for fisheries and coastal communities dependent on reefs (Das *et al*., 2023). In this context, understanding the ecological and socio-economic impacts of heat waves on fisheries is vital. Equally important is the exploration of adaptation strategies that can enhance resilience, ranging from technological innovations in aquaculture to adaptive management policies and community-based initiatives. This article aims to examine these dimensions, emphasizing both challenges and solutions for sustaining fisheries in an era of rising climate extremes.

Ecological Impacts of Heat Waves on Fisheries

Aquatic heatwaves, or prolonged periods of unusually warm water, have devastating ecological impacts on fisheries by causing widespread physiological stress, disrupting ecosystems and food webs, and altering the geographic distribution of marine species (Fig. 2). These events are becoming more frequent and intense, pushing aquatic systems past their thermal tolerance limits.

Physiological Stress and Mass Mortality: Heat-waves directly impact the physiology of fish, which are ectotherms (cold-blooded), meaning their body temperature is regulated by the surrounding water. As water temperatures rise, their metabolic rate increases, requiring more oxygen to function. However, warmer water holds less dissolved oxygen. This creates a critical imbalance, leading to respiratory stress, reduced growth, and impaired reproduction. In severe cases, this double stressor can lead to mass mortality events, which have been documented for various species, including fish, crabs, and seabirds, especially in the Arctic and subarctic regions (Benthuysen *et al.*, 2020).

Ecosystem Disruption and Food Web Collapse: Heatwaves can trigger a cascade of effects that disrupt entire ecosystems. They are a primary cause of coral bleaching (Fig. 1), where corals expel the symbiotic algae that provide them with energy, leading to starvation and death. Similarly, foundation species like kelp forests and seagrass meadows are highly vulnerable and can collapse, eliminating critical habitats and nurseries for countless fish species. This loss of habitat can reduce biodiversity and biomass. These events also alter the base of the food web, with shifts in plankton communities that can negatively affect higher trophic levels, leading to a major disruption in energy transfer and the collapse

of fisheries (Agarwal *et al*., 2024).

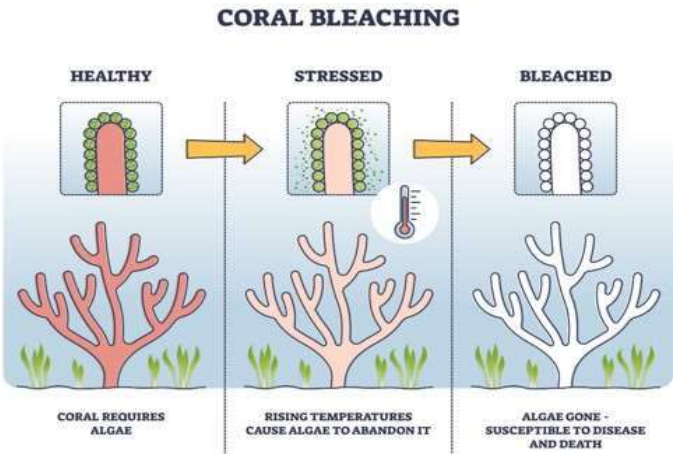

Fig. 1: Illustrated the process of coral bleaching

Changes in Species Distribution and Behaviour: As water temperatures increase, mobile species like fish are forced to migrate in search of cooler waters, a phenomenon known as poleward migration or "thermal displacement." This can cause a dramatic and rapid shift in the geographic range of fish stocks, sometimes over hundreds of kilometres in a matter of months. While this might lead to the emergence of new fisheries in previously cooler areas, it can devastate traditional fisheries that depend on species that have moved or disappeared from their historic grounds. These shifts create significant management challenges and can lead to a collapse in local economies (Bai *et al.*, 2020).

Increased Vulnerability to Disease and Harmful Algal Blooms (HABs): Warmer water temperatures weaken the immune systems of fish, making them more susceptible to parasites and diseases. Furthermore, heatwaves can trigger the proliferation of harmful algal blooms, which can produce toxins that contaminate seafood and pose a risk to human health. As these blooms decompose, they consume vast amounts of dissolved oxygen, creating "dead zones" that are uninhabitable for marine life and can lead to further mass mortality (He *et al*., 2024).

Socio-Economic Consequences

Aquatic heat waves have severe socio-economic consequences for fisheries, impacting everything from the profitability of the industry to the food security and livelihoods of coastal communities. These effects are a direct result of the ecological damage caused by extreme thermal events (Fig. 2).

Economic Losses and Job Insecurity: The most immediate socio-economic impact is a significant economic downturn for the fishing industry. Heat waves can lead to widespread fish die-offs and habitat destruction, causing a sharp decline in fish stocks. This forces governments to impose fishery closures or reduce catch quotas to allow populations to recover. A single marine heat wave can lead to massive losses, with one study estimating a single event's direct losses at over US$800 million, with additional, substantial indirect losses (Smith *et al.*, 2021). The closure of the Pacific cod fishery in the Gulf of Alaska in 2020 and the collapse of the scallop fishery in Western Australia in 2011 are stark examples of the financial ruin that can be wrought by these events. This economic fallout directly affects the livelihoods of fishers, processors, and all associated industries. Job insecurity and unemployment rise, particularly in regions that are heavily dependent on fisheries for their economic stability.

Disruption of Supply Chains and Food Security:

The decline in fish stocks and closure of fisheries can disrupt local, national, and even global seafood supply chains. Reduced supply leads to higher prices, making seafood less accessible and affordable for consumers. This can pose a significant threat to food security, especially in developing nations where a large portion of the population relies on fish as a primary source of protein.

Fig. 2: Aquatic heatwaves: impacts on fisheries

Management Challenges and Unpredictability: Heat waves introduce a new level of unpredictability for fisheries managers. The events are often sporadic and intense, making it difficult to set sustainable fishing quotas and develop long-term management plans. Species that shift their range in response to warming waters may move into new jurisdictions, leading to disputes over fishing rights and creating a need for new international cooperation and management agreements. Furthermore, the damage to infrastructure from extreme weather events, which are often linked to heat waves, can further hinder fishing operations and recovery efforts.

Impacts on Aquaculture: The aquaculture sector is also highly vulnerable. Fish farms are often located in specific, sheltered areas that are particularly susceptible to warming. Heat waves can lead to mass mortalities in farmed fish, as seen with salmon farms in Chile due to harmful algal blooms, causing significant financial losses. The industry must invest in costly adaptation measures, such as advanced aeration systems or relocating stock, to mitigate these risks.

Adaptation Strategies for Fisheries

Ecological and Technological Approaches: Developing ecological and technological solutions is a key pathway to reduce the vulnerability of fisheries to heat waves. Early warning systems, particularly satellite-based monitoring of sea surface temperatures (Yadav *et al.*, 2025), can provide timely forecasts of marine heatwaves (MHWs) and allow for preventive actions. Protecting and restoring critical habitats such as mangroves, seagrass beds, and wetlands helps buffer aquatic ecosystems from extreme thermal fluctuations. In aquaculture, selective breeding of heat-tolerant strains, such as genetically improved tilapia and carp, is showing promise in enhancing resilience. Similarly, water management innovations, including pond aeration and shading structures, can help maintain thermal balance and reduce mortality during heat stress events.

Fisheries Management Strategies: Adaptive management is vital for sustainable fisheries under changing climate conditions. Adjusting fishing quotas and implementing seasonal closures in line with heatwave forecasts can reduce pressure on

vulnerable stocks. Diversification of target species toward those more resilient to higher temperatures can stabilize catches and income for fishers. In areas severely affected by stock collapse, restocking and hatchery programs play an important role in rebuilding populations and sustaining local fisheries.

Policy and Governance Measures: At the policy level, integrating climate-related risks into national fisheries frameworks is essential for long-term resilience. Climate-resilient policies should account for the ecological and socio-economic impacts of heat waves. Insurance schemes can provide a safety net for small-scale fishers whose livelihoods are at risk from sudden losses. At the global scale, international cooperation through regional fisheries bodies, such as the Indian Ocean Tuna Commission, is necessary to coordinate adaptive responses and incorporate climate change projections into shared resource management.

Research Gaps and Future Directions: Despite these advances, critical research gaps remain. Long-term data on recurring heatwave impacts are scarce, limiting the ability to understand cumulative effects on fisheries and ecosystems. Species-specific responses also require further study, as tolerance thresholds vary greatly among species and life stages. A stronger integration of socio-economic models with ecological forecasts is needed to assess the vulnerability of fishing-dependent communities more effectively. Finally, innovation in aquaculture systems such as cooling technologies, recirculating aquaculture systems (RAS) and bio floc-based methods offers significant opportunities to enhance resilience but requires greater research investment and policy support.

Conclusion

Heat waves are emerging as one of the most pressing climate-related threats to fisheries world-wide. Their ecological effects ripple through aquatic food webs, while their socio-economic consequences endanger the livelihoods and nutrition of millions. Addressing these challenges requires an integrated approach that combines science, technology, governance and community resilience. Strengthening early warning systems, promoting adaptive fisheries management, investing in climate-smart aquaculture, and empowering vulnerable fishing communities are critical steps toward building resilience. Only through proactive adaptation can fisheries continue to play their pivotal role in food security and sustainable development in a warming world.

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The Role of Pollinators in Crop Production

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Abstract

Pollination, as a determinant in agriculture and food security, has historically received little attention and appreciation, in part because it is provided by nature at no explicit expense to human populations. Pollination services are declining around the world as farm fields expand in size and pesticides that harm beneficial insects, such as pollinators, as well as plant pests, are used more frequently. Pollination is crucial for agricultural production, and both insect- and wind-based pollination systems are being affected by asynchrony in flowering, meteorological events, and a high demand for insect pollinators. In agricultural ecosystems, pollinator diversity increases the quality and quantity of crop yield.

Introduction

Pollination is the transfer of pollen from the male parts (anthers) of a flower to the female parts (stigma) of another, or the same, flower. This enables plants to reproduce sexually, resulting in the production of seeds and fruits. Pollinators are critical to the sustainability of global agriculture because they fertilize blooming plants, allowing for fruit and seed production. However, not all plants require pollinators. Some rely on wind or water, but the great majority, including most of the food crops we consume, rely on pollinators like bees, butterflies, birds and other insects, emphasizing their importance in food security and ecosystem resilience. Native or wild pollinators can also play a role, as long as steps are taken to stop population declines caused by unintentional pesticide poisoning and habitat damage. This technique includes improving our understanding of the biology and ecology of pollinating insects, providing optimal nesting habitat, and assuring the availability of alternate sources of "forage" to support populations when the target crops are not in bloom (Kevan *et al.*, 1990).

Pollinators' Ecological and Agricultural Role

Pollination is critical to the functioning of ecosystems. Many plants rely on pollinators not only for reproduction but also for the health of their populations. Wild fruits, seeds, and nuts, which in turn support countless species of animals, all rely on this invisible service.

From an agricultural perspective, pollination is one of the cornerstones of global food production. According to the Food and Agriculture Organization

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(FAO), approximately 75% of flowering plants rely on animals for pollination. In fact, 35% of the world's food crops, including fruits, nuts, and vegetables, are dependent on animal-mediated pollination. Crops like almonds, coffee, apples, and blueberries all rely on these creatures to thrive. However, worldwide production quantities provide a different picture, since 60% of global output comes from crops that do not rely on animal pollination, 35% from crops that rely on pollinators, and 5% is unevaluated. Pollinators are critical for 13 crops; output is very pollinator-dependent for 30, moderately for 27, somewhat for 21, minor for 7, and of unclear value for the other 9 (Klein *et al.*, 2007). They are responsible for pollinating an estimated 75% of the major crops worldwide, including fruits, vegetables, nuts, and seeds. Insect pollination increased average crop yields by 18% to 71%, depending on the crop species. It also improved yield quality in most cases. For example, in oilseed rape, adequate pollination led to higher oil content and reduced chlorophyll levels; in buckwheat, it decreased the proportion of empty seeds; and in strawberries, it enhanced their commercial grade (Bartomeus *et al.*, 2014). According to a Science Daily news article on September 15, 2008, researchers have estimated that the global economic value of pollination services provided primarily by insect pollinators, especially bees, was approximately €153 billion in 2005 for the world's major food crops. This represented about 9.5% of the total value of global agricultural food production.

The study further indicated that the loss of pollinators could result in a reduction of consumer surplus ranging from €190 to €310 billion. A similar study also suggested that Wild bees and managed honeybees contributed similarly to pollination across most crops, including those in regions of intensive agriculture. The nationwide annual production value attributed to wild pollinators for the seven crops examined was estimated at over $1.5 billion, with the overall economic contribution of wild bees to all pollinator-dependent crops expected to be substantially higher (Reilly *et al.*, 2020). Hence, it is clear that the economic impact is staggering. The economic worth of such insects for pollination, seed establishment, and fruit creation far surpasses that suggested by more conventional indices, such as the value of honey and wax generated by bees.

The Decline of Pollinators: A Crisis in the Making

Unfortunately, pollinators are facing a multitude of threats, and their populations are in steep decline. Habitat loss due to urbanization, agricultural expansion, and deforestation is one of the biggest challenges. Modern farming practices, particularly monocropping and the extensive use of pesticides, also contribute to pollinator decline. These chemicals can be toxic to bees and other pollinators, disrupting their ability to forage and reproduce. Climate change is another emerging threat, altering the availability of flowers, changing migration patterns, and making weather conditions less predictable. Warmer temperatures may disrupt the timing of plant blooming, leaving pollinators and

flowers out of sync. In some parts of the world, diseases and parasites are also taking a toll. The varroa mite, a parasite that feeds on honeybees, has decimated entire colonies, while a range of pathogens can infect pollinators and further weaken their populations. Several measures can be implemented to safeguard pollinators, including the conservation and restoration of their natural habitats, reduction in pesticide usage, adoption of sustainable agricultural practices, and enhancement of public awareness regarding their ecological significance.

Conclusion

As we face growing environmental challenges, the importance of pollinators cannot be overstated. They not only play an essential role in the survival of plants but also in ensuring that humans and countless other species have food, clean air, and healthy ecosystems. The conservation of pollinators is fundamental to maintaining ecological balance and ensuring long-term agricultural sustainability. Proactive efforts to protect these species are essential for securing global food security and supporting future generations. By protecting pollinators, we not only safeguard biodiversity but also nurture the web of life that sustains our planet. So, the next time you spot a bee hovering over a flower, take a moment to appreciate the quiet work being done and remember, these tiny creatures are far from ordinary. They are, quite literally, the architects of the natural world.

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Smart Farming Revolution: How AI and Robotics are Transforming Agriculture

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Abstract

The integration of artificial intelligence (AI) and robotics in agriculture is transforming traditional farming practices and ushering in a new era of precision and efficiency. This paper explores how advanced technologies such as autonomous machinery, robotic harvesters, AI-powered crop monitoring, and automated weed control are addressing critical challenges in modern agriculture, including labor shortages, resource optimization, and environmental sustainability. By enhancing decision-making, reducing manual labor, and promoting eco-friendly practices, AI and robotics offer significant benefits in terms of productivity, cost-effectiveness, and sustainability. Despite challenges such as high initial investment, technical skill requirements, and data privacy concerns, the future of AI and robotics in agriculture remains highly promising. Continued innovation and adoption of these technologies will be key to meeting global food demands and ensuring a resilient, sustainable agricultural sector.

Integration of AI and Robotics in Farming Transforming Agriculture for the Future

In recent years, the integration of artificial intelligence (AI) and robotics in agriculture has been revolutionizing traditional farming practices. The adoption of advanced technologies such as autonomous machinery, AI-driven analytics, and robotic harvesters is reshaping the agricultural landscape, offering innovative solutions to challenges like labor shortages and resource optimization.

The Role of AI and Robotics in Modern Farming

AI-powered systems and robotics are playing a significant role in enhancing efficiency and productivity in agriculture. Some of the key areas where these technologies are making an impact include:

Autonomous Machinery: Self-driving tractors and robotic planters are reducing human dependency while ensuring precision in farming operations. These machines use GPS, machine learning, and real-time data analysis to navigate fields, optimize seeding, and improve overall efficiency.

Robotic Harvesters: Traditional harvesting methods require extensive manual labor, which is becoming increasingly scarce and costly. Robotic harvesters, equipped with AI and computer vision, can identify ripe crops, pick them efficiently, and reduce post-harvest losses.

AI-Powered Crop Monitoring: AI-driven drones and sensors collect real-time data on crop health, soil conditions and pest infestations. These insights allow

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farmers to make informed decisions, applying fertilizers and pesticides more accurately and reducing environmental impact.

Precision Farming: AI algorithms analyze weather patterns, soil health, and crop requirements to provide precise recommendations for irrigation, fertilization and pest control. This approach maximizes yield while minimizing waste and resource usage.

Automated Weed Control: AI-enabled robotic weeders can distinguish between crops and weeds, targeting only unwanted plants. This reduces the need for chemical herbicides, promoting eco-friendly farming practices.

Advantages of AI and Robotics in Agriculture

The integration of AI and robotics in farming presents numerous benefits:

Increased Efficiency: Automated machines operate continuously, increasing productivity while reducing manual labor.

Cost Savings: While initial investments may be high, long-term savings on labor and resource optimization outweigh the costs.

Enhanced Precision: AI algorithms minimize errors, ensuring that fertilizers, pesticides, and water are used in optimal quantities.

Sustainability: AI-driven solutions reduce environmental impact by promoting efficient use of water, energy, and chemicals.

Challenges and Future Prospects

Despite its promising potential, the adoption of AI and robotics in farming faces several challenges:

High Initial Investment: Advanced machinery and AI-powered tools require significant upfront costs, which may be a barrier for small-scale farmers.

Technical Expertise: Farmers need training and technical knowledge to operate and maintain these sophisticated systems.

Data Privacy Concerns: The collection and storage of agricultural data raise concerns about data security and ownership.

Looking ahead, the future of AI and robotics in farming appears promising. Advancements in AI-driven analytics, machine learning, and the Internet of Things (IoT) will continue to enhance precision agriculture, making farming more efficient, profitable and environmentally sustainable.

Conclusion

The integration of AI and robotics in agriculture is not just a trend; it is a necessity for meeting the increasing global food demand. As technology evolves, the agricultural sector must embrace these innovations to enhance productivity, reduce costs, and promote sustainable farming practices. By leveraging AI and robotics, farmers can pave the way for a smarter and more resilient agricultural future.

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Modern World Protein: Disadvantages and Competitive Solutions

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Introduction

India is a major agricultural nation, but with high levels of production comes the challenge of handling organic waste. Each year, large volumes of crop residues, food waste, and animal manure go unutilized. When left to decompose in open areas or landfills, this waste emits greenhouse gases such as methane and carbon dioxide, driving global warming. In recent years, the Black Soldier Fly (BSF) has gained attention as an innovative solution. Its larvae can effectively convert organic waste into useful resources, including protein for livestock feed, organic fertilizer, and potential energy sources.

Black Soldier Fly and its Applications

The Black Soldier Fly (*Hermetia illucens*) is a non-pest species that poses no threat to humans, as it neither bites nor transmits diseases like the common housefly. This makes it highly suitable for large-scale applications in organic waste management. The most remarkable stage of its life cycle is the larval phase, during which the larvae exhibit an extraordinary appetite for organic waste. They can consume and process food scraps, animal manure, and agricultural residues at a rapid rate, transforming these low-value materials into high-quality, nutrient-dense biomass within just a few weeks. This efficiency addresses two major challenges simultaneously reducing the burden of waste accumulation and generating valuable resources.

The versatility of the Black Soldier Fly's applications is one of its greatest strengths. Its larvae are widely recognized as a sustainable, protein-rich alternative to conventional animal feed ingredients such as fishmeal and soybean meal. By offering a circular, waste-to-protein solution, BSF farming helps meet the rising global demand for livestock and aquaculture feed while minimizing pressure on land and marine ecosystems. In addition, the by-product of larval processing, known as frass, is a nutrient-rich fertilizer that improves soil structure, enhances microbial activity, and promotes sustainable agriculture without relying on synthetic chemicals. Beyond feed and fertilizer, BSF products hold promise in renewable energy and biotechnological innovations. The fats present in BSF larvae can be extracted and refined into biodiesel, opening pathways for sustainable energy production that reduces dependency on fossil fuels. Furthermore, the insect's exoskeleton contains chitin, a natural polymer with broad applications. Chitin and its derivative, chitosan, are highly valued in various industries including pharmaceuticals, wound healing, food packaging, and biotechnology due to their

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antimicrobial and biodegradable properties.

Advantages

BSF farming is increasingly recognized because it:

- ✓ Helps reduce organic waste that would otherwise pollute the environment.

- ✓ Requires significantly less land and water than conventional protein sources like soybean or fishmeal.
- ✓ Produces protein with a good balance of amino acids, along with nutrient-rich fertilizer.
- ✓ Becomes cost-effective after initial setup.
- ✓ Supports a circular economy by converting waste into useful resources.

Disadvantages

Despite its benefits, BSF farming faces several challenges:

Competition with houseflies: If waste management is poor, housefly larvae may compete with BSF larvae, reducing efficiency.

Market acceptance: Many farmers and consumers are hesitant to use insect-based products; regulatory restrictions and short shelf life of fresh larvae make marketing difficult.

High initial investment: Setting up controlled rearing systems requires funds that small-scale farmers may find prohibitive.

Disease risks: Weak biosecurity can lead to outbreaks, causing losses in larval production.

Competitive Solutions

To address these challenges, researchers and industries are implementing several solutions:

Animal feed development: Dried BSF meal contains essential amino acids and is highly digestible, making it a viable alternative to fishmeal and soybean meal.

Biodiesel and cosmetic applications: The fat from prepupal larvae can be processed into biodiesel or refined for use in skincare and cosmetics.

Chitin-based products: Larval exoskeletons are a source of chitosan, which has applications in water treatment, food packaging, and medicine.

Economic potential: With increasing global demand for animal feed, BSF products are likely to capture a significant market share. Policy support, improved infrastructure, and awareness campaigns can further encourage adoption.

Conclusion

The Black Soldier Fly provides a novel solution for addressing both waste management and sustainable protein needs. Through the conversion of organic waste into animal feed, fertilizer, and valuable industrial materials, BSF farming not only safeguards the environment but also generates economic benefits. While challenges such as high initial investment, low awareness, and potential disease risks persist, these can be overcome with advancements in technology, supportive policies, and farmer education. With effective promotion, BSF farming holds strong potential to become a key component of sustainable agriculture in the coming years.

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Integrated Farming System for Improving Sustainable Agriculture

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Abstract

The Integrated Farming System (IFS) represents a holistic and sustainable approach to agriculture that seeks to optimize the use of available resources by integrating various agricultural components such as crop cultivation, livestock rearing, aquaculture, agroforestry, and agro-processing within a single farm unit. This system aims to enhance productivity, profitability, and ecological balance while minimizing waste and external inputs. In the face of growing environmental concerns, climate change, and resource constraints, IFS offers a viable solution to improve food security and the livelihoods of small and marginal farmers. This article explores the fundamental principles of IFS, its major components, benefits, challenges, and real-world applications. Through an in-depth analysis, it underscores the potential of IFS to transform traditional farming into a more resilient, efficient, and sustainable agricultural model that aligns with long-term ecological and socio-economic goals.

Introduction

Integrated Farming System (IFS) is an ecologically sustainable and economically viable farming approach that integrates multiple agricultural activities to optimize resource utilization and enhance productivity. It involves the combination of crop production, livestock rearing, aquaculture, agroforestry, and agro-processing within a single farming unit, creating a diversified and resilient agricultural system. IFS plays a crucial role in advancing sustainable agriculture by harmonizing ecological balance, economic viability, and social equity. The interconnected nature of IFS enables farmers to maximize the productivity of their land while minimizing waste and dependency on external inputs.

Principles of IFS

The foundation of IFS is built on several core principles that guide its structure and implementation:

Resource Optimization and Recycling

- ✓ Efficient use of on-farm resources (soil, water, labor, biomass)
- ✓ Reuse of by-products and waste materials
- ✓ Example: Cow dung used in biogas plants; slurry used as fertilizer.

Diversification of Enterprises

- ✓ Integration of multiple agricultural activities to spread risk and increase income
- ✓ Reduces dependency on a single source of income
- ✓ Example: If crops fail due to drought, income from poultry or dairy supports the household.

Sustainability and Environmental Protection

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- ✓ Conservation of natural resources (soil, water, biodiversity)
- ✓ Use of organic inputs and eco-friendly practices
- ✓ Reduces the ecological footprint and enhances long-term productivity.

Economic Viability and Risk Reduction

- ✓ Multiple income streams ensure financial stability.
- ✓ Protection against market and climate fluctuations.
- ✓ Helps farmers remain economically resilient in uncertain conditions.

Nutritional Security

- ✓ Produces a variety of food items: cereals, pulses, milk, eggs, fruits, fish, etc.
- ✓ Ensures a balanced diet for farm families
- ✓ Supports better health and reduces reliance on external food sources.

Adaptability to Local Conditions

- ✓ Tailoring the system to the region's climate, soil, water availability, and socio-economic context
- ✓ E.g., Rice-fish-vegetable systems in Eastern India; agro-silvi-pastoral systems in arid zones.

Employment Generation

- ✓ Labor-intensive model that provides year-round employment.
- ✓ Involvement of women and youth in diverse activities.
- ✓ Promotes rural livelihood development.

Importance of IFS for Improving Sustainable Agriculture

Resource Optimization and Waste Recycling: IFS ensures efficient utilization of available resources land, water, energy, and nutrients. By integrating livestock, fishery, crops, and trees, by-products from one component (like animal dung or crop residues) serve as inputs for another (such as organic fertilizer or animal feed), thus minimizing waste and promoting closed-loop farming.

Enhanced Productivity and Income: Combining multiple agricultural activities allows farmers to diversify their income sources. While monoculture farming often relies on a single harvest, IFS provides steady revenue from various products like milk, eggs, fish, vegetables, and timber. This not only increases overall farm productivity but also ensures financial stability for smallholders.

Soil Fertility and Health Improvement: IFS improves soil health by reducing the dependency on chemical fertilizers and encouraging organic farming practices. The use of compost, green manures, and animal waste enriches the soil with nutrients, increases microbial activity, and helps prevent soil degradation and erosion.

Biodiversity Conservation: By involving multiple crops, trees, and animal species, IFS fosters biodiversity on the farm. This biodiversity acts as a natural buffer against pests, diseases, and climate extremes, making the system more resilient and reducing the need for synthetic pesticides and herbicides.

Climate Change Mitigation and Adaptation: IFS contributes to climate resilience by diversifying production systems. If one component fails due to

weather events or market fluctuations, others may continue to support the farm. Additionally, practices like agroforestry and organic farming help sequester carbon, reduce greenhouse gas emissions, and improve the farm's ability to adapt to changing climatic conditions.

Employment and Livelihood Security: IFS generates year-round employment opportunities through its multiple activities. It also reduces migration by engaging rural populations in productive agricultural enterprises. This is especially significant in developing countries where agriculture supports a large proportion of the population.

Sustainable Food and Nutritional Security: By producing a variety of food products cereals, pulses, fruits, vegetables, milk, meat, and fish IFS enhances the availability of diverse and nutritious food. This helps address malnutrition and promotes food security at both household and community levels.

Reduction in External Input Dependency: IFS reduces farmers' dependency on costly inputs like synthetic fertilizers, pesticides, and feed. The internal cycling of resources minimizes costs and enhances the self-reliance of farm families, making agriculture more economically and ecologically sustainable.

Components of IFS for Improving Sustainable Agriculture

IFS is a diversified and synergistic farming approach that combines multiple agricultural enterprises on a single farm to increase productivity, profitability, and sustainability. Each component of IFS is carefully selected based on local agro-climatic conditions, available resources, and the socio-economic context of the farmer. These components interact with each other in a mutually supportive way, ensuring efficient resource use and ecological balance. Below are the major components of IFS:

Crop Production: Crop cultivation is the core of any IFS model. Multiple cropping systems such as intercropping, crop rotation, relay cropping, and mixed cropping are practiced to improve soil fertility, reduce pests and diseases, and ensure continuous income and food supply. Crops typically include:

- ✓ Cereals (rice, wheat, maize)
- ✓ Pulses (lentil, chickpea)
- ✓ Oilseeds (mustard, sunflower)
- ✓ Vegetables and fruits

Sustainability Impact: Enhances soil structure, diversifies food production, and reduces dependency on single crops.

Livestock Rearing: Livestock such as cattle, buffalo, goats, sheep, poultry, and pigs are integrated to provide milk, meat, eggs, manure, and draft power. Manure from animals is used as organic fertilizer in crop fields, reducing the need for synthetic inputs.

Sustainability Impact: Promotes nutrient recycling, improves farm income, and provides high-quality protein to households.

Aquaculture (Fish Farming): Fish culture is integrated into the farming system, particularly in areas with sufficient water resources or low-lying

lands. Common models include fish-cum-duck farming, fish-cum-paddy cultivation, or fish-cum-horticulture.

Sustainability Impact: Enhances protein availability, utilizes water resources efficiently, and diversifies income sources.

Agroforestry: Agroforestry involves growing trees and shrubs alongside crops and animals. Tree species are selected for their benefits such as providing fodder, fuelwood, timber, fruits, or improving soil fertility through nitrogen fixation (e.g., Leucaena, Gliricidia).

Sustainability Impact: Prevents soil erosion, improves carbon sequestration, enhances biodiversity and offers additional income.

Horticulture: Horticultural crops such as fruits, vegetables, spices, and medicinal plants are cultivated to increase farm diversity and income. Kitchen gardens or backyard horticulture is also common in small-scale IFS models.

Sustainability Impact: Improves nutritional security, generates additional income, and uses small land parcels effectively.

Vermicomposting and Organic Waste Management: Organic waste from crops and livestock is converted into compost or vermicompost. This organic manure enriches the soil with nutrients and beneficial microorganisms.

Sustainability Impact: Enhances soil fertility, reduces chemical fertilizer use, and manages farm waste sustainably.

Mushroom Cultivation: Mushrooms are cultivated using agricultural waste like straw, husk, and compost. They are a rich source of protein and can be grown in controlled environments.

Sustainability Impact: Provides nutritional food, utilizes waste, and generates high returns from low investment.

Beekeeping (Apiculture): Beekeeping supports crop pollination and provides honey and other products like beeswax. It is especially beneficial in horticultural-based IFS.

Sustainability Impact: Enhances pollination and crop yields, contributes to biodiversity, and provides income with minimal land use.

Biogas Production: Biogas units convert animal dung and organic waste into clean fuel and slurry. The slurry is used as an organic fertilizer.

Sustainability Impact: Provides renewable energy, reduces dependence on firewood and fossil fuels, and adds value to farm waste.

Poultry and Duck Rearing: Small-scale poultry or duck farming is often integrated into crop-livestock systems. They provide eggs, meat, and manure, and can be raised in backyard spaces.

Sustainability Impact: Offers quick returns, requires low investment, and complements crop and fish systems.

Contribution of IFS to Food and Nutritional Security

Production of Diverse Food Commodities

- ✓ IFS includes a wide range of enterprises: cereals, pulses, vegetables, fruits, milk, eggs, fish, and meat.

- ✓ This ensures availability of energy (carbo-hydrates), body-building nutrients (proteins), and protective foods (vitamins and minerals).
- ✓ Example: A farm integrating vegetables, dairy, and poultry can provide cereals, milk, eggs, and leafy greens for household consumption.

Year-Round Food Availability

- ✓ Different enterprises have varied harvesting or production cycles.
- ✓ Ensures a continuous supply of food throughout the year, reducing seasonal food insecurity.
- ✓ Example: Vegetables harvested in 30-60 days, eggs and milk produced daily, fruits seasonally.

Reduction in Food Expenditure

- ✓ On-farm production of diverse food items reduces the need to purchase food from the market.
- ✓ Enhances self-reliance and saves income for other household needs.

Improved Household Nutrition

- ✓ Promotes consumption of balanced and nutrient-rich diets at the household level.
- ✓ Reduces malnutrition, especially among women and children in rural areas.
- ✓ A balanced plate with rice, dal, vegetables, curd, and boiled egg can be supported by a typical IFS.

Income Generation for Food Access

- ✓ Diversified enterprises increase farm income, allowing farmers to purchase additional nutritious food not produced on the farm.
- ✓ Economic access to food is a key component of food security.

Resilience to Climate and Market Fluctuations

- ✓ In times of crop failure or price crashes, other components (e.g., poultry, dairy, fish) help ensure food availability and income.
- ✓ Enhances household-level food security under stress conditions.

Opportunities for Value Addition

- ✓ Surplus produce (milk, vegetables, fruits) can be processed into cheese, pickles, or juices for both household consumption and sale.
- ✓ Increases shelf-life and nutrient retention.
- ✓ Broader Impact on Community Nutrition
- ✓ Community-level IFS models can supply mid-day meal programs, local markets and cooperative nutrition programs.
- ✓ Can reduce local hunger and malnutrition by making nutritious food available and affordable.

Benefits of Integrated Farming System

Enhanced Resource Use Efficiency

- ✓ Utilizes resources like land, water, labor, and nutrients more efficiently by recycling waste from one component to another.
- ✓ Reduces dependency on external inputs (e.g., fertilizers, feed, pesticides).
- ✓ Example: Crop residues can feed livestock; livestock manure can fertilize crops or fish ponds.

Increased Farm Income and Profitability

- ✓ Diversified sources of income reduce financial risk.
- ✓ Better use of vertical and horizontal space allows for multiple enterprises (e.g., poultry under trees,

fish in rice fields).

- ✓ Multiple revenue streams buffer farmers against price drops or crop failure.

Improved Soil Fertility and Health

- ✓ Organic recycling (manure, compost, crop residues) improves soil structure and microbial activity.
- ✓ Reduces dependence on chemical fertilizers.

Reduced Environmental Impact

- ✓ Minimizes waste and pollution through nutrient cycling.
- ✓ Lower greenhouse gas emissions compared to intensive monoculture systems.
- ✓ Promotes biodiversity.

Climate Resilience

- ✓ Diversification reduces vulnerability to climate shocks like drought, floods, or pest outbreaks.
- ✓ Systems are more adaptive due to varied crops and enterprises.

Food and Nutritional Security

- ✓ Produces a variety of foods (grains, vegetables, milk, eggs, fish), improving household nutrition.
- ✓ Enhances year-round food availability.

Employment Generation

- ✓ Labor-intensive activities create on-farm jobs.
- ✓ Supports rural livelihoods, especially for small and marginal farmers.

Sustainable Water Management

- ✓ Integrated systems like rice-fish or agroforestry reduce water usage and increase retention.
- ✓ Promotes rainwater harvesting and efficient irrigation.

Pest and Disease Control

- ✓ Biodiversity in IFS reduces pest and disease incidence compared to monocultures.
- ✓ Integrated Pest Management (IPM) becomes more effective.

Women Empowerment and Social Inclusion

- ✓ Diversified activities (e.g., dairy, poultry, kitchen gardening) provide opportunities for women's involvement and income generation.

Challenges in Implementing Integrated Farming System

Lack of Awareness and Technical Knowledge

- ✓ Many farmers are not familiar with IFS concepts or how to integrate multiple enterprises effectively.
- ✓ Limited access to training and agricultural extension services hinders adoption.
- ✓ Poor understanding of the ecological interactions between different components (e.g., fish-livestock-crop systems).

Initial Investment and Financial Constraints

- ✓ Establishing an IFS requires upfront investment in infrastructure (e.g., livestock housing, fish ponds, compost units).
- ✓ Small and marginal farmers often lack access to credit or subsidies.
- ✓ Returns are long-term, which can deter farmers with immediate income needs.

Land Fragmentation and Size Limitations

- ✓ Fragmented or small landholdings restrict the diversification of enterprises.
- ✓ Urbanization and population growth further

reduce the available land per household.

Labor Requirements

- ✓ IFS is labor-intensive, requiring continuous attention and diverse skill sets.
- ✓ Migration of rural labor to urban areas limits workforce availability in agriculture.

Market Access and Infrastructure

- ✓ Inadequate market linkages for diversified produce like fish, dairy, or vegetables.
- ✓ Poor rural infrastructure (roads, cold storage, transportation) increases post-harvest losses.
- ✓ Lack of value addition facilities reduces potential income.

Policy and Institutional Barriers

- ✓ Existing policies often promote monoculture or single-enterprise subsidies (e.g., only for paddy or wheat).
- ✓ Fragmented governance across agriculture, fisheries, and livestock departments complicates integration.
- ✓ Weak extension systems limit technology transfer.

Climate and Environmental Constraints

- ✓ Climate variability (drought, floods, temperature extremes) can disrupt multiple components of the system simultaneously.
- ✓ Mismanagement can lead to environmental issues like nutrient leaching, water contamination, or disease spread among components.

Cultural and Behavioral Resistance

- ✓ Traditional practices and resistance to change can limit adoption.
- ✓ Social norms or taboos may restrict certain activities, like pig or fish farming, in some communities.

Monitoring and Evaluation Difficulties

- ✓ Measuring the effectiveness and productivity of complex, multi-component systems is difficult.
- ✓ Lack of standardized metrics and data collection tools for assessing IFS performance.

Research Gaps

- ✓ Limited localized research on optimal combinations of IFS components suitable for specific agro-climatic zones.
- ✓ Lack of demonstration models and pilot programs in many regions.

Conclusion

The Integrated Farming System (IFS) represents a comprehensive and sustainable approach to agriculture that aligns ecological balance with economic viability. By strategically combining different agricultural components such as crops, livestock, aquaculture, poultry, agroforestry, and biogas units, IFS creates a synergistic relationship among all elements of the farm. This integration promotes effective resource utilization, waste recycling, income diversification, and resilience against environmental stresses, making it a vital model for achieving sustainable agriculture. In conclusion, the Integrated Farming System offers a promising pathway toward sustainable agricultural development. It not only enhances productivity and profitability but also ensures environmental sustainability, food and nutritional security, and rural

empowerment. With appropriate policy support, training, and infrastructure, IFS can transform smallholder farms into resilient and self-sufficient units contributing significantly to national and global goals of sustainable agriculture and rural development.

Bee Venom: Composition, Therapeutic Properties and Potential Health Benefits

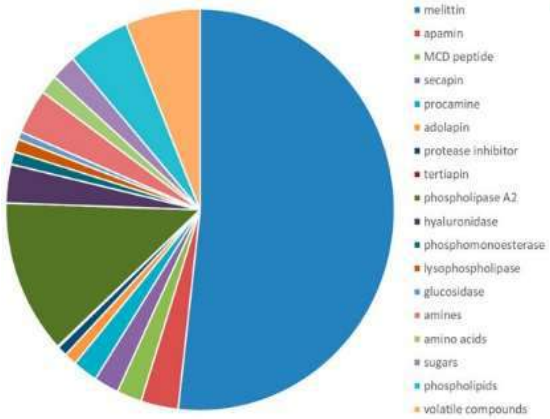
Bharaneedharan, Bharanisankar K. and Elango K.

Introduction

Bee venom (*Apitoxin*) is a natural defensive secretion produced by honeybees. It is a colorless, acidic liquid made up of peptides, enzymes, and small molecules, with Melittin being the most dominant component. When injected through a sting, it causes pain, redness, and inflammation, helping bees protect their colony. Apart from this natural role, bee venom has been widely studied for its potential medicinal uses, including anti-inflammatory, antimicrobial, and anticancer properties.

Bee venom Components

Bee venom is made up of a wide range of biologically active compounds:



Melittin: The most abundant peptide, responsible for pain and inflammation, but also studied for its medicinal properties.

Apamin: A neurotoxic peptide that affects the nervous system.

Phospholipase A2: An enzyme that damages cell membranes and enhances the effects of other venom components.

Hyaluronidase: Known as a "spreading factor" because it increases tissue permeability, helping the venom spread quickly.

Histamine: A small molecule that causes

Melittin

Melittin is the major active component of honeybee (*Apis mellifera*) venom, accounting for about 40-60% of its dry weight.Its biological activity includes the destruction of red blood cells, activation of pain receptors, release of inflammatory cytokines, and modulation of ion channels such as TRPV1 (Transient Receptor Potential Vanilloid 1) and sodium channels, which prolong pain sensations. Melittin has attracted interest for its potential medical uses due to its anti-inflammatory, anti-microbial, and anticancer properties, though its strong toxicity limits direct therapeutic application.

Therapitic Properties: Traditionally, bee venom was used to relieve pain, treat rheumatism, lower blood pressure, and boost immunity, often through direct bee stings or apipuncture, which combines acupuncture with venom. With modern extraction

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methods, bee venom can now be injected into affected areas or acupuncture points. Today, scientific studies continue to explore its therapeutic potential, particularly for anti-inflammatory, antimicrobial, and anticancer applications.

Anticancer Properties: Melittin (MEL) has been shown to inhibit the growth and proliferation of various cancer cells in vitro. Early studies demonstrated that MEL acts as a calmodulin inhibitor, reducing the clonogenic capacity of human leukemia and astrocytoma cells. It also enhances the cytotoxic effects of chemotherapeutic agents, such as bleomycin, in certain blood cell populations. Research indicates that MEL selectively targets cancer cells, sparing normal cells at concentrations that suppress tumor cell growth. This selectivity may be linked to differences in cell membrane binding sites and signaling pathways between normal and malignant cells.

Health Benefits of Bee-Venom

Anti-inflammatory effects: Bee venom, especially melittin, can reduce inflammatory markers such as TNF-α and IL-1β, potentially benefiting conditions like arthritis and certain cancers.

Relief of arthritis symptoms: Clinical studies, including bee-venom acupuncture, have shown symptom relief in rheumatoid arthritis comparable to conventional medications.

Neuroprotective effects: Preliminary research indicates that bee venom may improve motor function and reduce oxidative stress in Parkinson's disease, enhancing the effects of standard treatments.

Skin health and cosmetic applications: Bee venom demonstrates anti-inflammatory, antibacterial, and regenerative properties, improving conditions such as acne, eczema, alopecia, vitiligo, wound healing, and reducing wrinkles.

Immune modulation: Controlled low doses of bee venom can shift the immune system from an inflammatory to an anti-inflammatory state, enhancing immune tolerance while reducing harmful immune responses.

Conclusion

Bee venom is a natural substance produced by honeybees that contains several active compounds, the most important being melittin. Melittin causes pain and inflammation but also has useful properties like reducing swelling, fighting microbes, and showing anticancer effects. Other components such as apamin, phospholipase A2, hyaluronidase, and histamine also play important roles. Traditionally, bee venom was used through stings or apipuncture to treat pain and rheumatism, and today it is studied for treating arthritis, Parkinson's disease, skin problems, and for improving immune health. Overall, bee venom has many possible health benefits, but it must be used carefully because of its strong effects.

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Indian Monsoon: A Lifeline for Agriculture Economy

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Abstract

The Indian monsoon is one of the most significant climatic phenomena in the world, influencing agriculture, water resources, ecosystems and the national economy. Delivering nearly 75% of India's annual rainfall between June and September, the southwest monsoon sustains agriculture, which directly supports over half of the population. The northeast monsoon provides additional rainfall to the southeastern states, especially Tamil Nadu and Andhra Pradesh. The monsoon is governed by factors such as differential heating of land and sea, the Inter-Tropical Convergence Zone (ITCZ), jet streams and orographic barriers like the Himalayas and Western Ghats. Its timely arrival and distribution are critical for food security, hydropower generation, and rural livelihoods. However, the variability of the monsoon often results in droughts, floods and regional disparities. Climate change has further added unpredictability, with changing rainfall intensity and patterns. This article discusses the origin, mechanism, types, regional variations, significance, challenges and adaptation strategies related to the Indian monsoon, highlighting its role as both a blessing and a challenge for sustainable development.

Introduction

The Indian monsoon is one of the most complex and fascinating climatic systems in the world, influencing the rhythm of life across the subcontinent. It is not just a weather phenomenon but a socio-economic driver that determines agricultural output, water availability, rural livelihoods and even the overall GDP of the nation. Stretching from June to September, the southwest monsoon delivers nearly three-fourths of India's annual rainfall, while the northeast monsoon from October to December further supports southeastern states. The timing, intensity, and distribution of these rains have a direct bearing on cropping patterns, irrigation schedules, and food grain production. Historically, Indian civilization has been deeply tied to the monsoon cycle, with ancient texts, folklore, and festivals celebrating its arrival. Economists often describe India as a "monsoon economy," because a good monsoon boosts agricultural productivity, reduces food inflation and strengthens rural demand, whereas a poor monsoon can trigger droughts, affect employment and slow down economic growth. The monsoon also supports renewable energy through hydropower, replenishes groundwater reserves, and sustains rich ecosystems such as wetlands, forests,

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and coastal fisheries. However, the monsoon is also marked by high variability. Delayed onset, uneven distribution, or excessive rainfall often leads to floods, crop losses and infrastructure damage. With the growing influence of climate change, extreme weather events like cloudbursts, urban flooding and prolonged dry spells have become more frequent, making the monsoon increasingly unpredictable. Therefore, a deeper understanding of its mechanism, coupled with effective adaptation strategies, is essential for ensuring food security, climate resilience, and sustainable development in India.

Origin and Mechanism of the Monsoon

The Indian monsoon is a result of the interaction between land, ocean, and atmospheric systems, making it one of the most complex climatic phenomena in the world. Its mechanism can be explained through the following key factors:

Differential Heating of Land and Sea: During summer, the Indian subcontinent heats up much faster than the surrounding Indian Ocean. This leads to the formation of a strong low-pressure area over northwest India and the Tibetan Plateau, while the ocean remains relatively cooler with high pressure. The pressure difference causes moisture-laden winds from the Indian Ocean to rush toward the landmass, initiating the monsoon.

Inter-Tropical Convergence Zone (ITCZ) Movement: The ITCZ, also known as the monsoon trough, is a belt of low pressure where trade winds from both hemispheres converge. In summer, this zone shifts northwards towards the Tropic of Cancer, pulling the southeast trade winds across the equator. Due to the Coriolis effect, these winds get deflected and enter the Indian subcontinent as southwest monsoon winds.

Jet Streams: Jet streams play a critical role in monsoon dynamics. The Tropical Easterly Jet (TEJ) strengthens during the summer, helping the southwest monsoon establish and intensify. On the other hand, the Subtropical Westerly Jet (STWJ) retreats northwards in summer and returns southwards during winter, influencing the withdrawal of the monsoon.

Orographic Influence: Mountain ranges significantly impact rainfall distribution. The Western Ghats force moist winds from the Arabian Sea to rise, causing heavy rainfall on the windward side, while creating a rain shadow region on the leeward side (Deccan Plateau). Similarly, the Himalayas block the northward movement of moist winds, causing widespread rainfall in northern India and preventing the winds from escaping into Central Asia.

Types of Monsoons in India

India experiences two major monsoon systems:

Southwest Monsoon (June-September)

- ✓ Contributes nearly 75-80% of India's annual rainfall.
- ✓ Sets in by early June over Kerala and gradually advances northward to cover the whole country by mid-July.
- ✓ Two branches are observed:
  - **Arabian Sea Branch:** Strikes the Western Ghats, giving heavy rainfall to the west coast.

- **Bay of Bengal Branch:** Moves toward the northeast, giving rainfall to West Bengal, Bihar, and northeastern states, later merging over the Indo-Gangetic plains.

✓ Responsible for the success of *Kharif* crops like rice, maize, pulses, and oilseeds.

Northeast Monsoon (October-December)

✓ Occurs after the withdrawal of the southwest monsoon.

✓ Winds blow from the northeast, picking up moisture from the Bay of Bengal.

✓ Provides rainfall to Tamil Nadu, coastal Andhra Pradesh, Odisha, and parts of northeast India.

✓ Vital for Rabi crop cultivation in peninsular India, particularly for rice and groundnut in Tamil Nadu.

Regional Variations: The Indian monsoon exhibits sharp regional contrasts in rainfall due to diverse geography.

High Rainfall Areas: Mawsynram and Cherrapunji in Meghalaya are globally renowned for receiving the highest annual rainfall, exceeding 10,000 mm, because the Bay of Bengal branch of the monsoon is forced to rise over the Khasi hills. The Western Ghats, too, receive heavy rainfall on the windward side, nourishing dense forests and perennial rivers.

Moderate Rainfall Zones: The Indo-Gangetic plains, eastern coastal regions, and central India receive between 600-1,500 mm of rainfall annually. This makes them agriculturally rich and highly productive for crops like rice, wheat, and sugarcane.

Low Rainfall Areas: Western Rajasthan, Ladakh, and the rain-shadow regions of Karnataka, Maharashtra, and Andhra Pradesh remain arid with less than 300 mm of rainfall annually. These areas face frequent droughts, making them dependent on irrigation, groundwater and canal systems for farming.

Agricultural Significance

The Indian monsoon is the backbone of agriculture, which employs more than half of the nation's workforce.

***Kharif* Crops:** The timely arrival and distribution of the southwest monsoon determine the success of crops like paddy, maize, cotton, soybean, groundnut and pulses. A good monsoon directly boosts food grain output, ensuring food security.

Rabi Crops: Even though Rabi crops such as wheat, mustard, and barley are grown in winter, they depend on soil moisture and groundwater reserves recharged by the monsoon.

Impact on Cropping Patterns: A delayed or erratic monsoon delays sowing, shortens crop duration, and reduces yields. In contrast, excess rainfall often damages standing crops and causes soil erosion. Thus, monsoon behaviour dictates cropping intensity, crop choice and national agricultural growth.

Economic and Socio-Cultural Importance

The monsoon is deeply tied to India's economy and culture.

Economic Contribution: Agriculture contributes nearly 16-18% to India's GDP, and the rural economy depends heavily on monsoon rains. A good

monsoon lowers food inflation, strengthens rural demand, and drives overall economic growth.

Water Resources and Energy: Rivers, dams, and groundwater reserves replenished by monsoons sustain industries, urban water supply and hydropower projects.

Cultural Relevance: From festivals like *Onam* in Kerala to folk songs and literature across India, the monsoon has inspired traditions, rituals and art forms. Farmers in many regions still perform monsoon-invoking rituals, underlining its spiritual significance.

Advantages of the Monsoon

Agricultural Productivity: Provides the water needed for irrigation and rainfed agriculture.

Biodiversity and Forests: Monsoon rains nourish India's forests, wetlands and grasslands, supporting diverse flora and fauna.

Fisheries: Seasonal ocean upwelling triggered by monsoon winds enriches coastal waters with nutrients, enhancing fish production.

Economic Growth: A normal monsoon not only ensures food security but also boosts rural incomes, stimulates consumption, and strengthens markets.

Challenges and Limitations

While vital, the Indian monsoon also brings severe challenges:

Droughts: Monsoon deficiency leads to crop failures, scarcity of drinking water, livestock loss and rural distress migration.

Floods: Excessive rainfall often triggers floods, destroying crops, infrastructure and human settlements. The fertile Indo-Gangetic plains are frequently affected.

Uneven Distribution: Rainfall is not uniform; while the Northeast gets excess rain, parts of western and central India face drought conditions.

Urban Flooding: Rapid urbanization, poor drainage, and encroached waterways intensify flooding in cities like Mumbai, Bengaluru and Chennai.

Climate Change Impact: Global warming has made rainfall patterns more unpredictable, with fewer rainy days but heavier downpours, leading to extreme events like cloudbursts and flash floods.

Management and Adaptation Strategies

To harness the benefits of the monsoon while reducing risks, India needs strong adaptation measures:

Irrigation Development: Expansion of canal irrigation, drip, and sprinkler systems to reduce dependence on rainfall.

Watershed Management: Rainwater harvesting, check dams, percolation tanks and afforestation improve groundwater recharge and water security.

Climate-Smart Agriculture: Adoption of short-duration, drought-resistant and flood-tolerant crop varieties helps reduce risks from monsoon variability.

Forecasting and Early Warning: The Indian Meteorological Department (IMD) has advanced forecasting models that now predict monsoon onset and intensity with greater accuracy, providing farmers with timely advisories.

Policy and Institutional Support: Schemes like

Pradhan Mantri Fasal Bima Yojana (PMFBY), contingency crop plans, and subsidies for water conservation infrastructure strengthen resilience at the farmer level.

Case Examples

Drought of 2002: A severe 19% monsoon deficit reduced food grain output by nearly 20 million tonnes, highlighting India's vulnerability.

Kerala Floods of 2018: Unprecedented rainfall caused widespread flooding, demonstrating the growing risk of climate extremes.

Forecasting Advances: IMD has improved its capacity to predict the onset of monsoons within 2-3 days of accuracy, helping farmers and policymakers plan better.

Conclusion

The Indian monsoon remains a climatic marvel and a cornerstone of the nation's agricultural and economic foundation. While its bounty sustains life and livelihoods, its unpredictability often triggers hardships. To mitigate risks, India must enhance irrigation efficiency, adopt drought- and flood-resilient crops, strengthen early warning systems and invest in climate-smart agriculture. By combining traditional wisdom with modern science, the nation can harness the potential of the monsoon while reducing its vulnerabilities. In an era of global climate uncertainty, sustainable management of the monsoon's resources will be crucial for ensuring India's food security and long-term prosperity.

Improvement in Onion (*Allium cepa* L.) for Different Characters

Pankaj Kumar, M. L. Meena, Suraj Pasawan, Anjali, Rahul, Pradeep Kumar and Vishal Singh

Abstract

Onions (*Allium cepa* L.) are a biennial crop from the Alliaceae family. The comestible section of the bulbs is the expanded splint bases and compact stem. A different range of landraces and cultivars with expansive inheritable variation for colorful rates are available; species similar as *Allium cepa*, *A. fistulosum*, and *A. roylei* can be used to induce cultivars resistant to colourful conditions as well as asked agronomic traits. Traditional inheritable and factory parentage ways have been applied to ameliorate onion productivity, quality, and resistance to biotic and abiotic stressors. Still, its biennial life cycle, cross-fertilization, and severe inbreeding depression have made it delicate to characterise and develop advanced features. New technologies, particularly next- generation sequencing, are giving experimenters with inheritable coffers and ways to address these difficulties. Molecular labels are snappily developing and being used for germplasm analysis and mapping in onions thanks to these genomic technologies. These new technologies and moxie enable the coupling of molecular and conventional parentage, which speeds up onion development enterprise. In this study, we will bandy recent advances in onion genomes and molecular genetics, as well as unborn openings to ameliorate onion productivity and quality.

Introduction

Onions are among the most extensively grown vegetables in the world. It can be eaten either raw in salads or cooked to enhance taste to epicure dishes. Since ancient times, onions have been recognised as significant functional foods. The oldest form book ever discovered is a 4000- time-old complexion tablet from Mesopotamia, includes leeks, onions, and garlic as flavourings. Onions, garlic, and leeks are used for flavouring. Onions have been cultivated across a wide geographic range since domestication thanks to the use of several conventional parentage ways to ameliorate product, quality, and forbearance to biotic stressors. Still, the integrated use of genomics ways is needed to ameliorate onion parentage programs in order to meet consumer demand in the coming times. Conventional onion parentage ways and how inheritable coffers could speed up posterior parentage.

Onion parentage: The regular lineage programme began in 1960 in Baswant Pimpalgaon near in Nashik as well as subsequently in New Delhi at IARI. Prior to selection produced cultivars include N-2-4-1 and onion product is still dominated by Pusa Red. The program was further expanded through a collaborative relationship between Indian Council of Agricultural Research institutes under the National Horticultural Research and Development Foundation

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and State Agricultural Universities (SAUs). Consequently, 45 onion types have been produced and vended, including two F_1 hybrids and six multiplier onions.

Parentage for white onions: Indian white onion kinds generally have low TSS situations (10-14), making them infelicitous because of dehumidification. White Creole was developed by Jain Food Park diligence in Jalgaon after studying Indian kinds and land races with low TSS. Selection pressure for high TSS was also applied to White Creole, producing The TSS range for the V- 12 variety is 15-18 (particular communication). Within India a number of exploration institutes have tried to produce kinds of white onions that are applicable for different seasons. When the dehumidification rate of a many native and fantastic onion cultivars was examined, the dry matter ranged from 7.4 to 16.2.

Parentage for yellow Onions: While yellow onions thrive in the European request, they are n't veritably popular in India. Larger sizes (> 60 mm periphery), lower sweet, and single centred types are the introductory conditions for import. It's apparent that utmost of the study on onions has been conducted in the United States and Europe, with little to no exploration conducted in India. The new yellow onion variety "NuMex Starlite," created by Corgan and Holland in 1993, was resistant to Pyrenochaeta terrestris and bolting. Five intermittent selections from Texas Grano 502 PRR were used to produce the short- day variety.

Germplasm: For parentage programs to be successful over the long term, a variety of crop germplasm must be available (Glaszmann *et al.*, 2010). Onions have been grown for periods in multitudinous areas, and growers have chosen desirable populations grounded on indigenous requirements. As a result, a large number of cultivars and landraces with substantial inheritable variation for several attributes are available. Onion landraces and contemporary cultivars were gathered in a number of nations in the late 1980s as a result of the trouble of inheritable declination posed by the preface of F_1 mongrels (Fritsch and Friesen, 2002).

Flexibility: In bulb onions, blooming and bulbing are important adaptive features that are controlled by vernalisation and photoperiodic pathways, independently (Taylor *et al.*, 2010, Lee *et al*., 2013). Onion cultivars' low rigidity to significant losses occurs at different authorizations because of early flowering and dropped yield. Physiologically, although not molecularly or genetically, bulbing and flowering are well understood. Recent exploration, still, has shown that several genes regulate this onion growth phases (Taylor *et al.*, 2010).

Hybrid breeding for higher output: The main determinants of onion yield are bulb periphery, weight, and shape. Slow progress in adding bulb product is caused by low to moderate heredity for periphery and weight and moderate to high heritability for shape (McCollum 1966, 1968, 1971). Nevertheless, the rate of productivity increases should be accelerated by the continued creation of F_1 mongrels in long- and short- day onions (McCallum,

2007). Since the discovery of cytoplasmic- genic manly sterility (CMS), heterosis parentage has handed significant yield earnings. manly sterility systems utilised in marketable parentage are presently classified into two types S and T, with a high position of heterosis recorded (Sypein *et al.*, 1978).

Quality: Colour of the 8bulb (anthocyanin and flavonoid content), firmness, number of scales, growth points, neck consistence, total answerable solids (TSS), pungency, and antioxidants are used to estimate the quality of onion cultivars. Due to their moderate to high heredity and positive correlation, dry matter, TSS, and pungency can all be bettered at the same time by selection. It's challenging to produce onions with a high dry matter content that are less sweet and have a longer shelf life. Onion processing businesses demand cultivars have single-centered bulbs, high TSS, and dry matter, all of which are necessary for storehouse. Onion bulb colour varies extensively, and genetics are well understood (McCallum, 2007).

Bulb colour: Six loci (I, C, G, L, L2, and R) interact with one another to control flavonoid situations, performing in a wide range of bulb colours. Dominant alleles at the R and L or L2 loci produce red bulbs, whereas dominant alleles at the I locus produce white bulbs. When a dominant allele was present at the G locus, golden- multicolored bulbs formed (Kim *et al.*, 2005, Khar *et al.*, 2008 and Duangjit *et al.*, 2014). After studying the onion's flavonoid biosynthesis process, several implicit genes were set up. Dihydroflavonol 4- reductase (DFR) has been set up to be expressed more in red bulbs than in yellow onions (Kim *et al.*, 2005). It has been suggested that bulbs' red, pink, and yellow tinges are conditioned by four alleles expressing anthocyanidin synthase (ANS) (Kim *et al.*, 2006). Functional labels have been created from these campaigners, which may be utilised in marker supported selection for bulb colour. DFR and ANS are counterplotted on chromosomes 7 and 4, independently (Masuzaki *et al.*, 2006, Khar *et al.*, 2008, Kim *et al.*, 2009, Park *et al.*, 2013, Duangjit *et al.*, 2014).

Genetic maps: Experimenters can find marker particularity correlations that can be used in marker supported selection programs by creating crop inheritable charts (Varshney *et al.*, 2014). The BYG15- 23 9 AC43 F2 population was used to produce the first onion inheritable chart utilising 116 labels (RAPD and RFLP), which are divided into 12 relation groups with an average distance of 9 cM. manly sterility, bulb colour, and flavour (alliinase exertion) are three significant traits that correspond to distinct chromosomes (King *et al.*, 1998). According tomulti-locus RFLP marker aloneness, intra-chromosomal tandem duplications are the cause of onions' enormous genome size (King *et al.*, 1998). Ten relation groups at> LOD 4 have been produced by placing SSR and SNP labels on this relation chart (Jakse *et al.*, 2005, Duangjit *et al.*, 2013). Using an F_2 population (OH1 9 5225), in which 597 SNPs generated 10 relation groups at

LOD > 8, another relation chart was created. Both charts were combined using common SNPs (223) that insulated in both groups; the marker order remained the same with the exception of chromosomes 2 and 6 (Duangjit *et al.*, 2013). Nine relation groups were assigned 93 SNP labels with an average distance of 7.5 cM in a broad F_2 (Nasik Red 9 CUDH2150) (Baldwin *et al.*, 2012). These SNP-grounded charts will offer a helpful foundation for farther onion inheritable exploration. Relation maps grounded on AFLP labels have been constructed using aninter-specific F_2 population of *A. roylei, A. cepa* (van Heusden *et al*., 2000). Eight relation groups are present in the chart grounded on *A. cepa* labels (262) whereas 15 relation groups were discovered using *A. roylei* labels (243). Still, because of slanted marker isolation, manly and womanish charts were n't intermingled. Relative genomic examinations in the rubric Allium have been made easier by the posterior integration of manly and womanish charts utilising 74co-dominant labels (Baldwin *et al*., 2012). In order to produce an impregnate Dinter specific relation chart, it would be ideal to condense similar charts with SNPs or other sequence- grounded labels.

Resistance to disease and insects-pests: Onions are susceptible to several conditions and nonentity infestations. Among the most current Downy mildew, white spoilage (*Sclerotium cepivorum*), pink root (*Pyrenochaeta terrestris*), grandiloquent blotch (*Aspergillus niger*), stemphylium scar (*Stemphylium vesicarium*), iris unheroic spot contagion (IYSV), onion unheroic dwarf contagion (OYDV), and fusarium rudimentary spoilage (*Fusarium oxysporum*) are among the conditions that impact onion bulb and seed crops. *A. roylei*'s resistance to velvetlike mildew was linked and effectively transmitted (Scholten *et al*., 2007) to bulb onion. Several bulb onion and other allium germplasms have been shown to parade resistance to fusarium rudimentary spoilage, albeit not complete resistance. This resistance is controlled by depending on the germplasm, there could be one, two, or further genes, Taylor *et al*. (2013), Galvan *et al*. (2008), and Cramer (2000). By reducing photosynthetic exertion, performing as a complaint entry point, and acting as a vector for IYSV, onion thrips (*Thrips tabaci* L.) are among the insects that do the most detriment (Bag *et al*., 2014). The great maturity of onion farmers uses germicides to control thrips, while some employ natural and artistic operation ways. This approach has serious environmental issues and may produce thrips that are resistant to germicides. Onion cultivars that are naturally resistant to thrips are being developed in an attempt to address these problems. Germplasm from several nations has been delved, and a many tolerant sources have been set up for use (Diaz- Montano *et al*., 2011, Bag *et al*., 2014) in breeding sweats.

Seed yield: A species that outcrosses is the onion, and honeybees are utilised to pollinate marketable seed crops. The physical and biochemical characteristics of onions' blossoms impact honeybee attractiveness. Large ovaries, nectary volume, anthers and

tepals are exemplifications of flowery morphological traits that have been connected to further visits from notions and onion seeds product. Nectar sugar attention is the biochemical characteristic most explosively linked to seed affair and freak visits (Silva and Dean, 2000, Soto *et al*., 2013). According to these results, opting cultivars with high nectary volume and sugar content may prop in boosting pollination effectiveness and onion seed yield.

Production in Hybrid Form: For onions to produce mongrels, male sterile, maintainer, and pollinator must be available. It takes 4-8 times to identify the cytoplasm and 10-12 times to backcross the genome in applicable inheritable backgrounds using conventional styles. Marker supported selection of maps sterile and conservation lines in onion populations can speed up the parentage process (Havey, 2013).

Molecular Breeding of Onions: When combined with traditional styles, genomics supported parent-age has produced major advancements in several agrarian species. To make genomics- supported parentage possible for a range of bulb onions, molecular labels must be developed and QTL/ genes of interest must be linked.

Genomic editing and genetic modification as future breeding tool: Genome editing and inheritable revision have n't yet produced any marketable onion kinds, but they could give new types with distinctive characteristics. Onion is a poor weed contender, especially in the early stages of factory growth, and if not handled duly, it reduces yield. Onion farmers use homemade and chemical weed operation styles, which are both expensive and have negative environmental consequences. A pesticide resistant gene was developed via Agrobacterium intermediated metamorphosis to produce glyphosate (Roundup) resistant onions, although these shops are n't presently available for purchase.

Breeding Achievements and Challenges: Bulb onions have a great deal of inheritable variety, although crop development progress is n't as rapid fire as that of other monocot species, including meadows (McCallum, 2007, Varshney *et al*., 2012). The 19th century saw the morning of methodical parentage with mass selection in a number of nations, and themid-20th century saw the product of F_1 mongrels thanks to the discovery of cytoplasmic manly sterility (Brewster, 2008, McCallum *et al*., 2008). Presently, open- pollinated types (OP) are more common in Asia and Africa's short- day producing regions, while F_1 mongrels are more common in areas where long- day onions are grown (Currah and Proctor, 1990, Brewster, 2008). Over the once 50 times, onion product has doubled due in part to the arrival of enhanced OP types and F_1 mongrels (Brewster, 2008). Still, growing onion affair to satisfy demand is facing significant challenges due to population pressure and climate chang (Brewster, 2008). The strategic use of molecular ways to support germplasm conservation and selection to ameliorate product, quality, rigidity, storehouse, and complaint and pest resistance should

be bolstered in onion enhancement programs in order to overcome these obstacles.

Table 1: Varieties of onion developed by different organizations

S. No.	Organization	Variety	Colour of Bulb
1.	Agri. Dept. M.S.	N-2-4-1	Red
		N-53	Red
		N-257-9-1	White
2.	P.P.K.V., Rahuri	Basawant-780	Red
		Phule Safed	White
		Phule Swarna	Yellow
		Phule Samarth	Red
3.	IARI, New Delhi	Pusa Red	Red
		Pusa White Flat	White
		Pusa White Round	White
		Pusa Ratnar	Red
		Pusa Madhavi	Red
		Early Grano	Yellow
		Brown Spanish	Brown
4.	IIHR, Bangalore	Arka Niketan	Red
		Arka Kalyan	Red
		Arka Bindu	Red
		Arka Pragati	Red
		Arka Pitamber	Yellow
		Arka Lalima	Red
		Arka Kirtiman	Red
5.	HAU, Hissar	Hissar 2	Red
		HOS-1	Red
6.	NHRDF, Nashik	Agrifound Dark Red	Red
		Agrifound Light Red	Red
		Agrifound White	White
		Agrifound Rose	Red
		Agrifound red	Red
		L-28	Red
		Line-355	Red
7.	VPKAS, Almora	VL-1	Red
		VL-3	Red
8.	RAU, Rajasthan	Udaoipur 101	Red
		Udaipur 102	White
		Udaipur 103	Red
9.	CSAUAT, Kanpur	Kalyanpur red Round	Red
10.	PAU, Ludhiana	Punjab Selection	Red
		Punjab Red Round	Red
		Punjab Naroya	Red
		Punjab-48	White
		Punjab White	White
11.	TNAU, Coimbtore	CO-1	Red
		CO-2	Red
		CO-3	Red
		CO-4	Red
		MDU-1	Red
12.	RARS, Durgapura	Rajasthan Onion -1	Red
		Aprita (RO-59)	Red
13.	PDKV, Akola	Akola White	White
14.	DOGR, Rajagurunagar	Bhima Raj	Red
		Bhima Super	Red
		Bhima Red	Red
		Bhima Sakti	Red
		Bhima Kiran	Red
		Bhima Sweta	White
		Bhima Shubhra	White
		Bhima Dark Red	Red
		Bhima Light Red	Red
		Bhima Safed	White

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Conclusion

Onion breeding produces enhanced numbers and F_1 hybrids. With the development of genomic technology, experimenters can look at traits at the inheritable position in onions, speeding up crop development enterprise. Onion inheritable maps have shown a variety of traits, but marker- supported selection requires more nearly connected markers. To ameliorate marker recognition and the resolution of onion connection maps, large and different mapping populations are needed. New alleles that impact development and flavour should be set up by association mapping with sizable germplasm collections. Accordingly, this substance can be used more effectively in onion parentage systems. New onion kinds with enhanced traits will be possible because to the expansion of onion genomic resources brought about by advancements DNA sequencing technology and cooperation to produce bulb onion draft genomic sequences.

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The Enduring Legacy of Traditional Rice in Tamil Culture: A Holistic Perspective

Vengatesh M., Nivetha A. L. and Shridevi S.

The traditional rice varieties of Tamil Nadu are far more than just staple foods; they are living repositories of the region's cultural heritage, ecological wisdom, and ancestral health practices. Their legacy is an intricate tapestry woven with threads of history, agriculture, medicine, and social identity. In a world increasingly dominated by monoculture and processed foods, the enduring importance of these ancient grains stands as a testament to the profound knowledge of past generations and a crucial guide for a healthier, more sustainable future.

The Cultural and Historical Tapestry of Tamil Rice

The history of rice cultivation in Tamil Nadu dates back millennia, with evidence from the Sangam period (200 BCE - 200 CE) and beyond. The fertile delta of the Cauvery River, known as the "Granary of Tamil Nadu," was a cradle for a vast diversity of rice varieties, each with its own story and purpose. Unlike the standardized grains of today, this rice were deeply integrated into the social and cultural fabric of the community.

Rice in Ritual and Ceremony: In Tamil culture, rice is a symbol of life, prosperity, and fertility. It is an indispensable part of almost every significant ritual and ceremony:

Weddings: During a traditional Tamil wedding, a ritual called "kattiyana sathan" involves mixing seven different types of traditional rice with milk and jaggery, which is then fed to the bride and groom. This symbolizes a blessed and prosperous life together. At the end of the ceremony, rice is showered over the couple as a blessing for a fertile and abundant future.

Festivals: The harvest festival of Pongal is centered entirely around rice. Families boil newly harvested rice with milk and jaggery in a traditional pot until it overflows, symbolizing a bountiful harvest and prosperity. The dish itself is a celebration of the farmer's hard work and the blessings of nature.

Auspicious Occasions: From a newborn's first solid food (Annaprasana) to rituals honouring ancestors, rice plays a central role. Its presence is seen as a way to invite good fortune and peace.

The Naming of Grains: A Reflection of Wisdom

The names of traditional rice varieties in Tamil Nadu are not arbitrary; they often tell a story about their characteristics, origin, or intended use.

Mappillai Samba (Bridegroom's Samba): This

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reddish-brown rice gets its name from a traditional practice where it was fed to prospective grooms to provide them with the strength to lift a heavy rock a test of their physical prowess and a rite of passage.

Karuppu Kavuni (Black Kavuni): "Karuppu" means black, and "Kavuni" is believed to be a variation of "Kaani," a measure of land, suggesting that this rice was so prized that it was given as a gift. It also ties back to its "forbidden" status for commoners in other cultures, highlighting its rarity.

Poongar Rice: The name "Poongar" translates to a "beautiful flower," possibly referring to the rice's elegant form or its benefits for women's beauty and health.

Kattuyanam (Wild Elephant): This variety is so named because its plant grows tall enough for an elephant to hide in the field, a testament to its height and resilience without chemical fertilizers.

The Agricultural and Ecological Wisdom

The cultivation of traditional rice varieties is intrinsically linked to sustainable and ecologically sound farming practices that have been perfected over centuries. This stands in stark contrast to the modern-day monoculture of hybrid seeds that demand heavy chemical inputs and deplete soil health.

Resilience and Biodiversity

Traditional rice varieties are highly adapted to the local environment and climate. They possess a remarkable resilience to regional pests, diseases, and unpredictable weather patterns.

Drought and Flood Resistance: Varieties like Kattuyanam are known for their ability to withstand both droughts and floods, making them a reliable crop in an unpredictable climate.

Natural Pest Resistance: Many of these traditional strains have natural defenses against pests, eliminating the need for synthetic pesticides. This not only protects the environment but also ensures the safety and purity of the food.

This resilience and adaptability are a direct result of agricultural biodiversity. By cultivating a wide array of traditional rices, farmers maintained a diverse gene pool that made the overall food system more robust and secure.

The Synergy of Traditional Farming

The farming of these rices was part of a holistic, integrated system. Farmers understood the importance of maintaining soil health and used traditional methods that enriched the land rather than depleting it.

Natural Fertilizers: Instead of chemical fertilizers, farmers used organic manure, such as cow dung and crop residue, which improved soil structure and fertility.

Crop Rotation: The practice of rotating crops and intercropping with other plants helped to control

pests naturally and maintain a balanced ecosystem.

Water Management: Traditional water management techniques, like the use of small bunds and channels, ensured that water was used efficiently, especially for varieties suited to specific water levels.

The legacy of these traditional grains is therefore also a legacy of sustainable agriculture. By preserving and promoting their cultivation, we are not just saving a type of rice but also the ancient farming wisdom that is a key to ecological balance and food security in the future.

The Unrivalled Health and Medicinal Properties

The most compelling reason for the enduring legacy of traditional rice varieties is their extraordinary nutritional and medicinal value, which was a cornerstone of ancient Tamil health systems like Siddha medicine. These grains were not just food; they were a form of preventative and curative medicine.

Poongar Rice: A Fountain of Women's Health

As previously mentioned, Poongar rice is widely hailed as the "women's rice" for its profound benefits for female health.

Post-Natal Care: Consuming Poongar kanji (porridge) is a traditional practice for new mothers. It is believed to aid in a swift recovery, restore strength, and promote healthy lactation, ensuring the baby receives nutrient-rich breast milk.

Hormonal Balance: For young girls and women, it is believed to help in regulating menstrual cycles and balancing hormones. Its rich iron content is crucial for preventing anemia, a common health issue among women.

Karuppu Kavuni: The Antioxidant King

The deep black color of Kavuni rice is not just a visual treat; it is a sign of its rich concentration of anthocyanins.

Antioxidant Power: Anthocyanins are powerful antioxidants that combat oxidative stress, which is a major contributor to chronic diseases like heart disease, diabetes, and certain cancers. The high antioxidant capacity of Kavuni rice makes it a potent health-booster.

Heart and Liver Health: The combination of antioxidants and dietary fiber in this rice helps to lower "bad" cholesterol levels and supports overall cardiovascular health. It is also traditionally used to aid in detoxification and improve liver function.

Mappillai Samba: The Source of Strength and Vitality

This rice variety is specifically prized for its ability to increase strength and stamina. It is a dense, nutritious grain that is a great source of:

High Fiber: Its high fiber content aids in digestion and provides a feeling of satiety, making it a good choice for weight management.

Minerals: It is rich in essential minerals like zinc, magnesium, and iron, which are crucial for a healthy immune system and overall vitality.

Low Glycemic Index: Like many other traditional varieties, its low GI makes it a perfect choice for diabetics, as it prevents sudden blood sugar spikes.

The Path Forward: From Legacy to Revival

The enduring legacy of traditional rice is now

fueling a powerful revival movement in Tamil Nadu and beyond. This movement is a response to the growing awareness of the shortcomings of modern agricultural practices and a renewed appreciation for the wisdom of the past.

Economic Empowerment for Farmers: The increased demand for traditional rice varieties has created a viable market for small-scale farmers, providing them with a strong incentive to move away from chemical-dependent farming. By cultivating these rices, they can earn better prices and build more sustainable livelihoods, strengthening rural economies and communities.

Health-Conscious Consumers: Urban consumers, increasingly concerned about food safety and health, are actively seeking out traditional and organic grains. Farmers' markets, organic stores, and online platforms are making these once-rare grains accessible to a wider audience. This shift is driving a change in the food landscape and encouraging more farmers to adopt traditional methods.

Preserving Food Sovereignty: The revival of these traditional grains is a crucial step towards achieving food sovereignty the right of people to healthy and culturally appropriate food produced through ecologically sound and sustainable methods. By valuing local, indigenous varieties, communities can reduce their dependence on multinational corporations and ensure control over their own food systems.

In conclusion, the legacy of traditional rice in Tamil culture is a multi-faceted one. It is a story of resilience, a testament to ecological wisdom, a guide for a healthy life, and a blueprint for a sustainable future. By celebrating and preserving these ancient grains, we are not only honouring our past but also building a stronger, healthier, and more connected future. The simple grain of rice, in all its diverse and traditional forms, is a powerful reminder that sometimes, the best path forward is to look back to our roots.

Synthetic Biology in Crop Breeding

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Synthetic biology represents a revolutionary paradigm shift in crop breeding, moving beyond traditional genetic engineering to a more deliberate, design-driven, and holistic approach to modifying biological systems. Instead of simply transferring single genes, synthetic biology aims to engineer entire biological pathways, circuits, or even novel biological systems within plants to achieve complex desired traits. It applies engineering principles like standardization, modularity, and abstraction to biological components, enabling researchers to "design, build, test and learn" new plant functionalities.

What is Synthetic Biology in Crop Breeding?

At its core, synthetic biology in crop breeding is about:

Designing and Constructing New Biological Parts: Creating novel DNA sequences (genes, promoters, terminators, regulatory elements), RNA molecules, or proteins with specific functions that may not exist naturally or are optimized for a particular purpose.

Re-designing Existing Biological Systems: Modifying or rewiring existing metabolic pathways, gene regulatory networks, or cellular processes in plants to improve their performance or introduce new capabilities.

Applying Engineering Principles: Utilizing a systematic "Design-Build-Test-Learn" (DBTL) cycle, similar to engineering, to create predictable and robust biological systems within crops. This involves using computational tools for design, high-throughput methods for building and testing, and data analysis for learning and refinement.

Beyond Single Genes: While traditional genetic engineering often focuses on inserting one or a few genes, synthetic biology aims for more sophisticated changes, such as introducing complete synthetic metabolic pathways, stacking multiple genes in a controlled manner, or even building novel genetic circuits that respond to environmental cues.

Essentially, synthetic biology views genes, proteins, and metabolic pathways as "biological parts" or "modules" that can be assembled and optimized to create plants with novel and enhanced characteristics.

Key Tools and Technologies Enabling Synthetic Biology in Crops

Synthetic biology's power in crops is amplified by several cutting-edge technologies:

Advanced Gene Editing (CRISPR-Cas9 and variants): These tools allow for precise, targeted

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modifications (insertions, deletions, substitutions) to the plant genome. This is crucial for "rewiring" existing pathways or integrating newly designed synthetic circuits with high accuracy.

DNA Synthesis and Assembly: Rapid and cost-effective synthesis of custom DNA sequences (genes, promoters, regulatory elements) allows for the "building" of novel biological parts. Techniques like Golden Gate cloning enable efficient assembly of multiple DNA fragments into complex constructs.

Computational Design Tools: Software platforms and algorithms that help design new genetic circuits, predict metabolic flux, simulate pathway behaviour, and identify optimal genetic modifications. AI and Machine Learning play a significant role here.

High-Throughput Omics Technologies: Genomics , transcriptomics, proteomics, and metabolomics provide vast datasets to understand complex biological systems, identify potential targets for modification, and analyze the effects of synthetic interventions.

High-Throughput Phenotyping and Screening: Automated systems (including robotics) are essential for rapidly testing the performance of designed plant systems, providing feedback for the "Test" and "Learn" phases of the DBTL cycle.

Directed Evolution: Mimicking natural selection in a laboratory setting to evolve enzymes or proteins with improved properties (e.g., higher activity, altered substrate specificity) that can then be integrated into synthetic pathways in plants.

Applications of Synthetic Biology in Crop Breeding

Synthetic biology holds immense potential to address some of the most pressing challenges in agriculture:

Enhancing Crop Yield and Productivity

Improved Photosynthesis: Re-engineering photosynthetic pathways to make them more efficient. This could involve introducing components from C_4 plants into C_3 plants (like rice or wheat) or redesigning the Calvin cycle enzymes (e.g., Rubisco) for faster carbon fixation.

Optimized Plant Architecture: Designing plants with ideal canopy structures, branching patterns, or root systems for maximum light capture, nutrient uptake, and lodging resistance, while maintaining a high harvest index.

Increased Biomass Production: For bio energy crops, engineering pathways to boost the accumulation of specific compounds (e.g., cellulose, oil) or overall plant growth rate.

Enhancing Stress Tolerance and Resilience

Drought Tolerance: Engineering complex genetic circuits that allow plants to sense water deficit and precisely regulate water use, stomatal closure, and root growth in a finely tuned manner, without significant yield penalties.

Salinity Tolerance: Designing systems that enhance ion exclusion, compartmentalization of salt, or osmotic adjustment in saline environments.

Disease and Pest Resistance

Smart Immunity: Engineering plant immune systems to recognize specific pathogens more effect-

ively or to activate targeted defence responses only when necessary.

RNA Interference (RNAi): Designing plants to produce small RNA molecules that specifically silence genes in insect pests or pathogens, acting as highly targeted bio pesticides.

Synthetic Microbial Symbionts: Engineering beneficial soil microbes (e.g., bacteria, fungi) to enhance plant nutrient uptake or provide pathogen protection, then facilitating their stable association with plant roots.

Improving Nutritional Quality (Bio fortification)

Enhanced Micronutrient Content: Designing metabolic pathways to boost the accumulation of essential vitamins (e.g., Vitamin A in Golden Rice), minerals (e.g., iron and zinc), or beneficial phytonutrients in staple crops. This often involves introducing multiple genes from different organisms to build a complete pathway.

Improved Protein and Lipid Profiles: Engineering seeds to produce higher quality proteins or healthier fatty acid compositions.

Sustainable Agriculture and Environmental Impact Reduction

Nitrogen Fixation in Non-Legumes: The holy grail of plant synthetic biology is to engineer cereals (like rice, wheat, maize) to fix atmospheric nitrogen, significantly reducing the need for synthetic nitrogen fertilizers, which are energy-intensive to produce and cause environmental pollution (e.g., N_2O emissions, runoff). This involves complex pathway engineering from nitrogen-fixing bacteria.

Phosphorus Use Efficiency: Designing root systems to better acquire insoluble phosphorus from the soil or engineering plants to produce enzymes (phytases) that make phosphorus more available.

Biosensors for Precision Agriculture: Engineering "phytosensors" plants that can visually signal (e.g., by changing color or fluorescing) when they detect specific environmental stresses (drought, nutrient deficiency), pathogens, or pollutants in the soil. This provides real-time, in-situ information for precision farming.

Bioremediation: Engineering plants to absorb, detoxify, or sequester environmental pollutants from soil or water.

Examples of Synthetic Biology in Action (or under development)

Golden Rice: Often cited as an early example, it involved introducing multiple genes (from daffodil and a bacterium) into rice to enable beta-carotene (precursor to Vitamin A) synthesis in the endosperm, a trait not naturally present. While developed using classical genetic engineering, its complexity and pathway engineering aspects align with synthetic biology principles.

C_4 Photosynthesis in C_3 Plants: Large-scale research efforts aim to introduce the highly efficient C_4 photosynthetic pathway into C_3 crops like rice to significantly boost their yield potential. This is a monumental synthetic biology challenge involving the coordinated expression and regulation of many genes across different cell types.

Nitrogen Fixation in Cereals: Projects are under-

way to engineer nitrogen fixation pathways into maize or other cereals, a multi-gene, multi-pathway challenge.

Synthetic Gene Circuits for Stress Response: Researchers are designing synthetic gene circuits in model plants like *Arabidopsis* that can sense specific stress signals and trigger a targeted response, providing fine-tuned adaptation.

Enhanced Production of High-Value Compounds : Engineering crops or plant cells to act as "bio-factories" for pharmaceuticals, industrial chemicals, or specialized metabolites (e.g., artemisinin precursors in tobacco or yeast).

Challenges and Future Outlook

While revolutionary, synthetic biology in crop breeding faces significant challenges:

Complexity of Plant Systems: Plants are multi-cellular, have large and complex genomes (often polyploid), and interact intricately with their environment. Designing and integrating synthetic systems into these complex biological machines is far more challenging than in microbes.

Predictability and Robustness: Ensuring that engineered circuits function predictably and robustly across different environments and genetic back-grounds is difficult. Biological systems are inherently noisy and variable.

Off-Target Effects: Ensuring that synthetic modifications do not unintentionally disrupt other essential plant functions or create unintended phenotypic consequences.

Regulatory Hurdles and Public Acceptance: Products of synthetic biology, especially those involving foreign DNA or extensive genomic modifications, face similar (or even greater) regulatory scrutiny and public skepticism as traditional GMOs. Clear communication and robust risk assessment frameworks are crucial.

Cost and Scalability: The cutting-edge nature of these technologies means high development costs. Scaling up from lab-bench proof-of-concept to field-scale application for major crops remains a significant hurdle.

Intellectual Property (IP) and Commercial-ization: Navigating complex IP landscapes and ensuring equitable access to these technologies.

Future Outlook

Despite these challenges, the future of synthetic biology in crop breeding is incredibly promising.

- ✓ Convergence with AI/ ML
- ✓ Bio foundries
- ✓ Standardized Bio Bricks
- ✓ More Sophisticated Genetic Control
- ✓ Focus on Environmental Benefits
- ✓ Bio refineries on the Farm
- ✓ Non-transgenic Synthetic Biology

Conclusion

In India, with its vast agricultural sector and the imperative to enhance food security and sustainability under climate change, synthetic biology offers transformative potential. Investments in advanced research infrastructure, interdisciplinary training, and a clear, science-based regulatory frame-

work will be critical to harnessing this powerful technology for the benefit of Indian farmers and consumers.

Impact of Seed Certification in Crop Production

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Seed is the basic and most vital input in agriculture, as it determines the ultimate performance of a crop in terms of yield, quality, and adaptability. It is often said that "good seed is the key to good harvest." Farmers may apply fertilizers, irrigation, and crop protection measures, but without quality seed, the full potential of production cannot be realized. Studies have shown that seed quality alone can contribute 20-25% increase in crop productivity, independent of other inputs. To ensure that farmers have access to genuine, high quality, and genetically pure seeds, a systematic mechanism called seed certification has been established in most countries. Seed certification is a legally sanctioned process designed to guarantee that the seeds marketed to farmers conform to prescribed standards of genetic purity, physical quality, physiological vigour, and sanitary conditions. The impact of seed certification in crop production is multidimensional: it ensures higher productivity, improves farmer confidence, strengthens seed industries and contributes to national food security.

Concept and Process of Seed Certification

Seed certification is defined as the process of verifying and guaranteeing the quality of seeds through an official agency. It involves a sequence of checks and inspections, starting from the seed source to the final seed lot that reaches farmers.

Stages of Seed Multiplication and Certification

Breeder seed: Breeder seed is created from nucleus seed in an Agricultural University research facility under the direction of a skilled plant breeder. This ensures that foundation seed is supplied both initially and on a regular basis. A joint inspection team of scientists and officials from the certifying agency and the National Seed Corporation monitors breeder seed. Breeder seed crop genetic purity should be maintained at 100 percent.

Foundation seed: Foundation seed is the offspring of breeder seed and is produced under the technical supervision of competent plant breeders or technical officers by the State Farm Corporation of India, the National Seed Corporation, and the State Seed Corporation. A certification body oversees and approves its manufacturing. 99.5 percent genetic purity should be maintained in foundation seed.

Certified seed: The progeny of foundation seed, certified seed is produced under the supervision and approval of a certification agency. This class of seed is typically produced on progressive grower's farms by the State and National Seeds Corporation and private seed companies. This is the commercial seed

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that farmers may buy, and it should have a genetic purity of 99 percent.

Seed class	Tag colour
Breeder's seed	Golden yellow
Foundation seed	White
Registered seed	Purple
Certified seed	Blue

Each stage involves field inspections, isolation requirements to prevent crosspollination, and laboratory testing for germination percentage, purity, and moisture content.

Seed Certification Standards typically include

Genetic Purity: Ensuring the seed is true to type.

Physical Purity: Free from weed seeds, inert matter, or other crop seeds.

Germination Capacity: Minimum standard (e.g., 70-80% depending on crop).

Seed Health: Free from seed borne diseases.

Moisture Content: To ensure safe storage and longevity.

Factors	Standard	
	Foundation	Certified
Pure Seed (minimum)	98%	98%
Inert material (Minimum)	2%	2%
Other crop seed (maximum)	10/kg	20/kg
Other distinguishable varieties (maximum)	10/kg	20/kg
Total weed seed (maximum)	10/kg	20/kg
Objectionable weed seed (maximum)	2/kg	5/kg
Germination (minimum)	85%	85%

Impact of Seed Certification

Improvement in Yield: Certified seeds generally exhibit better germination, stronger seedlings, and uniform crop stand. This directly translates into higher yields per unit area. For example, in cereals like rice and wheat, yield increases of 15-20% are commonly reported when certified seed is used compared to farm saved seed.

Maintenance of Genetic Purity: Seed certification ensures that the variety grown remains genetically true to type. This prevents admixtures, maintains uniformity in traits like grain size, maturity period, and cooking quality, and protects the farmer's investment.

Uniformity in Crop Performance: Uniform crop stands help in better crop management, synchronized flowering, and ease of harvesting. This uniformity reduces competition among plants and allows more efficient use of inputs.

Resistance to Pests and Diseases: Certified seeds are carefully inspected and tested to minimize seed borne diseases. Moreover, many certified varieties are bred for disease resistance, which reduces crop losses and pesticide use.

Cost effectiveness and Efficiency: Although certified seeds may cost more initially, they save money in the long run through reduced input wastage, better crop establishment, and higher yields.

Role in Climate Resilience: Certified seeds often include varieties developed for drought tolerance, salinity resistance, or early maturity, thereby helping farmers adapt to changing climate conditions.

Socioeconomic and Market Impact

Farmer Income and Livelihood: Higher productivity from certified seeds directly improves farmer income. In addition, surplus produce of uniform quality fetches better market prices.

Boost to Seed Industry: Seed certification encourages the growth of both public and private

seed sectors by creating a transparent and reliable seed market. This has led to a flourishing seed industry in countries like India, which is now one of the largest seed markets globally.

National and International Trade: Certified seeds meeting international standards are eligible for export, strengthening foreign exchange earnings. Within domestic markets, certification helps reduce disputes and builds trust.

Community Empowerment: Certification schemes also promote farmer producer organizations (FPOs) and cooperatives to engage in seed production, generating employment and strengthening rural economies.

Challenges in Seed Certification

Despite its benefits, seed certification faces several hurdles:

Accessibility for Small Farmers: Many small-holders rely on farm saved seeds due to the higher cost of certified seed.

Infrastructure Limitations: Lack of sufficient seed testing labs, trained inspectors, and storage facilities affect timely certification.

Prevalence of Spurious Seeds: Uncertified or fake seeds often infiltrate markets, reducing farmer confidence.

Procedural Delays: Lengthy approval processes and inadequate manpower slow down certification, especially in peak seasons.

Awareness Gap: Many farmers are still unaware of the long-term benefits of certified seed.

Future Prospects and Policy Support

To maximize the impact of seed certification, several strategies can be implemented:

Digital Seed Certification: Use of block chain and QR code based traceability to ensure transparency.

Strengthening Infrastructure: Establishment of more seed testing laboratories at regional levels.

Participatory Seed Certification: Involving farmers and community groups in the certification process for decentralized quality control.

Government Incentives: Subsidies and support schemes to encourage adoption of certified seeds.

International Collaboration: Harmonizing national seed laws with global standards (e.g., OECD seed certification schemes).

Conclusion

Seed certification acts as the foundation of modern crop production systems. By ensuring genetic purity, disease free planting material, and quality assurance, it significantly enhances yield, stabilizes food supply, and boosts farmer incomes. Although challenges remain in accessibility, infrastructure, and farmer awareness, advancements in digital certification, policy support, and participatory approaches can make certified seed available to all sections of farming communities. In the long run, seed certification is not just a technical requirement it is a crucial strategy for ensuring food security, sustainable agriculture, and economic growth in developing as well as developed nations.

Melissopalynology: Scientific Perspectives on Honey, Pollen and Foraging Ecology

Priyanka K. and Nilima Karam

Abstract

Honey is not only a natural sweetener but also a source of healing, cultural significance, and ecological information. Embedded within honey are pollen grains, which serve as microscopic markers of its botanical and geographical origins a field of study known as melissopalynology. This discipline enables authentication of honey, classification as unifloral or multifloral, and mapping of bee foraging resources. In India, melissopalynological studies have revealed seasonal and regional variations in pollen composition, identified medicinal and economically important plant sources, and contributed to ecological monitoring and biodiversity assessment. Advances in microscopy, statistical analyses, and molecular tools have enhanced the accuracy and utility of pollen analysis. Melissopalynology thus integrates apiculture, food quality control, and environmental research, highlighting honey as both a valuable commodity and a natural archive of landscapes, plant diversity, and seasonal changes.

Introduction

Honey has fascinated humankind for centuries not only as a natural sweetener but also as a source of healing and cultural importance. Beyond its golden glow and rich taste, honey conceals microscopic clues about its origin. These clues are pollen grains, carried into honey during the foraging activities of bees. The science devoted to studying this pollen is known as melissopalynology, a discipline derived from the Greek words *Melissa* (bee) and *palynology* (study of pollen). At its core, melissopalynology identifies the botanical and geographical origins of honey, ensuring authenticity and quality in global markets. Its importance, however, extends beyond commerce, offering valuable insights into ecological monitoring, biodiversity assessment and plant-pollinator interactions. The roots of melissopalynology date back to 1885, when P fister first demonstrated that pollen in honey could reveal its floral source. Since then, the field has advanced significantly with the use of microscopy and statistical methods, broadening its scope and precision (Datta *et al.,* 2008; Ponnuchamy *et al*., 2014). In India, melissopalynology has gained momentum over the past decades, with studies spanning the Himalayan, peninsular, and coastal regions. These investigations highlight its wide-ranging potential, from supporting apiculture and honey authentication to contributing to food science and ecological research.

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Principles and Utility of Melissopalynology

Melissopalynology is built on the fact that pollen grains are morphologically distinctive. Their size, apertures, and surface ornamentation allow scientists to identify which plants bees visited. Since pollen enters honey both from nectar collection and incidental contamination during foraging, it provides a natural record of the floral environment within the bees' foraging radius.

The primary outcomes of melissopalynological analysis are:

- ✓ Classification of honey as unifloral or multifloral.
- ✓ Authentication of claims regarding floral or geographic origin.
- ✓ Mapping of bee forage resources to support apiculture.

Botanical and Geographical Authentication

Honey is broadly classified into:

Unifloral honey: Originating predominantly from one plant species (e.g., eucalyptus, mustard, or jamun). Such honeys often have distinctive colors, tastes, and aromas.

Multifloral honey: Derived from a diversity of species, reflecting the wider floral availability of a region.

Melissopalynology provides a pollen-based fingerprint to confirm authenticity. Examples

Andhra Pradesh: Tamarind (*Tamarindus indica*) and eucalyptus dominate in winter honey; palm (*Borassus flabellifer*) and jamun (*Syzygium cumini*) in summer (Ramanujam and Kalpana, 1992).

Uttar Pradesh: Jamun is consistently the main pollen in spring honey (Chaturvedi, 1989).

Kerala: Mixtures from rubber, tea, and wild forest species show how agriculture and forests intersect (Deodikar and Thakar, 1953).

These findings not only help authenticate honey but also reflect India's ecological diversity.

Seasonal and Regional Variability

Melissopalynology also reveals seasonal flowering cycles. Since honey contains pollen from blooming plants during the bees' active foraging, it serves as a seasonal archive of vegetation. For example, in Puducherry, a three-year study of 42 honey samples across tropical forests, coconut groves, agricultural fields, and shrub jungles revealed:

- ✓ 80 pollen taxa representing 41 families (trees, shrubs, herbs, climbers, grasses and sedges, epiphytes).
- ✓ Seasonal dominance: *Lannea* in summer, *Dodonaea* in winter patterns linked to rainfall and flowering cycles.
- ✓ Consistent presence of coconut (*Cocos nucifera*) as a year-round pollen source.

Such temporal patterns highlight the adaptability of bees to dynamic floral landscapes. On a larger scale, pollen in honey acts as an indicator of environmental change, reflecting deforestation, land-use shifts, or climate variability (Nagamani *et al*., 2020).

Methodological Developments

The field has grown beyond traditional

microscopy to include advanced methods:

Acetolysis and Microscopy: Classical method for identifying pollen grains.

Scanning Electron Microscopy (SEM): Provides high-resolution images of pollen surface details, critical for distinguishing similar species (Ramanujam and Kalpana, 1992).

Statistical Analyses: Techniques like Principal Component Analysis (PCA), Linear Discriminant Analysis (LDA), and Bray Curtis indices help classify honeys by season and region (Nagamani *et al*., 2020).

Molecular Tools: DNA barcoding complements microscopy, useful for pollen types difficult to identify morphologically.

These methods improve accuracy, reproducibility, and the integration of palynological data with ecological and biochemical studies.

Applications in India

India's diverse climates and flora make it an ideal ground for melissopalynology. Contributions include:

Bee forage mapping: Early work by Deodikar and Thakar (1953) and later studies across Andhra Pradesh, Maharashtra, and Uttar Pradesh identified major nectar and pollen sources, guiding beekeeping.

Medicinal pollen identification: Pollen from plants like jamun (*Syzygium cumini*), bitter gourd (*Momordica charantia*) and periwinkle (*Catharanthus roseus*) all known for medicinal uses have been traced in honey (Chaturvedi, 1989; Ramanujam and Kalpana, 1992).

Quality control: The Food Safety and Standards Authority of India (FSSAI) and Bureau of Indian Standards (BIS) require pollen analysis alongside tests for pH, moisture, enzyme activity, and sugar composition (Shukla and Rao, 2021).

Ecological monitoring: Honey pollen records flowering times, habitat diversity, and even climate-driven shifts in vegetation.

Broader Scientific and Commercial Relevance

The scope of melissopalynology extends across multiple domains:

Apiculture: Helps locate optimal hive sites and supports production of high-value unifloral honeys.

Food authentication: Prevents adulteration and misbranding through reliable pollen fingerprints.

Biodiversity assessment: Captures plant diversity of landscapes without destructive sampling.

Climate research: Detects shifts in flowering patterns, rainfall impacts on pollen diversity, and pollinator resilience.

Sustainable agriculture: Identifies critical forage plants and aids in pollinator conservation (Bhusari, Mate and Makde, 2005; Datta *et al*., 2008).

Conclusion

Melissopalynology has grown from a specialized field into a multidisciplinary science that integrates apiculture, ecology, food safety, and environmental monitoring. By studying pollen grains in honey, it helps determine botanical and geographical origins, track seasonal vegetation cycles, and understand bee foraging patterns. In the Indian context, research has mapped nectar sources,

detected medicinal pollen types, and improved honey authentication, although the need for standardized methods and comprehensive pollen reference libraries persists. With rising global demand for authentic honey, melissopalynology remains crucial not only for ensuring product integrity but also for providing deeper ecological insights into pollinators and biodiversity, showing that honey is far more than a sweetener it is a natural archive of landscapes and seasons.

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Computer-Controlled Devices (Automated System) in Agriculture

Deepali Mudgal, Alka Mishra and Abhishek Yadav

Introduction

Automated system in Agriculture is a combination of both software and hardware which is designed and programmed to work automatically without the need of any human operator or worker to provide inputs and instructions for each operation or agricultural activities. Farm Automation or smart farming is a variety of technological interventions and innovations to optimize the food production process and improve the quality by using the computer-controlled techniques. Automated System allow us to monitor the processes in the real time and problem identification. But in case of manual system. It is not possible to coordinate all the operation together. When we use the Automation process in the Farm Practices or the agricultural activities, it is regarded as Farm Automation. Thus, Farm Automation is defined as the utilization of different technological innovations to upgrade and automate the farming practices. As, the traditional farming practices involves large number of workers and time consuming in nature, farm automation plays a huge role in acquiring more time and resources to redirect their properties. The development and adaptation of various types of drones and robotics technology have helped farmers to tackle the rigorous nature of their profession with greater ease. Some Examples of Farm Automation device or techniques are described below:

Robotics application in Planting: Planting crops across large area usually takes several hours of hard labour. This task can also be executed with the help of robots and drones that are capable of planting and other applications. Drone Seed, for example, is a planting drone that's used to help reforest large spaces that have been affected by forest fires. This drone is capable of locating and targeting the precise areas on the ground that are ideal for seeding. They then use compressed air to shoot the seeds onto the ground without allowing them to scatter because of the wind.

Drones for Irrigation: The irrigation of fruits and vegetables crops in the field is an important step to ensure the health and wellbeing of the produce across their various cycles. Irrigation requirement for agricultural crop is very high, although irrigation is a technique that's been in practice for several decades now, the technologies related to irrigation have stagnated, due to various reasons. This is why drones are being sought after to help to reduce the burdens of irrigation for farmers. Drones such as the Agras MG-1 are capable of carrying 10 litres of liquid in a

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single fill and they can cover over 6,000 square meters of farmland in just under 10 minutes. Such drones are capable of understanding and adapting to the various specifics of a farm such as altitude, types of plants being grown, and even the weather conditions. When combined with monitoring technology, these drones can identify specific sections of the farm that require greater attention and match these needs with immense ease.

Analytical and Monitoring Tools: Usually, the farmers need to spend a huge amount of money to monitor and analyse the conditions of their crop manually, but by using the Farm Automation, using the helps of drone techniques, it is useful to monitor the farm land easily. These drones can be programmed to seek and identify various specifics to help better knowledge information to the farmers. This includes using different sensors and cameras such as infrared technology to be able to identify damaged crops, keep a check on nutritional levels, and even offer a 3D field map to the farmers.

Harvest Automation Tools: The harvesting time is the most important phase of farming, which is also labour intensive. Harvest robots are therefore being developed to aid in this crucial juncture. Abundant is an excellent example of a harvesting robot that specializes in apples. The use of vacuum technology in this bot has been known to make an enormous difference in its execution. Agrobot is another similar invention that's used to help farmers harvest strawberries. It uses A. I technology to understand the ripeness of the fruit before it can harvest them.

Automatic Irrigation: Two main functions that can be carried out by the automated irrigation includes SDI (subsurface drip irrigation) assistance and providing information through sensors. SDI technology is useful for providing precise levels of water to necessary plants and controlling the drip. When coupled with IoT sensors, it can help farmers study the moisture levels in the soil at all points and take necessary action when necessary.

Robotics for Seeding and Weeding: Seeding and weeding practices also labour intensive. Farming robots have been specially created to help in this process. These robots utilize technologies such as artificial intelligence and computer vision to maximize their efficiency and thereby make full use of the resources at hand, even the process of applying fertilizers can be done with high accuracy with these robots, and their accuracy has an incredible impact on the soil and environment of the region.

Automated Tractors: Automated tractors have been making waves in the field of Agricultural engineering and technology. These machines can be remotely controlled and can help farmers open up a lot of spare time in order to focus on the more immediate needs of their farms. Smart tractor technology is certainly on the up and up, and it's expected that these vehicles will become fully autonomous in the near future. This means that they will be able to utilize various ancillary technologies such as GPS and light detection sensors to carry out various functions of the farm without the supervision of the farmers. A good example of automated tractors

comes from Bear Flag Robotics who specializes in creating driverless factors. Farmers can now remotely plan the routes of these vehicles and even gain real-time reports of their land as the tractor goes about its duties.

Automatic Milking System (AMS): Automatic milking system (AMS) also called Voluntary milking system (VMS), were developed for the process of automatic extraction of milk from the dairy animals, especially the dairy cattle. The core of such systems that allows complete automation of the milking process is a type of agricultural robot. Therefore, it is also regarded as robotic milking. Common systems rely on the use of computers and special herd management software. They can also be used to monitor the health status of cows.

Instead of being milked collectively at predetermined times, voluntary milking gives the cow the freedom to choose her own milking schedule and interval. Since the cow may choose to be milked at any moment during the day, AMS necessitates total automation of the milking procedure. A milking machine, a robotic arm for automatic teat-cup application and removal, a teat position sensor (often a laser), and a gate system for managing cow traffic make up the milking unit. The cows spend the majority of their time sleeping or eating in the free-stall area, but they may be kept in a barn permanently. Some AMS manufacturers have suggested employing a selection gate to let only milked cows into the outside pastures if cows are to be grazed as well.

A cow ID sensor reads the cow's identification tag (transponder) and transmits the cow ID to the control system when the cow decides to enter the milking unit (because of the very tasty feed she finds in the milking box). The automatic gate mechanism removes the cow from the unit if it has been milked too recently. Automatic teat cleaning, milking cup application, milking, and teat spraying occur if the cow is able to be milked. The cow in the milking unit must be offered concentrated feedstuffs as a perk for coming to the milking unit. An AMS can milk between 50 and 70 cows per milking unit. AMS usually achieve milking frequencies between 2 and 3 times per day, so a single milking unit handling 60 cows and milking each cow 3 times per day has a capacity of 7.5 cows per hour. This low capacity is convenient for lower-cost design of the robot arm and associated control system, as a window of several minutes is available for each cow and high-speed operation is not required. Since the early 1990s, AMS devices have been commercially accessible and have demonstrated a reasonable level of success in putting the voluntary milking approach into practice. The Netherlands has been the site of a large portion of the research and development. Denmark and the Netherlands are home to the greatest number of farms with AMS.

Advantages

- ✓ Labour elimination
- ✓ Consistency in milk production
- ✓ Increased in milking frequency

- ✓ Lower stress environment
- ✓ Better herd management

Disadvantages

- ✓ Initial cost is very high
- ✓ Increased electricity cost
- ✓ Complexity of equipment
- ✓ Difficult to apply in pasture systems
- ✓ Lower milk quality.
- ✓ Possible increase in stress
- ✓ Decreased contact between farmer and herd

Advantages in Farm Automation

To meet the growing needs of farmers: The current traditional farming practices will not be able to meet the agricultural need. By using the farm automation and smart agricultural farming technology, it is possible to maximise the potentials of farmlands, minimise the stress on farmers. Over the time, the automation in farming will be able to match the needs of our population.

To solve the labour shortage issues: As we know the agricultural practices are labour- intensive in nature. Due to the shortage of labour worldwide, it badly affects the agricultural practices. In most of the areas, agriculture practices are not followed due to the severe shortage of labour. Robots and drones can be used to tackle this issue by the means of automation.

To create an eco-friendly environment: Due to the higher use of chemicals and cutting down the trees in forest, which have a negative impact on our environment. In case of smart farming techniques, the main aim is to maximize the utility of space and improvement of existing processes to protect the environment.

Challenges of Farm Automation

The drone technology and robotics application are the new inventions which are being adopted for agriculture. These techniques also involve very high initial investment costs, so most of the farmers are not able to afford such costly technologies specially in India. In India farm fragmentation and size of farmers is very small, so farm automation is not justified much. Farm Automation is possible in India at co-operative basis only.

Mangrove Conservation Strategies: Safeguarding Coastal Life and Livelihoods

Sujeet Kumar Rai, Ravi Kumar, Amit Singh Kshatri and Sonal Chourasia

Abstract

Mangrove habitats, sometimes known as the "green guardians of the coast," are crucial for preserving biodiversity, coastline protection, and coastal livelihoods. They act as natural storm barriers, provide a significant amount of carbon sequestration, and act as nurseries for marine life. But as urbanization, aquaculture, and deforestation increase, the amount of mangrove cover worldwide has been worryingly decreasing. Conservation strategies that integrate traditional knowledge with modern science, such as policy interventions, community-led projects, and restoration, are examined in this article. To ensure food security, climate resilience, and the viability of coastal ecosystems over the long run, these efforts need to be reinforced.

Introduction

Mangrove ecosystems in coastal locations support local residents' lives both directly and indirectly. Key socioeconomic benefits of healthy mangroves include lowering poverty, boosting local productivity, fostering resilience, producing money for resource users, and ensuring food and subsistence security. Ecosystem services provided by mangrove forests fall into four categories: providing, regulating, supporting, and cultural (Dulyakasem *et al.,* 2025). Mangrove ecosystems offer vital ecological, economic, and social advantages, yet they are severely degraded by both natural and human-caused factors. With an emphasis on combining conservation with sustainable economic endeavours, this study examines ecosystem-based conservation tactics in Muara Gembong District (Sitiningrum *et al.,* 2025). Recent studies conducted in Indonesia, home to some of the largest mangrove regions in the world, demonstrate the enormous potential of mangroves to mitigate climate change with efficient management. According to a 2024 study, Indonesian mangrove forests store more than 3,200 Megatonnes of carbon (MtC), with the Papua and Kalimantan regions contributing the most. Although many management models currently prioritize ecological sustainability over immediate advantages to the welfare of the local people, conservation, restoration, and blue carbon monetization efforts were identified as key policy levers (Handayani *et al.,* 2024). According to certain worldwide datasets, planted mangroves can restore up to

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70-75% of the carbon stocks of intact mangrove forests in 20 years. This suggests that restoration initiatives can significantly reduce historical losses if they are carefully planned and closely monitored (Bourgeois *et al.*, 2024). Rich biodiversity and prolific coastal fisheries, which are essential to food security and revenue in many developing nations, are also supported by mangroves. Many marine species can find perfect nursery homes in their submerged roots and dense foliage. Mangrove ecosystem health has a direct impact on the economic and social well-being of innumerable coastal communities. As a result, preserving mangroves is not only important for the environment but also for human equity and existence. These contributions guarantee the preservation of marine resources and ecosystem services, which is in direct accordance with SDG 14: Life below Water (A Al-Asif, 2025).

Nature's Coastal Shield: The Role of Mangroves

Mangroves are essential as natural coastal barriers because they defend against tidal floods, storm surges, and erosion while also promoting biodiversity and regulating the climate. They protect infrastructure and human communities from harsh weather events and sea level rise by stabilizing coasts and dissipating wave energy through their special root systems (Su *et al*., 2021). Tropical coastal ecology and coastal managers are becoming more aware of the notion that mangroves could shield coastal populations from coastal risks such cyclones, wind and salt spray, tidal bores, and coastal erosion. Numerous quantitative and modeling studies have demonstrated the ability of mangrove forests to reduce wave energy. The amount of energy absorbed is highly dependent on the density of the forest, the diameter of the stems and roots, the shape of the forest floor, the bathymetry, the incoming waves' spectrum properties, and the tidal stage at which the wave crosses the forest (Blankespoor *et al.*, 2017). Mangrove forests serve as barriers between the ocean and the land. They lessen coastline erosion, trap sediments, and lessen the impact of storms and waves thanks to their extensive root systems. The efficiency of mangroves in lowering storm surge flooding varies depending on local terrain, species composition, and forest density, according to studies; however, widespread mangrove covering typically results in significant decreases in coastal vulnerability (Su *et al*., 2021).

Threats to Mangrove Ecosystems

According to Cahyaningsih *et al.* (2022), urbanization, deforestation, industrial pollution, and the effects of climate change, such as rising sea levels and more intense storms, are all posing a growing danger to mangrove ecosystems. The livelihoods and resilience of more than 1.3 billion people living close to tropical coasts, especially fishing communities, depend heavily on coastal ecosystems. Pollution, local deterioration, overfishing, and climate change are all risks to these ecosystems. Social-ecological variables unique to each site influence how different communities view these difficulties (Fardin, 2025). In addition to natural hazards like erosion and typhoons, mangroves are also subject to significant

human-caused stresses like pollution, over-exploitation, land conversion, and aquaculture. Climate change will make these threats much more severe. Global conservation and restoration initiatives are in progress, but effective long-term management requires incorporating local livelihoods and community involvement. Hydropower projects, while providing renewable energy, significantly impact riverine environments (Rahman *et al.,* 2025; Shruthi *et al.,* 2025).

Fig. 1: Showing Threats to Mangrove Ecosystems

Important coastal ecosystems, mangrove forests offer priceless services like carbon sequestration, biodiversity preservation, and protection against coastal erosion. These habitats in Benoa Bay, Bali, Indonesia, are coming under more and more strain from tourism, infrastructural expansion, and urbanization. To evaluate changes in mangrove canopy cover from 2013 to 2023 and correlate them with mangrove management strategies, this study used satellite imagery. Mangrove area has somewhat decreased overall, with certain regions seeing decreases as a result of development pressures supporting urban infrastructure and tourism facilities, while others have benefited from replanting efforts (As-syakur *et al.,* 2025). Coastal industrialization and agriculture introduce heavy metals, chemicals, and microplastics into mangroves, raising ecological risks and reducing ecosystem services. In estuaries like China's Pearl River, over 80% of vulnerable mangroves are threatened by land-based pollution and reclamation (Maiti and Chowdhury, 2013). Climate change drives mangrove loss through rising seas, higher temperatures, and stronger cyclones. Mangroves struggle to keep pace with rapid sea level rise beyond ~7 mm year^{-1}, leading to die-offs. By 2100, over half of mangrove regions, especially in Southeast Asia, may face severe risk, threatening dependent coastal populations (Hülsen *et al.,* 2025).

Conservation Strategies in Action

Ecological restoration, community involvement, strong legislative frameworks, and the integration of sustainable livelihoods have become key components of conservation initiatives for mangrove ecosystems. In a number of nations and areas, these strategies have produced quantifiable results in recent years (Kikpa *et al.,* 2025). Through community-driven conservation, residents are empowered to maintain and restore mangroves while sustaining their livelihoods. Over 11 km² of mangroves were restored in Gujarat through Joint Forest Management, while Senegal's CBEMR strategy

increases resilience in areas that are vulnerable to disasters. Healthy ecosystems and long-term management are promoted by combining restoration research with traditional knowledge (Heck *et al*., 2024). Restoring mangroves successfully requires addressing hydrological imbalances and encouraging natural regeneration as opposed to mass planting. Thailand's 2024 Mangrove Alliance aims to increase national cover by 10-15% and manage approximately 30% of mangroves, emphasizing biodiversity, ecosystem health, and community roles. Restoring site conditions guarantees long-term healing (Barona *et al*., 2025). Through incentives, prohibitions, and sustainable management practices, more than 80% of mangroves worldwide will have legal protection by 2025. PES and blue carbon credits are two tools that help local stewardship, and nations like India offer national policies and financial support to conserve over 38 mangrove habitats (Slobodian *et al*., 2025; Kshatri *et al*., 2025). Aquaculture, mangrove-based businesses, and sustainable tourism are supporting local economy and conservation objectives. Wildlife viewing, guided boat tours, and local cuisine are all examples of ecotourism activities that are booming throughout Southeast Asia and India. These activities raise money for conservation and enhance household welfare (Malik *et al.,* 2025).

The Role of Local Communities and Indigenous Knowledge

The conservation, restoration and sustainable management of mangroves depend heavily on local people and traditional knowledge. By actively participating in the planting, monitoring, and protection of mangroves, the community promotes long-term conservation results. For instance, communities established forest farmer organizations in North Sumatra, Indonesia, which actively maintain mangroves through practices like patrolling and replanting, aided by community laws and local education. Traditional knowledge and local residents are essential to mangrove conservation, restoration, and sustainable management. Through active community involvement in mangrove planting, monitoring, and protection, long-term conservation outcomes are fostered. In North Sumatra, Indonesia, for example, communities formed forest farmer organizations that actively preserve mangroves through replanting and patrolling, supported by local education and community regulations. Community voices are being given top priority in international forums and national discussions on mangrove governance, acknowledging that just laws, policies, and funding sources must empower those who directly rely on and safeguard mangroves. In order to scale community-led conservation across many locations, multi-stakeholder collaboration is emphasized by initiatives such as the Global Mangrove Alliance and UNESCO's MangRes project (Nasution *et al.,* 2025).

Future Pathways: Blending Science and Tradition

The future of mangrove conservation rests on the ability to effectively combine scientific know-

ledge with traditional ecological knowledge (TEK) held by the local population to develop a collaborative approach that respects both empirical rigor and cultural legacy. Addressing past divisions between the two knowledge systems, this integrative approach provides a path ahead for mangrove ecosystems that are more resilient and sustainable (Prism Sustainability Directory, 2025). Through locally tailored monitoring, culturally relevant restoration methods, and the transfer of knowledge across generations, this participatory paradigm promotes empowerment. Cohesion and stewardship are strengthened in the face of global changes as empowered communities develop social and ecological resilience (Prism Sustainability Directory, 2025; East Africa Wetlands, 2025).

Conclusions

Human well-being, biodiversity, and coastal resiliency all depend on mangrove ecosystems. Their capacity to protect against storm surges, support fisheries, and store carbon makes them essential for meeting the demands of local livelihoods as well as the difficulties posed by the global climate. Yet, the speed at which they are declining as a result of aquaculture, urbanization, and climate change demands immediate attention. Restoration, community involvement, robust policy frameworks, and the fusion of scientific innovation and traditional wisdom are all essential components of successful conservation programs. Global and regional success stories demonstrate that mangroves may be sustained and restored when governments, non-governmental organizations, and coastal communities collaborate. In the end, preserving these "green guardians" means preserving coastal life, livelihoods, and the future of the planet's climate.

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High-Tech Horticulture: The Future of Sustainable Farming

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Horticulture has always been at the heart of human civilization, providing us with fruits, vegetables, flowers, and ornamental plants that enrich both nutrition and culture. Traditionally, it has relied on soil, weather, and manual labor. But in today's rapidly changing world, where climate variability, land scarcity, and food demand are pressing challenges, horticulture is undergoing a transformation. The concept of high- tech horticulture has emerged as a revolutionary solution, blending modern science and technology with age-old cultivation practices.

What is High-Tech Horticulture?

High- tech horticulture refers to the use of advanced methods and infrastructure to grow crops under controlled or semi-controlled conditions. Instead of depending on natural soil and rainfall, these systems employ modern tools such as polyhouses, greenhouses, hydroponics, vertical farming, tissue culture labs, and precision agriculture technologies. The goal is to increase productivity, improve quality, reduce risks, and make farming more resource-efficient and profitable.

Key Components of High-Tech Horticulture

Protected Cultivation: Crops are grown inside structures such as polyhouses or greenhouses, where temperature, humidity, and light can be adjusted according to plant needs. This shields crops from harsh weather, pests, and diseases, ensuring stable and higher yields.

Soilless Farming: Techniques like hydroponics, aeroponics, and aquaponics allow plants to grow without soil, using water-based nutrient solutions or mist. These methods save up to 80-90% water and are highly suitable for urban areas and regions with poor soils.

Precision Agriculture: Tools such as drones, satellite imagery, soil sensors, and GPS systems help farmers monitor plant health, soil fertility, and irrigation needs. With data- driven insights, farmers can reduce fertilizer and pesticide usage while maximizing crop output.

Automation and AI: Smart irrigation systems, climate control devices, and robotic harvesters are being integrated into horticulture. Artificial intelligence can predict pest outbreaks, recommend nutrient applications, and even optimize harvest schedules.

Biotechnology and Tissue Culture: Through tissue culture, millions of uniform, disease- free seedlings can be produced in a short time. Biotechnology also enables the development of high- yielding and climate- resilient crop varieties.

Benefits of High-Tech Horticulture

Higher Productivity: Yields are 3-10 times greater compared to conventional farming.

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Efficient Resource Use: Modern irrigation systems cut water use drastically, while precision farming reduces excess fertilizer and pesticide application.

Quality Produce: Crops are uniform, pesticide-free, and often meet international export standards.

Year-Round Cultivation: Farmers can grow off-season vegetables, exotic flowers, and fruits regardless of external climate.

Better Income Opportunities: High- value crops like strawberries, orchids, capsicum, and medicinal plants provide lucrative returns and open new avenues for entrepreneurship.

Challenges and the Way Forward

Despite its promise, high- tech horticulture faces certain hurdles. High initial investment costs, limited technical know-how, and lack of awareness among small farmers remain major barriers. However, government subsidies, training programs, and private sector innovations are helping bridge this gap. With proper guidance and support, high- tech horticulture can become accessible even to small and marginal farmers.

Conclusion

High-tech horticulture is not just an advancement in farming techniques it is a paradigm shift in agriculture. It offers a way to feed growing populations, conserve resources, and adapt to climate change while ensuring profitability for farmers. As technology continues to evolve, this modern approach will play a crucial role in shaping a sustainable and prosperous future for global agriculture.

Important Chemical Constituents in the Oil of Different Aromatic Plants and their Uses

Deepanjali Maurya, Hari Baksh, Rajaneesh Singh and Aman Srivastav

Aromatic plants are the plants which contain or emit a strong, pleasant and distinctive smell due to the presence of essential oils or other volatile compounds. These plants include herbs, shrubs, climbers and trees. Essential oils are mainly a complex mixture of cyclic or acyclic monoter-penoids. These terpenoids are basically secondary metabolites. These aromatic plants have a variety of complex chemical compounds. It contains odorous volatile Substances, which occur as essential oil and oleoresin in one or more plant parts, namely- root, wood, stem, foliage, flowers and fruit. Essential oil is concomitant to fragrance or perfume because these fragrances are oily in nature representing the essence or active constituents of plants. They are called volatile or ethereal oils as they evaporate at ordinary temperatures. They are constituting hundreds of organic compounds including terpenoids, benzen-oids, organic sulphur and nitrogenous compounds, which work at different levels. Essential oils contribute to about 17% in the world of fragrance and flavour industry. The extent of usage of essential oils is 55-60% for flavours in food industry, 15-21% for fragrances in perfumery or cosmetic industry, 10-20% as starting material for isolation of components, 5-10% as active substances in pharmaceutical preparations and 2-5% for natural products.

Essential oils and aroma chemicals constitues e a major group of industrial products as it is used in perfumes, cosmetics, flavouring of food and drink, and for making scenting incense and household cleansing products. Beyond scent, aromatic plants also contain biologically active compound, such as polyphenolics, which possess antioxidant, anti-microbial and anti-inflammatory properties. Essential oils are obtained by distillation. In these plants content of essential oil is very low, typically 1 to 3% of the plant weight. They are thus low-volume, very high value products. Now a day's aromatherapy is an emerging science of healing by using natural plant essential oils, which have therapeutic effect on body, mind and soul by reducing stress and promoting relaxation. Some well-known aromatic plants and their properties are discussed here under:

Citronella (*Cymbopogon winterianus*): It is a large, perennial, steamless, aromatic grass which is also known as Java Citronella and belonging to family Graminae. Its oil have many important chemical constituents like- Citronellal, Geraniol, Geranyl acetate, Citronellol, Limonene, Linalool, Eugenol, Borneol etc. The economic part is leaves which gives good oil recovery of 1.0 to 1.2 percent from steam distillation.

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Its oil is mostly used in cosmetics, perfumery and flavouring industries for making different products like- soaps, detergents, soap flakes, household cleansers, technical products and also to make mosquito repellents products. Java-2, Jorhat-C2, CIM-Jeeva, Mandakini, Manjari, Medini, CIMAP-Bio-13 are some high yielding varieties.

Lavender (*Lavandula angustifolia*): It is an aromatic shrub belonging to family Lamiaceae. It produces volatile terpenoids like- Linalool and Linalyl acetate that serve as resources for essential oil. Its oil contain 50-53% of ester. It is mostly used in perfumes. CIMAP-B-15 (Sher-e-Kashmir) and Karlovo are its important varieties.

Lemongrass (*Cymbopogon flexuosus*): It is a stemless, perennial aromatic grass belonging to family Graminae. It is locally known as Coachin or Malabar grass. Citral-a, Citral-b, Farnesol, Farnesal, Terpieol, Nerol and Borneol are some important chemical constituents. The economic part is leaves which gives 0.3 to 0.6 percent essential oil by distillation. The oil is mostly used for perfumes, hair oils, disinfectants, cosmetics products, scenting soaps, flavouring curries, wines, sauces and also helpful agaist headaches and toothaches. It has anti-bacterial and insect repellent properties. CIM-Swarna, Chirharit, Pragathi, Praman, Nima, Krishna, Kalam, Sugandhi, Cauveri, SD-68, GRL-1, RRL-16 are some important varieties of Lemongrass.

Khus grass (*Chrysopogon zizanioides*): It is a tall, perennial grass also known as Vetiver and belonging to the family Graminae. It produce dense, spongy, aromatic root systems with fine rootlets and root content 1-1.5 percent essential oil (Veteverol). Its oil has carminative, anthelmintic and refrigerant properties and also used in perfumes, cosmetics and scenting soaps. Dharini, Gulabi, Keshari, Sugandha, CIM-Vridhi, ODV-3 are some important varieties.

Oil bearing rose (*Rosa damascena*): Now a days, Apart from aesthetic importance, the rose are of high economic benefits, and religious significance. The rose thus, merits pride of place as the 'Queen of flowers'. The fragrance of damask rose surpassess all the other roses. It belonging to the family Rosaceae. The economic part is petals, which contains 0.025- 0.030 percent oil and Major chemical constituents of oil is Citronellal, Geranial, Neral, Phenyl ethyl alcohal & Cis and Trans-rose oxide. Noorjahan, Rani Sahiba, Jwala and Himrose are some important varieties. Rose water, Gulkand, Rose attar, Pankhuri, Roseotto are some valuable products of rose.

Mentha (*Mentha spp.*): It is an aromatic herb of mediterranean origin, belonging to the family Labiatae. Menthol, Carvone, Piperiton, Menthone, Menthafuron, Linalool, Linalyl acetate etc. are its

important chemical constituents. The oil percentage is 0.5-0.6%. CIM-Kranti, CIM-Saryu, Kosi, Himalaya (MAS-1), Shivalik, Gomati and Kiran are some important varieties. Mentha's whole plant is of economic importance and used for following purposes like-pain balm, menthol crystal, gastro stimulant, cough syrup, toothpaste, medicines, perfumes, scenting soap, confectionery, chewing gum, cosmetics etc.

Basil (*Ocimum spp.*): It is very popular aromatic herb commonly known as Tulsi and belonging to the family Labiateae. Methyl chavicol, methyl cinnamate, Eugenol, Linalool, Camphor, Citral, Thymol etc. are some important chemical constituents of its oil. The oil percentage varies 0.4-0.5%, which is obtained by steam or hydro distillation. CIM-Soumya, CIM-Ayu, CIM-Angana, CIM-Kanchan, CIM-Sharada are some important varieties of Tulsi. Basil's economic part is whole plant and used for flavoring food stuff, sausages, pickles, beverages, confectionery goods, mouth-washes, dental creams, and in treatments of ringworm, coughs, cold, dysentery, dyspepsia, gastric disorders, earache, snakebite, scorpion sting and dog bite. Its oil has anti-bacterial and insecticidal properties and leaves have antipyretic, demulcent, expectorant and carminative properties.

Kewda (*Pandanus fascicularis*): It is an aromatic, perennial, dioecious shrub with fragrant flowers, belonging to the family Pandanaceae. It is also known as Screw pine. The chief constituents of the oil is Methyl ether of beta phenyl ethyl alcohol (60-80%), which imparts its fascinating odour. The economic part is male flower, 1000 flowers gives 18 litres of kewda water and little amount of oil. Pandnus/ Kewda contains phytochemicals like steroids, carbohydrates, phenols, isoflavones, alkaloids, glycosides, vitamins and amino acids. Kewda oil is a stimulant, antispasmodic, antioxidants, antidiuretic, anti-microbial, anti-diabetic, anti-neoplastic, relieves headache and rheumatism. Kewda water is used in flavouring syrups, soft drinks and Mughlai cuisine. Kewda attar is used in scenting soaps, cosmetics, bouquets, lotions, snuff, hair oils and incense sticks. Kewda aroma in beetal (pan masala) and tobacco is very popular. Fancy articles like mats, hats and bags are made with its leaves.

Geranium (*Pelargonium graveolens*): It is a perennial, bushy plant belonging to the family Geraniaceae. Main chemical constituents in oil is Citronellol and Geraniol. Its economic part is leaf blade which yields 0.8-0.15 percent oil and oil is widely used for scenting soaps and for isolation of rhodinal which forms part of most high grade perfumes. As aromatic plants are widely used for human well-being and for income generation, providing raw materials for perfumes,

flavors, cosmetics, traditional medicines and supporting environmental sustainability. Their importance spans healthcare, offering cost-effective remedies and natural compounds for new drugs. So its cultivation, production, distillation and proper management needs support by Government institutions.

In India key institutions supporting aromatic plant growth includes CSIR-Central Institute of Medicinal and Aromatic Plants (CIMAP) for research and technology, the National Medicinal Plants Board (NMPB) for cultivation, conservation, and marketing support, and organizations like the Medicinal and Aromatic Plants Association of India (MAPAI) for industry networking and advocacy. These organizations provide farmers with improved agro-technologies, technical assistance, training and access to markets, aiming to boost the sector and improve rural livelihoods.

Simulation Models for Intercropping: A Scientific Perspective

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Introduction

Sustainable agriculture is a cornerstone of food security and environmental resilience in the modern world. With increasing population pressure and climate variability, innovative cropping systems are required to maximize productivity without compromising ecological integrity. Among these, intercropping defined as the simultaneous cultivation of two or more crop species on the same field - has gained particular importance in tropical and rain-fed regions. Intercropping cereal and legume species provides numerous agronomic and ecological benefits, such as improving soil fertility, controlling weeds, reducing erosion and enhancing overall system productivity. However, the complexity of interactions among multiple species makes it challenging to design efficient intercropping systems solely through field experimentation. To overcome this limitation, simulation models have emerged as powerful tools to analyze, predict and optimize intercropping performance under diverse conditions.

Intercropping Systems: Principles and Applications

Intercropping is a traditional yet scientifically relevant practice that involves growing multiple crop species together. For instance, cereal-legume intercropping has been widely adopted in tropical agriculture due to its ability to harness complementary resource use. Legumes fix atmospheric nitrogen, thereby improving soil fertility, while cereals provide structural support and reduce lodging problems. The integration of crops leads to higher crude protein yields, better forage preservation and enhanced control of root parasitic infections. The advantages of intercropping include higher productivity per unit area, efficient utilization of resources, reduced soil runoff and risk mitigation against crop failure. It also serves as an ecological insurance mechanism, providing stability in abnormal years. Nevertheless, intercropping has disadvantages such as management difficulties, harvesting challenges and limitations in using modern agricultural machinery.

Modeling in Agricultural Systems

Agricultural models are mathematical frameworks that represent the complex interactions between plants, soil and the environment. Unlike physics and engineering, where universal models exist, agricultural models are developed for specific purposes and tailored to particular systems.

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Crop growth models, in particular, simulate daily growth and development of crops by incorporating soil properties, weather conditions and management practices. These models have evolved over the past four decades to achieve high levels of accuracy, allowing researchers and farmers to optimize fertilizer application, irrigation scheduling and crop rotation strategies. They also help in understanding how nutrient availability, nitrogen mineralization and drought stress influence crop productivity. The primary aim of crop models is to estimate harvestable yield, but they also provide insights into system dynamics that are otherwise difficult to capture experimentally.

Types of Crop Growth Models

Crop growth models can be categorized into several types depending on their design and application. Empirical or statistical models are based on observed data and regression equations, offering quick yield estimates, but their applicability is often limited to specific sites. Mechanistic models, on the other hand, simulate biological and physical processes, providing a deeper understanding of crop responses under varying conditions. Deterministic models predict outcomes with certainty, while stochastic models incorporate randomness to reflect natural variability. Static models do not account for time-dependent changes, whereas dynamic models simulate system behavior over time using differential equations. Simulation models, which are largely mechanistic and dynamic are particularly valuable for investigating management strategies, as they integrate climatic, soil and crop parameters. Optimizing models aim to identify the best management practices, though they may simplify biological processes in favor of decision-making efficiency. Together these models form a diverse toolkit for agricultural research and management.

Simulation Models for Intercropping and Multispecies Systems

Modeling intercropping systems presents unique challenges because plant mixtures involve complex interactions that cannot be studied effectively through isolated field trials. Empirical approaches are limited by site-specific data, making mechanistic and dynamic models more suitable for analyzing interspecific competition and cooperation. Models such as CROPSYS, APSIM, STICS-CA and WaNuLCas have been developed to evaluate resource use and productivity in mixed cropping systems. These models often operate at daily time steps and incorporate soil-water-nutrient dynamics along with crop physiology. The spatial and temporal arrangement of species - such as strip *vs.* mixed systems or simultaneous *vs.* sequential planting - significantly affects outcomes and must be carefully represented in models. By integrating ecological principles, simulation models allow researchers to test innovative designs and predict long-term sustainability of intercropping systems.

Model Development, Calibration and Validation

The development of simulation models involves careful design, calibration and validation. Calibration refers to adjusting parameters so that the

model aligns with observed data. This ensures that simulations reflect real-world conditions. Validation involves testing the calibrated model against independent datasets to evaluate its accuracy. However, validation remains challenging in agriculture due to soil heterogeneity, variability in weather conditions and measurement uncertainties. In many cases, crop models must rely on approximate data, which may limit their predictive power. Nonetheless, model calibration and validation are critical steps that enhance the reliability of simulation outcomes, making them valuable tools for decision support in agriculture.

Advantages and Future Directions: Simulation models provide several advantages in agricultural research and practice. They reduce the need for costly and time-consuming field trials, identify constraints in crop production and help maximize yield through optimized management practices. Models also allow researchers to evaluate risks associated with different strategies and to analyze the long-term impact of interventions. Looking forward, the integration of artificial intelligence, remote sensing and big data analytics into crop modeling will further enhance their precision and applicability. Future research should focus on refining intercropping models to account for spatial heterogeneity, multi-seasonal dynamics and climate variability. These advancements will help establish simulation models as essential components of climate-smart agriculture and systemic agronomy.

Conclusion

Simulation models for intercropping are powerful tools that combine scientific understanding with practical applications in sustainable agriculture. They allow researchers to explore complex plant interactions, optimize resource use and develop resilient farming strategies. While challenges remain in calibration, validation and data quality, the continued advancement of modeling approaches promises to enhance food security and environmental sustainability. Intercropping models exemplify how ecological principles can be translated into actionable agricultural practices, ensuring that farming systems remain productive and sustainable in the face of global challenges.

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Precision Farming / Precision Agriculture

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Introduction

Precision farming uses technology, such as GPS, remote sensing, to manage and apply resources like water, fertilizer, and pesticides precisely to site-specific areas of a field based on their exact needs. This "site-specific" approach, also known as site-specific crop management, helps to optimize crop yields, improve resource efficiency, reduce waste, and minimize the environmental impact of farming, making it a more sustainable and cost-effective method compared to traditional blanket applications. The idea: "right input, right place, right time, right rate."

The concept of precision agriculture first emerged in the United States in the early 1980s towards the end of the 1980s, this technique was used to derive the first input recommendation maps for fertilizers and pH corrections. The use of yield sensors developed from new technologies, combined with the advent of GPS receivers, has been gaining ground ever since. Around the world, precision agriculture developed at a varying pace. Precursor nations were the United States, Canada and Australia. In Europe, the United Kingdom was the first to go down this path, followed closely by France, where it first appeared in 1997-1998. In Latin America the leading country is Argentina where it was introduced in the middle 1990s with the support of the National Agricultural Technology Institute, Brazil established a state-owned enterprise. The development of GPS and variable-rate spreading techniques helped to anchor precision farming management practices.

Definition and Scope

Precision farming actually is application of technologies and principles to manage spatial and temporal variability associated with all aspects of production (Pierce and Nowak, 19990).

Precision farming is the technology which involves the targeting of inputs to arable crop production according to crop requirement on the localized basis Precision agriculture can be defined as the application of principles and technologies to manage variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality.

Precision Farming (PF) - précised application of inputs (Water, fertilizer, pesticides etc.) at the correct time to the crop for increasing its productivity and maximizing its yields. Precision farming refers to the use of advanced technologies (sensors, GPS, GIS, remote sensing, data analytics, automation) to monitor and manage spatial and temporal variability in fields.

History of precision farming in India

The history of precision farming in India

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dates back to the early 2000s when the country began exploring ways to improve agricultural productivity through advanced technologies. While traditional farming practices were dominant, there was growing recognition of the need for more efficient and sustainable agricultural methods.

Key Milestones in the History of Precision Farming in India

Early 2000: Introduction of Technology: Precision farming began to gain attention in India with the introduction of GPS technology and satellite imagery. In this period, the Indian government, along with research institutions, started exploring ways to use technology for better land management, irrigation systems, and crop monitoring.

2005: National Initiative on Precision Farming: The Government of India launched the National Mission on Precision Farming (NMPF), aiming to increase productivity and reduce input costs. The initiative focused on adopting satellite-based mapping and soil health management to improve crop yields.

2010: Growth in Adoption: The use of Global Positioning System (GPS), drones, and remote sensing technology began to increase. Pilot projects in states like Punjab, Maharashtra, and Andhra Pradesh demonstrated the potential of precision farming in improving crop management and resource use efficiency. Research institutions like ICAR (Indian Council of Agricultural Research) started conducting studies and training programs to promote these technologies among farmers.

2014-2015: Private Sector Involvement: Private companies and startups began offering technology-based solutions such as variable rate technology (VRT) for fertilizers, automatic irrigation systems, and data analytics platforms to help farmers make data-driven decisions. This period saw the rise of AgTech in India.

Recent Developments

Ongoing Challenges: Despite some progress, precision farming in India still faces challenges such as high technology costs, limited awareness, small landholdings, and poor internet connectivity in rural areas. However, ongoing efforts by the government, research bodies, and the private sector are focused on making these technologies more accessible to Indian farmers.

Need of precision farming

Precision Farming (PF), also known as Precision Agriculture, has emerged as a transformative approach to overcome the limitations of conventional agricultural practices. It addresses the core challenges of resource efficiency, yield stagnation, environmental concerns and profitability:

For Assessing and Managing Field Variability

Agricultural fields are not uniform. Variations in soil properties (texture, fertility, moisture), topography, pest incidence, and crop growth patterns exist within even small landholdings. Traditional farming practices treat the field uniformly, which often leads to:

- ✓ Over- or under-application of inputs in different areas.

- ✓ Uneven yields and sub-optimal performance.
- ✓ Wastage of resources and environmental degradation.

For Doing the Right Thing, in the Right Place, at the Right Time

This principle lies at the heart of precision agriculture. By collecting and analysing field data, precision farming helps farmers make informed decisions on:

- ✓ What action to take (e.g., fertilize, irrigate, spray)
- ✓ Where to apply the action (specific zone or patch of field).
- ✓ When to apply (based on crop growth stage or weather conditions).

For Higher Productivity

Precision farming allows farmers to adopt targeted and optimized management practices, leading to:

- ✓ Increased crop yield per unit of land
- ✓ Improved plant health and uniformity
- ✓ Better utilization of soil potential across different zones

For Increasing the Effectiveness of Inputs

Inputs like fertilizers, seeds, pesticides, and water are expensive and often used inefficiently in traditional agriculture. Precision farming ensures:

- ✓ Improved input-use efficiency: Each unit of input delivers more output
- ✓ Reduced input wastage: No over-application in areas that don't need it
- ✓ Cost savings and higher profitability

For Maximum Use of Minimum Land Unit

With land becoming scarce and fragmented, especially in countries like India, the optimal use of every square meter of land is crucial. Precision farming helps in:

- ✓ Identifying underperforming zones and correcting them.
- ✓ Rehabilitating degraded or low-potential areas through corrective actions.
- ✓ Improving the overall land productivity without expanding acreage.

Techniques in Precision Agriculture

Soil Sampling and Mapping: Create detailed maps of soil properties.

Self-directed Machinery: Tractors, combines, and other farm equipment can be automated and guided by GPS systems.

Variable Rate Application (VRA): adjustment of input application on the go, in real-time, based on GPS data.

Crop Monitoring: Drones or satellites are used for remote sensing to monitor crop health, growth stages, and to detect pest or disease outbreaks.

Yield Mapping: Yield monitors on harvesters collect data on crop yield throughout the field

Data Analytics and Artificial Intelligence (AI): AI predict trends, optimize input usage and enhance decision-making.

Components of Precision Farming

- ✓ Crop Characteristics: Stage of crop, crop health, nutrient requirements etc.
- ✓ Detailed soil layer with physical and chemical properties, depth, texture, nutrient status, salinity

and toxicity, soil temperature etc.

- ✓ Micro-climate data (seasonal and daily) about crop canopy temperature, wind direction and speed, humidity etc.
- ✓ Surface and sub-surface drainage conditions, Irrigation facilities, water availability, and other planning inputs of interest
- ✓ Farm machinery and Equipment equipped with sensors

Basic Steps in Precision Farming

Assessing Variation: This is the foundational step in precision agriculture. Every piece of farmland has spatial and temporal variations in key parameters such as:

- ✓ Soil type and fertility
- ✓ Moisture levels
- ✓ Crop growth and health
- ✓ Pest and disease incidence
- ✓ Topography and drainage

Managing Variation: Once the field variability is assessed and mapped, the next step is to develop and implement site-specific management strategies. This is done through:

- ✓ Variable Rate Application (VRA) of: Fertilizers, Seeds, Irrigation, Pesticides.
- ✓ Automated machinery and equipment guided by GPS and data inputs to apply inputs at variable rates.
- ✓ Zonal management: dividing the field into management zones with similar characteristics and treating them accordingly.

Evaluation: The final step is to evaluate the outcomes of the precision interventions. This includes:

- ✓ Measuring crop yields and comparing them across different zones.
- ✓ Analysing cost-effectiveness and profitability.
- ✓ Assessing resource use efficiency (e.g., fertilizer-use efficiency, water-use efficiency).
- ✓ Monitoring environmental impact

Key Concepts in Precision Agriculture

Site-Specific Management (SSM): Adjusting farming practices within a field, as soil quality, moisture, temperature, and crop conditions.

Global Positioning System (GPS): Precise tracking of farm equipment for field mapping and soil sampling.

Geographic Information Systems (GIS): Decision-making and planning the site-specific treatments for Gelds.

Variable Rate Technology (VRT): Application of inputs at variable rates based on the needs.

Remote Sensing: Helps in monitoring crop health, detecting pest infestations, or identifying soil issues.

Internet of Things (IoT) and Sensors: Provide real-time data on soil moisture, temperature, weather conditions, and crop growth.

Global Positioning System (GPS) n Precision Agriculture

GPS refers to ground-based technology permitting growers to gather data with accurate location information in real-time. GPS is suitable for the following tasks:

- ✓ Mapping of irrigation systems, fields, and roads, Detection of areas with problem plants, Soil

testing in specific field areas, the tractor driving with a parallel steering system, VRA for precise seed and fertilizer application.

GIS Technology in Precision Agriculture: GIS in precision agriculture permits farmers to view records, such as soil survey maps and plant characteristics. Satellite images and aerial photo-graphs provide additional information. Another handy feature of GIS is analyzing multiple farm management options by comparing and manipulating data layers.

GIS + Remote Sensing in Precision Agriculture: GIS in Remote Sensing technology allows growers to observe the yield health using satellite images. They provide up-to-date information on moisture stress, disease, structural anomalies, and nutrient levels. Modern PF satellite imagery has a high spectral resolution, allowing growers to get the most accurate data.

VRT in Precision Agriculture: VRT - allows growers to apply fertilizer, chemicals, seeds, etc. to a different parts of a field depending on their needs. Also, farmers can test the soil for nutrients, such as nitrogen, and feed only those areas that lack certain nutrients.

Yield Monitoring and Mapping in Precision Agriculture: GPS and satellite remote sensing are used for providing data of landscape, earth, and weather. PF yield map, EOSDA Crop Monitoring functionality allows growers to effectively monitor the readiness of crops for harvest with the help of vegetation indices.

NDRE (Normalized Difference Red Edge) index is excellent for such purposes, which more clearly shows the state of vegetation in the later stages of culture's development. It has to analyse the vegetation along with the entire depth of foliage.

Micro Irrigation (Drip Irrigation): A micro-irrigation system allows growers to effectively plan the field's irrigation b identifying areas with high or low soil moisture. Precision agriculture irrigation makes it possible to carry out variable rate irrigation (VRI) to vary the water supply volume for different field parts. This level of control can significantly improve irrigation efficiency and result in significant water savings. One of the indexes used in EOSDA Crop Monitoring is NDMI.

Site-Specific Crop Management (SSCM): It is an agricultural management concept based on monitoring, counting, and reacting to crop variability between fields or within one area. Most current SSCM methods use accurate global positioning combined with site-specific measurements to quantify spatial changing field conditions. They are field data collection (such as pest presence) and remote sensing data (such as from satellites). EOSDA Crop Monitoring allows growers to use management zones in precision agriculture effectively. It can identify problem areas in a field with various possible pathogens: pests, fungus, fertilizer misuse, weeds, lack of moisture, etc. Once identifying a site with deviations, the farmer can send a scout to make a report based on the data collected during the inspection.

Soil Mapping in Precision Agriculture: Precision agriculture is impossible without quality ground mapping. With its help, farmers evaluate the soil properties, its chemical composition, the nutrients' presence, etc. Soil mapping practice has existed for a long time, but modern technologies provide even more detailed information, making the new generation of digital maps more efficient. For obtaining data, farmers use several types of precision agriculture sensors: optical sensors interpret data based on the coefficient of reflection of light from the ground; electrochemical sensors analyse the soil electrical characteristics, such as the potassium's presence; mechanical sensors in contact with the ground determine the types and density of the elements.

IoT in Precision Agriculture: IoT system gives farmers more control over the field with dedicated data sensors remote control, and an IoT platform. With IoT based precision agriculture, growers can control all the most critical information: from air temperature to soil conditions

Artificial Intelligence and Machine Learning: Al and precis agriculture are constantly being improved and provide new intelligent tools for managing agricultural production. Image-based pattern recognition systems allow applications to adjust the watering and nutrition of plants according to their type. For example, sprayers equipped with AI can recognize specific weeds and spray them without affecting the crops.

Benefits of precision farming

Precision farming provides benefits such as increased crop yields, reduced input costs (water, fertilizer, pesticides), enhanced environmental sustainability, and improved crop quality by using data and technology to apply resources only where needed.

Economic Benefits

Cost Savings: Farmers reduce expenses by minimizing the use of costly inputs like water, seeds, and fertilizers.

Higher Yields: Targeted application of resources optimizes plant growth, leading to increased crop production and potential for higher profits.

Reduced Labor: Automation and remote monitoring decrease the need for manual labor, improving efficiency and cutting operational costs.

Environmental Benefits

Sustainable Resource Use: Precision farming promotes efficient water management and reduces the excessive use of fertilizers and pesticides.

Reduced Pollution: Limiting chemical runoff protects soil and water quality, minimizing harm to surrounding ecosystems and wildlife.

Improved Soil Health: The careful, targeted use of inputs helps maintain soil health and prevent degradation over time.

Operational and Agricultural Benefits

Informed Decisions: Technology provides farmers with data-driven insights, enabling them to make timely and precise decisions regarding crop management.

Improved Crop Quality: Maintaining consistent

conditions and providing optimal resources leads to more uniform and higher-quality crops.

Risk Management: Early detection of pests, diseases, or nutrient deficiencies allows for timely interventions, preventing significant crop losses.

Optimized Planting: Precision techniques like variable rate seeding ensure the right amount of seeds are planted in specific areas, maximizing crop potential.

Conclusion

Precision farming in India is a transformative approach that leverages technology to optimize crop yields, reduce waste, and minimize environmental impact. It offers a sustainable and efficient way to feed the growing population while preserving natural resources. By harnessing data analytics, remote sensing, and automation, precision farming can increase efficiency, profitability, and contribute to sustainable agricultural practices. It has the potential to revolutionize the agriculture sector and contribute to India's overall economic growth. Thus, precision farming is undoubtedly the future of agriculture in India.

Marker Assisted Selection (MAS)

Koushik Prasad J. and S. Subhashini

Abstract

Marker Assisted Selection (MAS) has emerged as one of the most powerful tools in modern crop improvement. It combines traditional plant breeding with molecular biology by using DNA markers to identify desirable traits. This approach allows faster, more precise, and efficient selection of plants, leading to the development of disease-resistant, stress-tolerant, and high-yielding varieties. MAS has been successfully applied in rice, wheat, maize, and tomato, significantly contributing to food security and sustainable agriculture. With advancements in genomics, bioinformatics, and biotechnology, MAS is expected to play a pivotal role in future crop improvement programs worldwide.

Introduction

Agriculture has always been the backbone of human civilization. With the global population expected to cross 9 billion by 2050, food security has become one of the greatest challenges of our time. Traditional plant breeding methods, though successful in producing many improved varieties, are often slow, less precise, and dependent on environmental conditions. In response, modern science has provided powerful tools such as Marker Assisted Selection (MAS) to accelerate crop improvement.

Marker Assisted Selection uses: DNA markers as flags to identify specific genes linked to desirable traits such as disease resistance, drought tolerance, grain quality, or higher yield. By combining classical breeding with molecular biology, MAS provides a faster, more accurate, and efficient pathway to develop superior crop varieties.

Types of Molecular Markers Used in MAS

- ✓ RFLPs (Restriction Fragment Length Polymorphisms)
- ✓ RAPDs (Random Amplified Polymorphic DNA)
- ✓ AFLPs (Amplified Fragment Length Polymorphisms)
- ✓ SSR (Simple Sequence Repeats or Microsatellites)
- ✓ SNPs (Single Nucleotide Polymorphisms)

Among these, SSR and SNP markers are the most commonly used in modern MAS programs.

Steps in Marker Assisted Selection

- ✓ Identification of Trait of Interest
- ✓ Discovery of DNA Markers
- ✓ Marker Validation

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- ✓ Screening Breeding Populations
- ✓ Selection and Crossing

This process allows scientists to select the best plants in the early stages, even when the trait is not visibly expressed.

Advantages of MAS

Time Efficiency: Reduces breeding cycles and speeds up the release of new varieties.

High Accuracy: Identifies genes even if traits are influenced by the environment.

Early Selection: Traits can be selected at the seedling stage.

Useful for Complex Traits: Helps in selecting traits controlled by multiple genes.

Cost-Effective: Reduces the need for repeated field trials.

Applications of MAS in Crop Improvement

Disease Resistance: Rice resistant to Bacterial Leaf Blight and Blast, wheat rust resistance genes.

Abiotic Stress Tolerance: Sub1A gene in rice for flood tolerance, drought-tolerant maize.

Quality Improvement: Protein in wheat, aroma in Basmati rice, sugar in sugarcane.

Hybrid Breeding: Identification of restorer or maintainer genes for hybrid seed production.

Case Studies

Rice (Swarna-Sub1): Flood-tolerant rice variety developed using MAS.

Wheat: Resistance to stem rust (Ug99) introduced using DNA markers.

Tomato: Breeding of varieties resistant to Tomato Yellow Leaf Curl Virus.

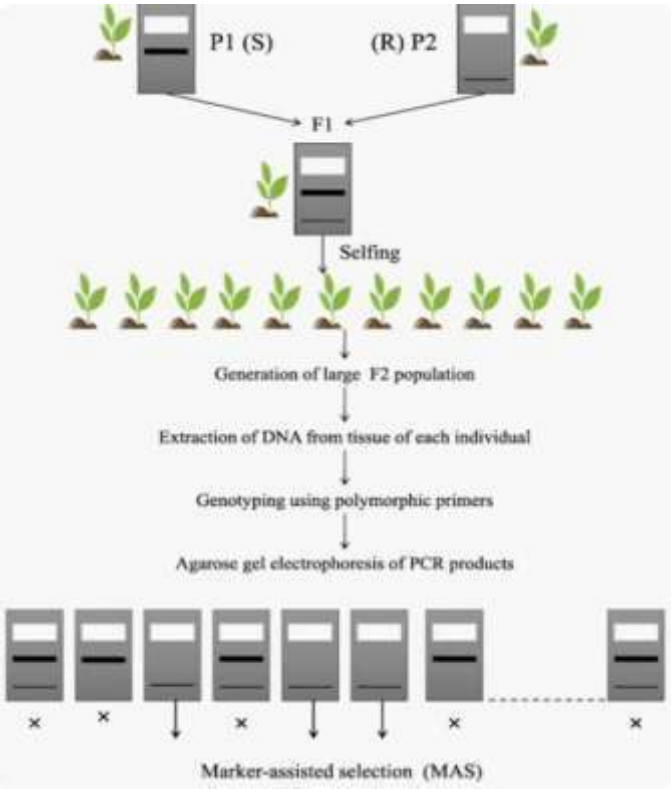
Future Prospects

Genomic Selection (GS): Uses entire genome data.

CRISPR-Cas9 and Gene Editing: MAS combined with gene editing.

Integration with Artificial Intelligence: AI predicts reliable marker-trait associations.

Flowchart of Marker Assisted Selection



Conclusion

Marker Assisted Selection is a revolutionary tool in modern agriculture. By linking molecular biology with plant breeding, it allows scientists to overcome the limitations of traditional methods. MAS has already delivered disease-resistant, stress-tolerant, and high-quality crop varieties, and its potential is still growing. As climate change and population growth continue to pressure agriculture, MAS will play a critical role in ensuring food security, sustainability and resilience in global farm-

ing systems.

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Components of Genetic Variance

R. M. Rajkumar and S. Subhashini

Abstract

Genetic variance is the foundation of evolutionary biology and quantitative genetics, explaining how traits differ within and among populations. It arises from the combined effects of additive, dominance, and epistatic genetic components, each contributing to the overall variability of traits influenced by multiple genes. Understanding the components of genetic variance is crucial for plant and animal breeding, evolutionary studies, and conservation genetics. This article explores the concept, its partitioning, statistical modeling, and its importance in heritability, breeding, and long-term evolutionary potential.

Introduction

Variation is the essence of genetics. In any population, individuals differ in traits such as height, yield, or disease resistance. This variation can be broadly classified into genetic variance (due to inherited factors) and environmental variance (due to surroundings). Partitioning genetic variance helps us predict the resemblance between relatives and design effective selection strategies in breeding programs. The concept of genetic variance was formalized in the early 20th century by Ronald Fisher, who laid the foundation for quantitative genetics. His partitioning of phenotypic variance into genetic and environmental components enabled scientists and breeders to understand the heritable portion of variability in complex traits. Today, these concepts are widely used in agriculture, medicine, and evolutionary biology.

Components of Genetic Variance

The total phenotypic variance (VP) observed in a population can be divided into two major components: genetic variance (VG) and environmental variance (VE). Mathematically, VP = VG + VE. Further, the genetic variance can be partitioned into three key components:

Additive Genetic Variance (VA): Additive genetic variance is the portion of variance attributable to the sum of average effects of alleles. It reflects the predictable, cumulative contribution of individual alleles to a trait. This component is especially important because it is directly transmitted from parents to offspring. Selection acts efficiently on additive variance, making it the driving force in plant and animal improvement programs.

Dominance Variance (VD): Dominance variance arises when alleles at the same locus interact in a

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non-additive way. For instance, if one allele completely masks the effect of another (complete dominance), the contribution to genetic variance cannot be explained simply by additive effects. Dominance plays a crucial role in hybrid breeding programs, where heterozygous combinations can lead to higher performance compared to inbred lines.

Epistatic Variance (VI): Epistatic variance results from interactions among genes located at different loci. Epistasis occurs when the effect of one gene depends on the presence of another gene. Though often smaller in magnitude, epistatic effects are important in complex traits and can contribute to heterosis (hybrid vigor). Epistasis is also considered significant in evolutionary processes, where gene interactions influence adaptive landscapes.

Importance in Breeding and Evolution

Understanding the components of genetic variance is fundamental for predicting genetic gain, estimating heritability and applying efficient selection strategies. Some key applications include:

Plant and Animal Breeding: Additive variance enables predictable genetic gain.

Hybrid Breeding: Dominance and epistatic variance are utilized in developing hybrids.

Conservation Biology: Genetic variance is crucial for adaptability.

Evolutionary Biology: Natural selection acts primarily on additive variance.

Conclusion

Genetic variance, divided into additive, dominance, and epistatic components, is central to understanding heredity and selection. Among these, additive variance is the most significant in breeding and evolution, as it directly predicts the response to selection. With advances in molecular genetics and computational tools, our ability to estimate and utilize genetic variance in practical breeding programs has greatly improved.

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Seed Enhancement Technologies for Precision Agriculture

Sherina Parveen, S. Subhasini and K. Cholan

Abstract

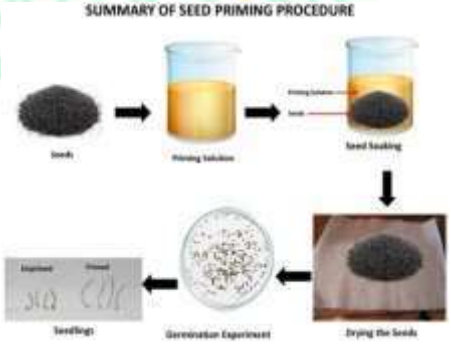
Seed enhancement technologies (SETs) are a suite of physical, chemical, biological and mechanical treatments applied to seed before sowing to improve germination, seedling establishment, and early growth under a variety of field stresses. When combined with precision agriculture (PA) which uses data, sensors, and variable-rate technologies to match inputs to site-specific conditions SETs can substantially increase crop establishment reliability, input-use efficiency, and yield stability. This article reviews major categories of seed enhancement (priming, coating, pelleting, bio-priming, and invigoration), explains how they integrate with precision tools (seed sensors, variable-rate planters, site-specific prescriptions, and decision support systems), highlights benefits and trade-offs, and suggests directions for research and on-farm adoption.

Introduction

Poor and uneven crop establishment is a common cause of yield loss, especially under marginal soils, moisture stress, low temperatures, pests and saline or compacted seedbeds. Seed enhancement technologies were developed to reduce this vulnerability by improving physiological readiness, protecting seeds from threats, and tailoring seed behavior to sowing systems. Precision agriculture provides the spatial and temporal intelligence needed to deploy SETs where they deliver the largest return e.g., different seed treatments in low versus high-performing field zones, or modified pelleting for planter types. The synergy between SETs and PA enables smarter, more sustainable cropping.

Major Seed Technologies

Seed Priming: Priming involves controlled hydration of seeds to initiate early metabolic processes without completing germination, followed by re-drying. Types include hydropriming (water), Osmo priming (osmotic solutions), matrix priming, and oxygen priming. Benefits: faster and more uniform germination, improved emergence under temperature or moisture stress.



Limitations: reduced shelf-life in some cases and

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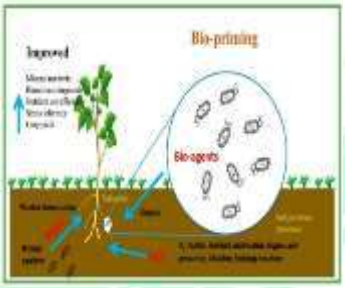
need for controlled processes to avoid premature germination.

Coating and Pelleting: Coatings are thin layers of polymer, fertilizers, or protective agents applied to seed; pelleting is a heavier wrapping that changes seed size/shape for precise mechanical planting. Coatings can include micronutrients, polymer films to moderate imbibition, or carriers for bio stimulants. Pelleting improves singulation in planters, enabling uniform depth and spacing especially valuable for very small or irregular seeds. Trade-offs include added cost, increased seed size affecting sowing rates, and environmental concerns if non-biodegradable polymers are used.

Bio-priming and Microbial Inoculation: Bio-priming combines priming with beneficial microbes (rhizobia, mycorrhizae, PGPR) to promote early root growth, nutrient uptake and disease resistance. Microbial seed coatings enable direct delivery to the seed rhizosphere. Challenges include maintaining microbial viability during storage and ensuring consistent field performance across environments.



Seed Invigoration and Treatments: Treatments include low-dose chemicals (e.g., growth regulators), cold plasma, nanomaterials, and hormesis-based approaches that stimulate stress tolerance. These can accelerate emergence and enhance vigor but need careful dosing and safety evaluation.

Protective Treatments (Insecticides, Fungicides and Polymers): Protective seed treatments reduce early losses from soil-borne pests and pathogens. Polymer seed coatings can also act as moisture modulators. Regulatory and environmental considerations (e.g., neonicotinoids and pollinator concerns) influence treatment choices.

Integration with Precision Agriculture

Site-specific Application: Precision agriculture maps within-field variability (yield maps, soil electrical conductivity, moisture sensors). Using those maps, different seed enhancement strategies can be prescribed: e.g., primed seed in low-moisture patches, microbial-coated seed in nutrient-deficient zones, or pelleted seed in areas with rough seedbeds to improve placement.

Variable-Rate Seeding and Treatment Delivery: Modern planters with multiple hoppers and sectional control can deliver variable seeding rates and, with emerging equipment, variable seed batches (different coatings/pellets) across a field. This allows matching seed type and treatment to macrozones in a single pass.

Sensing and Decision Support: Real-time sensors (soil moisture, temperature) and decision-support platforms can recommend when primed seed is advantageous (e.g., when soil temps predict poor emergence). Remote sensing (NDVI, multispectral) can help evaluate establishment success and adjust subsequent management. Digital records of treatment locations and performance (linked to harvest maps) enable farmers and advisors to evaluate cost-effectiveness. Trials across zones can quantify

benefits of SETs under specific stress profiles, informing iterative improvements.

Benefits and Economic Considerations

Improved Establishment: Faster, more uniform emergence reduces re-seeding and increases early vigor.

Input Efficiency: More reliable stands mean fertilizer and water are used by intended plants, improving return on inputs.

Risk Management: In marginal seasons, SETs reduce stand failure risk and stabilize yields.

Mechanization Compatibility: Pelleting and precision-compatible coatings enable high-speed sowing with fewer skips or doubles.

Costs include treatment and equipment expenses, potential increased seed price, and the need for on-farm data systems. The economic payoff depends on crop value, field variability and frequency of stress events; precision targeting improves ROI by applying SETs only where needed. Environmental, Regulatory, and Practical.

Challenges

Environmental Concerns: Non-biodegradable polymers or harmful agrochemicals in coatings can cause pollution. Biodegradable materials and responsible chemical choices are preferable.

Regulatory Limits: Seed-applied pesticides and novel technologies face regulatory scrutiny that varies by country.

Storage and Viability: Some primed or microbially coated seeds have shorter shelf-life and require controlled storage.

Equipment and Complexity: Variable-rate and multi-batch seed delivery systems are emerging but not yet ubiquitous; adoption requires investment and training.

Future Directions and Research Needs

Smart Coatings: Biodegradable, responsive polymers that modulate water uptake and release nutrients or microbes on demand.

Integrated Delivery Systems: Planters capable of switching seed treatments mid-run and tracking placements digitally.

Microbial Formulations: Robust, field-stable inoculants that survive storage and diverse soils.

Decision Algorithms: AI models that predict when and which SETs will pay off using historical and real-time data.

Life-cycle Assessments: Environmental impact studies comparing SET options to support sustainable policies.

Conclusion

Seed enhancement technologies offer powerful tools to improve crop establishment and resilience. When combined with precision agriculture's spatial intelligence and variable-rate capabilities, SETs become selectively powerful applied where they matter most and evaluated with data. The future lies in smart, sustainable coatings and delivery systems, stronger microbial science, and decision-support tools that translate field variability into cost-effective treatment prescriptions. Adoption will depend on demonstrable economic benefits, regulatory support, and farmer-

friendly technology integration.

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Seed Processing, Storage and Legislation

L. Sakthi Rahul, S. Subhasini and K. Cholan

Abstract

Seeds are the fundamental input in agriculture, and their quality directly influences crop productivity and food security. To ensure high-quality seeds reach farmers, three critical components come into play: processing, storage, and legislation. Seed processing involves cleaning, grading, drying, treating, and packaging harvested seeds to improve purity, viability, and uniformity. Proper storage under controlled moisture, temperature, and humidity conditions helps maintain seed vigor and extend shelf life, with storage methods ranging from short-term farmer-level practices to long-term gene bank conservation. Alongside these technical measures, strong seed legislation plays a vital role in regulating the production, certification, and distribution of seeds, protecting farmers from spurious or substandard materials. Acts such as the Seeds Act (1966), Seed Rules (1968), Seed Control Order (1983), and PPV&FR Act (2001) in India provide the legal framework for seed quality assurance. Together, seed processing, storage, and legislation form the backbone of modern seed technology, ensuring the supply of reliable and improved seed varieties for sustainable agriculture.

Introduction

Seeds are the foundation of crop production and play a vital role in the success of agriculture. The availability of good-quality seeds not only ensures higher yields but also enhances resistance to pests, diseases, and adverse environmental conditions. In fact, it is often said that “good seed is the most important input for agriculture” because even with fertilizers, irrigation, and pesticides, the potential of a crop cannot be realized without quality seeds. However, seeds harvested directly from the field are usually mixed with impurities such as stones, soil, weed seeds, broken or immature grains, and may also carry pathogens. To make them suitable for sowing, they undergo a systematic process known as seed processing, which improves purity, germination, and overall performance. Once processed, seeds must be stored carefully, since they are living entities that respire and lose viability over time. Effective seed storage techniques help maintain vigor and germination capacity until the next planting season or even for several years. In addition to technical measures, the seed sector is governed by seed legislation a set of laws and regulations that ensure farmers receive certified and reliable seeds. These legislations safeguard farmers from poor-quality or

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misbranded seeds and provide a framework for seed certification, labeling, and distribution. Thus, the combined efforts of processing, storage, and legislation form the backbone of seed technology, ensuring that farmers get access to high-quality planting material, which in turn guarantees agricultural sustainability and food security.

Seed Processing, Storage and Legislation

Seeds are the foundation of agriculture. Good quality seeds determine the success of crops, ensuring better yield, disease resistance, and food security. To maintain seed quality, three important aspects come into play: processing, storage, and legislation.

Seed Processing: Seed processing is the stage where raw seeds harvested from the field are cleaned, treated, graded, and packed to make them suitable for sowing. This step ensures that only healthy, uniform, and viable seeds reach farmers.

Steps in Seed Processing

Pre-cleaning: Removal of larger materials like stalks, leaves, stones, and soil clods.

Cleaning: Elimination of dust, chaff, broken seeds, weed seeds, and other impurities using air-screen cleaners.

Grading: Separation of seeds based on size and weight to improve uniformity in germination.

Seed Treatment: Application of fungicides, insecticides, or bio-fertilizers to protect against storage pests and field diseases.

Drying: Seeds are dried to safe moisture levels (generally 8-12%) to prevent fungal growth and spoilage.

Packaging: Seeds are packed in moisture-proof bags with labels indicating germination percentage, purity, and date of packing.

Seed Storage: Seeds are living organisms. They respire and deteriorate over time if not stored under proper conditions. The goal of storage is to maintain seed viability and vigor until the next planting season.

Factors Affecting Seed Storage

Moisture Content: High moisture promotes fungal attack; seeds should be dried to recommended levels before storage.

Temperature: Low temperature slows down seed metabolism. Ideal storage is in cool, dry conditions.

Relative Humidity (RH): High RH causes seeds to absorb moisture, reducing viability. RH below 50% is generally desirable.

Storage Containers: Airtight containers like aluminum tins, polylined bags, or vacuum-sealed packs extend seed life.

Seed Type: Cereals store longer than oilseeds, which are more prone to deterioration.

Types of Storage

Short-term Storage: For one season (farmers' level).

Medium-term Storage: 1-5 years (commercial seed industry).

Long-term / Gene Bank Storage: For preserving

genetic resources, using low temperature (-18°C) and low moisture.

Seed Legislation: Seed legislation refers to the laws and regulations framed by governments to ensure farmers get access to high-quality seeds. These laws prevent the sale of spurious, low-quality, or misbranded seeds.

Objectives of Seed Legislation

- ✓ To maintain the standard of seed quality (purity, germination, vigor).
- ✓ To protect farmers from fake or adulterated seeds.
- ✓ To regulate seed certification, labeling, and marketing.
- ✓ To safeguard the interests of plant breeders and seed companies.

Examples in India

The Seeds Act, 1966: The first law to regulate quality control, labeling, and certification.

Seed Rules, 1968: Detailed procedures for seed testing and certification.

Seed Control Order, 1983: Seeds declared as an essential commodity; sale of substandard seeds punishable.

Protection of Plant Varieties and Farmers' Rights Act, 2001 (PPV&FR): Protects breeders' rights but also recognizes farmers' rights to save, use, exchange, and sell seeds (except branded seeds).

New Seed Bill (proposed): Aims to further strengthen seed quality regulation and introduce stricter penalties.

Conclusions

- ✓ Seed processing, storage, and legislation together form the backbone of modern agriculture.
- ✓ Processing ensures clean, healthy, and viable seeds.
- ✓ Storage maintains quality until the next season.
- ✓ Legislation protects farmers from exploitation and guarantees access to certified seeds.
- ✓ By strengthening these three pillars, nations can ensure better crop productivity, food security, and agricultural sustainability

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Residue Retention and Microbial Regeneration: Building Fertile Soils Naturally

B. Venkatanna, Pole Akhila, P. C. Latha and R. Mahender Kumar

Abstract

Stubble burning, though widely practiced for quick field clearance, severely damages soil microbes that are essential for nutrient cycling, organic matter decomposition, and overall soil fertility. Sustainable alternatives such as residue incorporation, mulching, composting, and the use of microbial decomposers like Pusa Decomposers provide organic matter and energy to microbial communities, helping them thrive. These microbes, in turn, release vital nutrients, improve soil structure, and enhance crop productivity. Shifting towards microbe- friendly stubble management not only reduces environmental pollution but also builds healthier soils and supports long-term agricultural sustainability.

Introduction

Rice (*Oryza sativa* L.) is the staple food of India, meeting nearly 60% of the caloric needs of the population. Every year, millions of tonnes of crop residues, including straw, stalks, and crowns, are generated after harvesting. Farmers often refer to these residues as “stubble” or “trash.” While mechanized harvesting has increased efficiency, it has also left behind vast quantities of residues that require management before the next cropping cycle. The prevailing practice of stubble burning, especially in rice-wheat systems of northern India, has short term convenience but devastating long-term consequences. One of the most critical yet often overlooked impacts is on the soil microbial population which is the invisible workforce that drives nutrient cycling, improves soil fertility, and sustains plant health.

Microbial Impacts of Stubble Burning

When stubble is burnt, soil surface temperatures can reach up to 500°C. Such intense heat results in in the following:

- ✓ Sterilization of top 10-15 cm of the soil.
- ✓ Destruction of the earthworms, bacteria, fungi, and actinomycetessurving in the top layers.
- ✓ Disruption of microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN).
- ✓ Alteration in the microbial diversity and enzymatic activity.

Several studies have reported that stubble burning reduces bacterial and fungal counts by over 50% compared to residue retained soils. The loss of

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beneficial microbes leads to a decline in soil organic carbon turnover, suppression of enzyme activity (e.g., phosphatases, dehydrogenase), and reduced nutrient mineralization. The result is a biologically inactive soil that requires higher fertilizer inputs for the next crop.

Why Microbes Matter in Residue Management

Microbes play a prominent role in the recycilng of crop residues. When the residues are retained or incorporated microbes have role in:

Carbon cycling: Microbes decompose lignin and cellulose, releasing carbon into the soil organic matter pool.

Nutrient mineralization: Bacteria and fungi convert residues into plant-available forms of nitrogen, phosphorus, and potassium.

Soil aggregation: Microbial exudates bind soil particles, improving aeration and water retention.

Biological buffering: Diverse microbial communities protect against pathogens and environmental stress.

Enzyme activity: A reliable marker of microbial functioning *i.e.,* dehydrogenase reflects oxidative activity of living microbial cells and phosphatases indicate phosphorus cycling and availability. Both activities decline sharply after burning but recover rapidly under residue retention and microbial inoculation.

Alternatives to Burning: Microbe-Friendly Options to protect microbial health, several strategies can be adopted:

Residue Incorporation and Mulching

- ✓ Using rotary mulchers, straw choppers, or seeders that incorporate residues directly into the soil.
- ✓ Provides a substrate for microbial growth and boosts microbial biomass carbon.

Microbial Decomposer Cultures

- ✓ Low-cost bioformulations such as "Pusa decomposer" (fungal + microbial consortium) "waste decomposer" (a consortium of beneficial bacteria) accelerate decomposition.
- ✓ When applied with jaggery solutions, they rapidly convert residues into humus-rich organic matter.

Composting and Vermicomposting

- ✓ Controlled decomposition of residues creates nutrient-rich compost teeming with microbial life.
- ✓ Vermicomposting with earthworms enhances microbial activity and adds beneficial enzymes.

Crop Rotation and Diversification

- ✓ Introducing legumes, maize, or sunflower in *rabi* seasons after paddy not only reduces residue load but also supports nitrogen-fixing bacteria.
- ✓ Enhances rhizosphere microbial diversity.

Biochar Production

- ✓ Instead of burning residues in open fields, converting them into biochar can provide long-lasting carbon sources that microbes colonize and use for nutrient cycling.

Ecological and Agronomic Benefits of Microbe-Friendly Management

- ✓ Enhances soil nutrient cycling efficiency, reduc-

ing dependence on chemical fertilizers.

- ✓ Improves soil structure, infiltration, and moisture retention through microbial activity.
- ✓ Increases soil organic carbon sequestration, mitigating greenhouse gas emissions.
- ✓ Restores the balance of beneficial microbial guilds, leading to healthier crop growth.

Conclusion

Stubble burning is more than an air pollution crisis, it is a biological crisis in the soil. Each fire wipes out millions of microbes that silently recycle nutrients and sustain crop productivity. By adopting residue incorporation, microbial inoculants, composting, and diversified cropping, farmers can nurture microbial life and build resilient soils. Protecting microbes is protecting the foundation of farming itself. A shift away from burning towards microbial enrichment is not only an environmental necessity but also an agronomic strategy that ensures long-term fertility, reduced input costs, and sustainable harvests.

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Seed Borne Genetic Disorder

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Abstract

Seeds are not only carriers of life but also carriers of problehidden within their genes. Seed-borne genetic disorders are inherited defects that pass from one plant generation to the next through seeds. Unlike seed-borne diseases caused by fungi or bacteria, these disorders originate from errors in the DNA itself. They can result in weak seedlings, abnormal growth, or reduced yield. Common examples include albino seedlings lacking chlorophyll, male sterility that prevents plants from producing pollen, and dwarfism that alters plant height. While some genetic disorders reduce seed quality and productivity, others are used positively in crop improvement for example, dwarf genes in rice and wheat that led to the Green Revolution, or male sterility systems used in hybrid seed production. Understanding seed-borne genetic disorders is therefore important not only for protecting crops but also for advancing agricultural biotechnology.

Introduction

Seeds are the starting point of every crop, carrying within them the potential for healthy plants and bountiful harvests. But along with useful traits, seeds can also carry hidden problems. Most people are familiar with seed-borne diseases caused by fungi, bacteria, or viruses, which can infect plants and reduce yields. Less commonly known, however, are seed-borne genetic disorders problems that arise not from outside infections but from the seed's own DNA. These disorders are passed from one generation to the next, much like inherited diseases in humans. When errors occur in the genetic code of a plant, they can affect how the seed develops, how the seedling grows, and even how much the crop ultimately produces. Examples include albino seedlings that fail to make chlorophyll, male sterile plants that cannot produce pollen, or dwarf plants with reduced height. Interestingly, not all seed-borne genetic disorders are harmful. Some, such as dwarfing genes and male sterility, have been turned into powerful tools in plant breeding, helping farmers grow higher-yielding and more resilient crops. Thus, understanding seed-borne genetic disorders is vital not only to prevent crop losses but also to harness their potential in agricultural innovation. Seed-borne disorders are plant diseases transmitted through seeds, posing a major threat to

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agriculture by spreading pathogens like fungi, bacteria, and viruses globally, leading to crop losses and impacting biodiversity. Examples include Bakanae disease in rice, caused by *Fusarium moniliforme*, and leaf spot in leguminous crops. Effective management involves rigorous seed health testing, use of disease-free seeds, chemical seed treatments, and integrated pest management strategies to prevent further spread.

Seed-Borne Disorders

- ✓ Seed-borne disorders are diseases of agricultural crops caused by pathogens (fungi, bacteria, viruses, nematodes) that are present within or on the seeds themselves.
- ✓ These pathogens can remain dormant within the seed, causing infection when the seed germinates, leading to poor seedling vigor, disease symptoms, or reduced crop yield.

Examples of Seed-Borne Pathogens and Diseases

Fungi: *Fusarium moniliforme*, which causes Bakanae disease of rice and *Colletotrichum lupini*, a fungal pathogen affecting lupins.

Bacteria: *Pseudomonas syringae*, associated with pea bacterial blight, and *Burkholderia glumae* and *Pantoea dispersa*, which can cause severe yield losses in rice and maize, according to ScienceDirect.

Viruses and Nematodes: Other groups of pathogens that can also be transmitted via seeds, although fungi and bacteria are most frequently discussed in this context, as noted by ScienceDirect.

Impact on Agriculture

Reduced Crop Yield: The presence of pathogens can significantly reduce germination rates and overall crop productivity.

Global Dissemination of Pathogens: Infected seeds act as a primary vehicle for spreading plant pathogens to new regions and even new continents.

Economic Losses: Outbreaks can lead to severe economic losses, affecting crop quality and market value.

Threat to Biodiversity: The spread of pathogens can impact the biodiversity of crops and ecosystems.

Management and Control Strategies

Seed Health Testing: A crucial first step involves thorough testing to detect the presence and level of seed-borne pathogens.

Seed Certification: Programs for seed certification are vital to ensure that seeds are free from diseases and pathogens.

Chemical Treatments: Chemical seed treatments are effective for controlling many seed-borne diseases, but not all.

Integrated Disease Management (IDM): A combination of cultural, eco-friendly, and chemical methods is used to manage diseases at economically sustainable levels.

Resistant Varieties and Breeding: Breeding for disease resistance and selecting for high-quality, disease-free seeds are key strategies to reduce risk.

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Genetic Purity Testing in Seed Production

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Abstract

Genetic purity testing is an essential component of seed production to ensure that farmers receive high-quality seeds that are true-to-type. It refers to the verification of the genetic identity and uniformity of a seed lot with respect to the variety or hybrid. Maintenance of genetic purity is crucial for achieving higher crop yields, uniform performance, and sustaining farmer confidence. Several methods are used for purity testing, including morphological, chemical, biochemical, and molecular techniques. With advancements in biotechnology, modern molecular markers now allow highly precise and reliable testing. This ensures seed companies can deliver quality-assured seeds for global agriculture.

Introduction

Seed is the basic input in agriculture, and its quality directly affects crop productivity. Among the different quality parameters, genetic purity is the most important, as it determines the authenticity of the variety or hybrid. Even a small level of impurity can lead to yield reduction and crop variability in the field. Ensuring genetic purity is particularly vital in hybrid seed production, where cross-pollination and mechanical admixtures can easily contaminate the seed lot. To overcome these challenges, systematic methods of genetic purity testing are followed during seed certification and quality control.

Methods of Genetic Purity Testing

Grow-Out Test (GOT): Field-based method where seeds are grown and morphological traits are compared with the standard variety. Reliable but time-consuming and influenced by environment.

Chemical Tests: Example: Phenol test in rice to differentiate varieties. Simple and cost-effective but applicable only to limited crops.

Biochemical Tests: Electrophoresis of seed proteins or isozymes helps detect variation among varieties. Provides better accuracy than morphological methods.

Molecular Marker Techniques: Includes RAPD, SSR, SNP, and AFLP markers. Highly accurate, environment-independent, and increasingly adopted by seed companies.

Advantages of Genetic Purity Testing

- ✓ Ensures true-to-type seeds for farmers.
- ✓ Maintains brand reputation of seed companies.
- ✓ Facilitates seed certification and trade.
- ✓ Prevents yield losses due to admixtures.

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- ✓ Allows early detection of off-types using DNA-based methods.

Applications in Seed Production

Hybrid Seed Industry: Verification of male and female parent lines.

Variety Release and Maintenance: Checking breeder seed purity before multiplication.

Seed Certification: Mandatory purity testing for certified seed lots.

Research Programs: Ensuring integrity of germplasm collections.

Flowchart: Genetic Purity Testing Process

- ✓ Seed Sampling
- ✓ Selection of Test Method
- ✓ Evaluation (Morphological / Chemical / Biochemical / Molecular)
- ✓ Comparison with Standard Reference
- ✓ Certification / Rejection of Seed Lot

Conclusion

Genetic purity testing is indispensable in modern seed production. From traditional grow-out tests to advanced molecular techniques, these methods safeguard the authenticity of varieties and hybrids, ensuring better crop performance. As agriculture faces growing demands for higher yield and food security, the adoption of molecular marker-based testing will become increasingly important.

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Soil Moisture Sensors

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Abstract

Soil moisture sensors play an essential role in advancing irrigation management and supporting sustainable agriculture by providing real-time measurements of soil water content. Utilizing mechanisms such as capacitance and resistive sensing, these devices detect changes in soil properties to deliver precise moisture data that informs water application decisions. Careful selection and placement of sensors, along with routine calibration and integration with digital tools, ensure reliable readings and efficient farm operations. The adoption of energy-efficient, network-connected sensor systems has transformed environmental monitoring and precision farming, enabling growers to conserve water and respond rapidly to changing field conditions. Collectively, these advances highlight the significance of innovative sensor technologies for optimizing agricultural productivity and resource stewardship.

Introduction

Soil moisture sensors are devices designed to accurately measure how much water is available in the soil, a crucial factor for healthy plant growth and effective irrigation management. Their main role is to help farmers, horticulturists, and researchers schedule irrigation and conserve water.

Functional Principles

These sensors employ several mechanisms to monitor soil water:

- ✓ Capacitance sensors assess the changes in dielectric properties of soil, which shift as moisture levels change. This makes them suitable for measuring volumetric water content, delivering reliable readings in real time.
- ✓ Resistive sensors use two probes inserted into the soil, relying on the principle that wet soil is more electrically conductive than dry soil. The difference in resistance helps calculate how much water is present.

Advanced sensors often feature energy-saving designs, solar-powered batteries, and wireless modules for remote data collection. These features allow for sustained use in fields and link sensor data to mobile apps via IoT networks.

Typical Uses and Placement Strategies

In farming, these sensors are strategically placed within zones where roots are most concentrated. Additional sensors may go deeper for monitoring both irrigation effectiveness and water drainage. Farmers use sensor data to automate irrigation scheduling, ensuring crops get the water they need while avoiding unnecessary waste. Consistent sensor checks and calibration keep read-

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ings accurate and systems functional.

Considerations for Sensor Selection

When choosing a soil moisture sensor, several practical points must be considered:

Soil type: Some sensors perform better in sandy or clay-rich soils due to different electrical properties.

Budget and maintenance: Durability, weather resistance, and low-maintenance design are critical features for long-term field use.

Integration and data access: Many modern sensors connect to cloud services or custom dashboards, allowing growers to monitor soil moisture remotely.

User support and ease of setup: Clear manuals, technical support, and intuitive software boost sensor adoption and effectiveness.

Technological Features

- ✓ Sensors may measure and record moisture levels multiple times daily and alert users to abnormal readings that might indicate flooding or sensor issues.
- ✓ Power-efficient hardware, such as solar panels and intelligent microchip control, extend the system's usability and decrease maintenance needs.
- ✓ Modern systems utilize data analytics and can create charts and averages to help decision-making.

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Role of Robotics in Agriculture

Ashwani Thakur

Abstract

Agriculture is undergoing a major transformation as robotics and smart technologies reshape the way food is produced. With the global demand for food increasing and resources becoming limited, farmers are under pressure to grow more with less. Robotics, when combined with artificial intelligence (AI) and the Internet of Things (IoT), offers practical solutions by making farming tasks faster, more accurate, and less dependent on manual labor. From monitoring crop health and managing weeds to harvesting delicate fruits and using drones for soil analysis, robots are becoming an essential part of modern farming. Their use not only saves time and reduces costs but also improves yields and minimizes environmental impact through precise input use. Overall, robotics represents a step toward climate-smart and sustainable agriculture that can secure food production for the future.

Introduction

The digital transformation of agriculture is being driven by the need for food security, environmental sustainability, and the use of new technologies. As the world's population grows, agricultural systems are being asked to produce more with fewer resources than ever before. Traditional farming methods are slowly being replaced by smart agricultural technologies that make farming more efficient, accurate, and flexible. Smart farming uses AI, the Internet of Things (IoT), and robots to make farming better in many ways, such as keeping an eye on the health of crops, making the best use of resources, and protecting the soil. Robotics is also very important for managing livestock, post-production, and transportation in the field. Agricultural robotics gave the people who worked in the field a lot of benefits and advantages business and industry by making things run more smoothly, making more things, lowering production costs, cutting down on manual labor and the need for workers, and so on. Robots can still be useful in these kinds of hard jobs. Precision agriculture and digital farming are being made possible by robotics in conjunction with sensors, artificial intelligence (AI), and the internet of things (IoT). Adoption is expected to increase productivity, lessen environmental impact, and assist farmers in managing agronomic systems that are becoming more and more complex.

Applications of Robotics in Agriculture

Crop Monitoring and Assessment: Camera-and sensor-equipped robots can identify pests, diseases, nutrient shortages, and plant stress before they become widespread. For example, the Flourish project integrated ground robots and aerial drones to map weeds and measure nitrogen, allowing for

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prompt interventions.

Harvesting: Delicate fruits and vegetables need to be harvested quickly and carefully. To pick crops like apples and strawberries with the least amount of damage, modern harvesting robots use robotic arms, soft grippers, and vision systems.

Weed Control and Plant Care: By distinguishing weeds from crops using AI-based vision systems, robots can mechanically uproot them or apply targeted herbicides, lowering the need for and expense of chemicals.

Sowing and Planting: Robotic planters and autonomous seed drills guarantee precise depth and spacing, enhancing germination and cutting down on waste.

Agricultural Robot Applications

Multitasking agricultural robots, typically has the ability to run or complete tasks automatically, slowly, or repetitively. Farmers may be able to focus more on the field and increase agro production in this way. The majority of robotic applications in agriculture are used for picking and harvesting. It provides both speed and increased accuracy. Therefore, it aids in enhancing not just the size of yields, but it also aids in cutting down on crop waste. The demand for food is the main reason for the uses of robot in agriculture. Robotics is very much associated with the various pre and postproduction of agriculture and similar sectors.

Weed Robots: These are smart agriculture robots (agri-bots) uses digital image processing to go through the images of weeds in their weeds and spray them directly by using their robotic arms to detect similarities with crops.

Harvesting Robotics: The use of agri-business for crops resolves the labour shortages problem. These new machines can be operated 24/7 through the delicate selection process of fruits and vegetables. These machines use a combination of image processing and robotic weapons to determine fruit in order to control quality. Because of high operating costs for crops focusing on agro-based early harvesting, fruit is like apples. Greenhouse harvesting also applies to high-value crops such as tomatoes and strawberries with these bots.

Drones: Drones are majorly used by the agriculture industry for monitoring and make tasks easy for farmers and thus enhance their productivity. They are used to monitor soil, spraying, watering and planting. Monitoring the soil helps farmers connect what is needed to help their crops grow better. Drones evaluate temperature, land slope, moisture, which gives them the right soil samples.

Advantages of Robotics in Agriculture

Labor savings: Robotics addresses labor shortages and lessens reliance on seasonal labor.

Precision input use: By applying fertilizer, pesticide, and water according to site, robots reduce waste.

Better crop health: Timely management is ensured by early disease or stress detection, which raises yields.

Data-driven choices: Farmers can take actionable insights from integrated sensors and imaging system.

Conclusion

Robotics is not about replacing farmers but about empowering them with tools to produce more with less. By automating routine tasks, improving accuracy, and generating actionable data, robots can help meet the dual challenge of increasing food production while protecting natural resources. However, for widespread adoption, affordability, farmer training, and supportive policies will be critical. In the coming years, robotics will be a cornerstone of sustainable and climate-smart agriculture.

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Role of AI and IoT in Modern Agronomy

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Abstract

Feeding the world sustainably has become one of the biggest challenges of our time. With rising populations, climate change, shrinking water resources, and stressed soils, farming needs a smarter way forward. Artificial Intelligence (AI) and the Internet of Things (IoT) are offering exactly that. Together, they make farming more precise, efficient, and resilient by turning raw data into actionable insights. This article explains how AI and IoT are reshaping agronomy, highlights their real-world benefits, looks at the challenges, and explores what the future may hold for farmers worldwide.

Introduction

Farming has always been the backbone of human survival. But today, farmers face a storm of challenges unpredictable weather, water shortages, degraded soils, pests that arrive uninvited, and the demand to produce more food than ever before. Traditional methods, based on intuition and general advice, are no longer enough. This is where Artificial Intelligence (AI) and the Internet of Things (IoT) step in. Imagine fields where sensors constantly "listen" to the soil and climate, and AI tools analyze that data to guide farmers on when to irrigate, fertilize, or protect crops. It's farming made smarter, sharper, and more sustainable.

IoT in Agronomy: The Sensor Backbone

IoT is like giving farms a nervous system. Tiny devices and sensors spread across fields continuously collect information and send it to a central hub. Here's what they can do:

Soil and crop monitoring: Sensors track soil moisture, nutrients, pH, and temperature. This allows farmers to act exactly when and where the crop needs help.

Smart irrigation: Instead of wasting water, IoT-driven irrigation systems deliver the right amount at the right time. In some trials, water savings reached 20-50%.

Greenhouse control: IoT maintains temperature, humidity, and CO_2 at perfect levels, helping crops flourish in controlled environments.

Automation: Pumps, drones, and robots can be triggered by IoT data to spray, irrigate, or fertilize automatically.

Connectivity: Smart farming depends on strong networks. New hybrid models using LPWAN and 5G are cutting costs and improving coverage in rural areas.

AI in Agronomy: Turning Data into Decisions

While IoT collects information, AI is the brain that interprets it. By using machine learning

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and deep learning, AI can:

Predict yields: Combining weather, soil, and crop data, AI models estimate harvests with remarkable accuracy.

Detect pests and diseases: Drones and cameras scan leaves, while AI recognizes early signs of stress sometimes with accuracy above 99%.

Guide fertilizer use: AI pinpoints where nutrients are lacking and suggests precise application, saving costs and reducing pollution.

Support decisions: From sowing to harvest, AI tools provide farmers with timely, personalized advice.

Climate-smart farming: By simulating climate impacts, AI helps adjust cropping patterns for resilience.

AI + IoT: A Closed-Loop Ecosystem

When AI and IoT come together, farms become truly intelligent. Picture this:

- ✓ A soil sensor detects low moisture → AI calculates the crop's water need → irrigation valves open automatically.
- ✓ A drone scans the field, spots nutrient stress → AI highlights affected areas → a sprayer applies fertilizer only where needed.
- ✓ Weather and soil data combine → AI predicts a pest outbreak → farmers receive alerts before the first signs appear.

Benefits of AI and IoT in Agronomy

Higher yields: Smarter decisions can boost harvests by 10-25%.

Efficient resource use: Water, fertilizers, and pesticides are applied only when needed.

Risk reduction: Farmers get early warnings about pests, diseases, or weather extremes.

Cost savings: Less waste and automation cut production costs.

Farmer empowerment: Real-time dashboards and mobile alerts put knowledge directly in farmers' hands.

Environmental protection: Reduced runoff and chemical use safeguard soil and water.

Challenges along the Way

- ✓ High initial costs for sensors, drones, and AI tools.
- ✓ Poor connectivity in rural areas.
- ✓ Data overload handling and storing massive amounts of farm data isn't simple.
- ✓ Skills gap farmers need training to trust and use these systems.
- ✓ Privacy concerns questions remain about who owns and controls farm data.
- ✓ Localization issues AI models trained in one region may not work perfectly in another.

Conclusion

AI and IoT are not just buzzwords they are reshaping the future of agronomy. Together, they turn farming into a data-driven, precise, and adaptive process. While challenges like cost and connectivity remain, the potential is enormous: higher productivity, sustainable resource use, and resilient farming communities. The next decade will likely see widespread adoption, driven by innovation and supportive policies. Ultimately, the goal is clear: a food-secure and climate-resilient future where tech-

nology works together with farmers not as a replacement, but as a trusted partner.

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Role of Drones in Agriculture

Rahat Sharma

Introduction

Drones, sometimes referred to as Unmanned Aerial Vehicles (UAVs), have become a game-changing agricultural technology in recent years. Drones provide tools for increasing productivity, accuracy, and environmental stewardship as pressures from population growth, climate change, labor shortages, and the need for sustainable farming increase. This article examines the applications of drones in agricultural systems, their advantages, adoption barriers, and potential applications.

Applications of Drones in Agriculture

Crop Monitoring and Health Assessment: High-resolution photos of crops can be taken by farmers using drones fitted with thermal, multispectral, or hyperspectral cameras. By identifying changes in vegetation indices (such as the Normalized Difference Vegetation Index, or NDVI), chlorophyll content, water stress, and temperature anomalies, these photos aid in the evaluation of plant health. Timely intervention is made possible by early detection of disease, nutrient deficiencies, or pest infestation.

Precision Application of Inputs: Drones allow for variable and spot-treatment instead of sprinkling water, pesticides, or fertilizers evenly over entire fields. By only spraying chemicals where necessary, they can save money, lessen their impact on the environment, and reduce input waste. Certain drones are employed for biological agent distribution or seeding.

Field management, surveying and mapping: Accurate maps of topography, terrain, and soil characteristics can be created by UAVs. Land use planning, drainage, irrigation design, soil erosion aided by these maps. They can also help with monitoring maturity and estimating yield.

Optimizing Irrigation and Water Management: Drones assist in identifying areas of the field that are either over- or under-watered by using moisture-sensing or thermal imaging technologies. Drones can direct more effective irrigation distribution when used in conjunction with IoT systems, which will save water.

Management of Disease and Pests: Quick aerial surveillance makes it possible to spot pest infestations or disease outbreaks before they become widespread. Instead of using pesticides everywhere, drones enable localized treatment by enabling early symptom detection.

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Estimating Harvesting Efficiency and Yield: Drones can help with yield estimation, harvest schedule planning, and labor optimization by closely monitoring crop growth and condition. Though it is still in its infancy, some research also looks into automating or assisting with harvesting.

Benefits

Increased Productivity and Efficiency: Better yields and less waste result from quicker data collection, more accurate interventions, and decision-making.

Cost savings: include faster operations, less labor, and less use of water, fertilizer, and pesticides.

Environmental Sustainability: Targeted spraying and decreased chemical runoff lessen environmental contamination. preservation of water supplies.

Improved Risk Management: Better mapping for irrigation, flood, and drought risk, as well as early disease and pest detection, aid in planning and mitigating.

Challenges

Legal and Regulatory Barriers: Drone use is subject to complicated or onerous regulations in many nations, including those pertaining to safety, airspace permissions, and licensing.

High Initial Costs: Drones with sophisticated sensors, cameras, and spraying systems can be prohibitively expensive for small farmers.

Limited Flight Time/Payload: Operations are restricted by battery life and payload capacity, especially when transporting pesticides or larger chemical tanks. Weather (rain, wind) further limits use.

Technical Skill & Data Processing Requirements: Taking pictures is one thing, but turning them into useful information through image analysis, GIS, and machine learning takes experience. Many farmers might not have access to these services or skills.

Issues with Data Privacy and Ownership: Who is the owner of the generated data? How is it shared, stored, and safeguarded? Clarity in regulations is not always present.

Prospects for the Future

Integration with AI, IoT, and Big Data: To make farming more proactive, drones are being combined with real-time sensor networks, machine learning, and predictive analytics.

Swarm and Autonomous Drone Operations: When several drones work together and have autonomous navigation, they can cover a wider area and conduct continuous monitoring.

Lowering Costs and Expanding Access: As hard-

ware prices decline, smallholder farmers may be able to purchase drones thanks to more lightweight, effective models, leasing options, or shared services.

Regulation and Policy Support Harmonization: Clear guidelines on safety, licensing, airspace use, data ownership are needed to remove barriers.

Conclusion

Drones have a lot of potential to change agriculture. Precision farming, resource optimization, environmental preservation, and increased yields are all supported by their capacity to deliver real-time, fine-scale aerial information. Cost, regulations, and technical skills are some of the adoption barriers that still exist, but they are being gradually removed. Drones are expected to become commonplace instruments in sustainable agriculture as technology develops and infrastructure and policy support it.

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Role of GPS in Modern Agriculture

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Abstract

The Global Positioning System (GPS) has revolutionized modern agriculture by enabling precise and efficient farm management. GPS technology allows accurate positioning, navigation, and real-time monitoring, facilitating applications such as field mapping, precision planting, variable-rate input application, yield monitoring, and autonomous machinery guidance. By integrating GPS with Geographic Information Systems (GIS) and other digital tools, farmers can reduce input costs, improve productivity, and promote sustainable agricultural practices. Despite challenges such as high initial investment, technical training requirements, and occasional signal errors, GPS continues to play a critical role in transforming traditional farming into data-driven, precision agriculture. The advancement of multi-constellation Global Navigation Satellite Systems (GNSS) and integration with emerging technologies like drones, remote sensing, and Internet of Things (IoT) devices promises further enhancement of GPS applications, contributing to global food security and environmental sustainability.

Introduction

Agriculture, the backbone of human civilization, is undergoing a rapid transformation due to technological innovations. The ever-increasing global population, climate change, and the need to produce more food with fewer resources have created pressure to modernize traditional farming practices. Among the various digital tools available today, the Global Positioning System (GPS) has emerged as a cornerstone of precision agriculture. GPS technology allows farmers to precisely monitor, manage, and optimize their field operations, thereby reducing costs, conserving resources, and boosting productivity. Unlike conventional farming methods, which rely heavily on intuition and experience, GPS-driven agriculture brings scientific accuracy and data-driven insights to decision-making.

Working Principle of GPS in Agriculture

GPS relies on a constellation of satellites orbiting the Earth, which transmit signals to ground-based receivers. These receivers are often installed on tractors, harvesters, drones, or even handheld devices used by farmers. By calculating the time taken for signals to travel from at least four satellites, the receiver determines its exact location in terms of latitude, longitude, altitude, and time. In agriculture, this high-precision location data is integrated with farm equipment, enabling real-time navigation and guidance. For example, tractors fitted with GPS can follow straight or curved paths with sub-meter or

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even centimetre accuracy when combined with Differential GPS (DGPS) or Real-Time Kinematic (RTK) systems. This ensures efficient use of farmland, minimizes overlaps, and reduces unnecessary fuel and input costs.

Applications of GPS in Modern Agriculture

Field Mapping and Land Preparation: GPS-based field mapping allows farmers to create highly accurate digital boundaries of their land. This is particularly useful in large or irregularly shaped fields where traditional measurement is time-consuming and prone to error. With GPS mapping, soil sampling points can be georeferenced, enabling site-specific management of soil fertility and irrigation needs. The resulting data supports the development of prescription maps, which guide variable rate technology for fertilizers and pesticides.

Precision Planting and Seeding: Planting is one of the most critical stages in crop production. Uneven seed spacing or depth can significantly impact crop establishment and final yield. By integrating GPS with planting machinery, farmers can ensure that seeds are placed uniformly across the field. This reduces seed wastage, ensures optimal plant populations, and allows for even crop growth. For row crops such as maize or cotton, GPS-enabled planting also improves mechanical weeding and harvesting efficiency.

Variable Rate Technology (VRT): GPS plays a central role in site-specific crop management. With VRT, farm equipment applies inputs such as fertilizers, pesticides, and irrigation water based on spatial variability detected within the field. For example, high-yielding zones may receive more nutrients, while low-potential areas are managed with reduced inputs. This not only lowers production costs but also reduces environmental pollution by minimizing nutrient leaching and chemical runoff.

Yield Monitoring and Mapping: Modern harvesters are equipped with GPS receivers and yield sensors that record grain flow, moisture content, and location simultaneously. These data points are used to generate yield maps, which reveal spatial variability in productivity across the field. Yield maps allow farmers to analyse long-term trends, identify management zones, and make informed decisions for the next planting season. Over time, this leads to more consistent and profitable crop production.

Autonomous and Smart Machinery: The integr-ation of GPS with artificial intelligence and geographic information systems (GIS) has enabled the rise of autonomous agricultural machinery. GPS-guided tractors and drones can perform operations such as tillage, spraying, and harvesting with minimal human supervision (8). Drones equipped with GPS also support crop scouting by capturing high-resolution images, detecting nutrient deficiencies, and identifying pest infestations. This shift toward automation reduces labor dependency, increases operational efficiency, and supports 24/7 farming operations.

Resource Conservation and Sustainability: One of the most important contributions of GPS in agricul-

ture is its role in sustainability. By minimizing overlaps during planting, spraying, and harvesting, GPS reduces fuel consumption and greenhouse gas emissions. Furthermore, precision application of agrochemicals helps protect biodiversity, soil health, and water resources. As global agriculture shifts towards climate-smart practices, GPS serves as a vital enabler of sustainable intensification.

Challenges in Using GPS in Agriculture

Despite its proven benefits, the adoption of GPS technology in agriculture faces several challenges. The initial investment in GPS-enabled machinery and receivers can be prohibitive, particularly for smallholder farmers in developing countries. Additionally, successful operation requires technical training, and a lack of digital literacy may limit adoption among older farming communities. Signal errors also present a challenge. Factors such as heavy cloud cover, tree canopies, or tall buildings may interfere with satellite signals, reducing accuracy. Although technologies such as RTK-GPS offer centimetre-level precision, they are more expensive and require reliable connectivity. Addressing these issues is critical for ensuring equitable access to GPS technology in agriculture.

Future Prospects

The future of GPS in agriculture is promising. Integration with other Global Navigation Satellite Systems (GNSS) such as Galileo (Europe), GLONASS (Russia), and BeiDou (China) is expected to further enhance accuracy and reliability. Farmers will increasingly rely on multi-constellation receivers, which reduce signal errors and provide uninterrupted coverage. Moreover, combining GPS with emerging technologies such as remote sensing, drones, Internet of Things (IoT), and machine learning will revolutionize farm management. For instance, GPS-enabled IoT sensors can monitor soil moisture in real time, while machine learning algorithms use georeferenced yield data to predict future productivity trends. Such innovations will not only improve efficiency but also help agriculture adapt to climate change and ensure food security.

Conclusion

The Global Positioning System has become a fundamental tool in modern agriculture. Its applications span from mapping and planting to yield monitoring and autonomous machinery. By enabling precision and efficiency, GPS reduces costs, conserves resources, and supports environmentally sustainable practices. Although challenges such as cost and technical barriers remain, continuous advancements in GNSS integration and digital farming are set to expand its role. Ultimately, GPS will remain a key driver in transforming agriculture into a data-driven, sustainable, and resilient industry capable of meeting global food demands.

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Role of Modern Technologies in Conservation Agriculture

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Abstract

Conservation agriculture (CA) is a sustainable farming approach focused on protecting soil, water, and biodiversity while ensuring food security. At its core, CA relies on minimal soil disturbance, continuous soil cover, and diverse crop rotations. However, modern technologies have significantly enhanced the effectiveness and scalability of these practices. This article explores how innovations like GPS, GIS, variable rate technology, drones, and AI are transforming CA into a precise, data-driven approach. Tools such as no-till seeders, residue management equipment, and improved crop varieties are making it easier for farmers to adopt eco-friendly methods. Meanwhile, digital platforms and renewable energy systems are improving access to real-time information and reducing carbon footprints. Together, these technologies are helping farmers improve productivity, adapt to climate change, and practice agriculture that's both profitable and sustainable. While the potential is vast, making these tools accessible especially to smallholder farmers remains crucial for widespread adoption.

Introduction

A sustainable farming method called conservation agriculture (CA) aims to maintain soil, water, and biodiversity while guaranteeing food security. Its three primary tenets are diversified crop rotations, permanent soil cover (cover crops or mulch), and minimal soil disturbance (no-till farming) (FAO, 2011). However, only with the incorporation of contemporary technologies has it become feasible to successfully apply these principles on a large scale. The effectiveness, accuracy, and sustainability of conservation agriculture techniques have been revolutionized by developments in biotechnology, renewable energy, machinery, and information technology. This article examines how contemporary technology is promoting conservation agriculture and how it affects environmental health, productivity and resource efficiency.

Technologies for Precision Agriculture

Applications of GPS and GIS: Nowadays, a lot of people use the Global Positioning System (GPS) and Geographic Information Systems (GIS) to maximize input use, crop management, and land preparation. Site-specific farming, in which inputs like seeds, fertilizer, and pesticides are applied according to spatial variability, is made possible by these technologies. For example, GIS-based mapping enables farmers to implement focused interventions by identifying areas that are prone to erosion, moisture distribution, and variations in soil fertility

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(Mulla, 2013). This accuracy improves sustainability, encourages soil conservation, and lessens resource waste.

Variable Rate Technology (VRT): VRT allows the automatic adjustment of fertilizer, pesticide, and irrigation rates based on field conditions. By preventing over-application, it reduces nutrient runoff, groundwater pollution, and soil degradation (Gebbers and Adamchuk, 2010). VRT also minimizes input costs and ensures that soil health is maintained under conservation agriculture systems.

Drones and Remote Sensing: Crop monitoring has been transformed by Unmanned Aerial Vehicles (UAVs) and satellite imagery. These instruments aid in the evaluation of vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), which offer information on pest infestations, nutrient shortages and plant stress. Drones are especially helpful in conservation agriculture for tracking crop residue management, soil cover percentage, and cover crop performance (Hunt *et al.*, 2013). Additionally, remote sensing supports adaptive management in conservation agriculture by enabling early warning systems for climate-induced stresses.

Contemporary Conservation Tillage Equipment

No-Till Planters and Seeders: Specialized tools like zero-till drills, strip-till machines, and direct seeders have enabled the mechanization of no-till farming. These devices maintain soil structure and organic matter by allowing for the precise application of seeds and fertilizers with the least amount of soil disturbance (Jat *et al*., 2014). By enabling the direct sowing of wheat into rice stubble, Happy Seeders have considerably decreased crop residue burning in areas such as South Asia.

Tools for Residue Management: In conservation agriculture, tools like mulchers, straw spreaders, and residue shredders are crucial for preserving soil cover. By recycling biomass into the soil, these devices increase organic matter and improve moisture retention. By incorporating these instruments into agricultural systems, greenhouse gas emissions are decreased and carbon sequestration is promoted.

Biotechnology and Better Crop Types: A key component of conservation agriculture is the creation of crop varieties that are resistant to pests, drought, and nutrient use. Genetically modified crops guarantee resilience in stressful situations like water scarcity or degraded soils and lessen reliance on chemical inputs (Tester and Langridge, 2010). Higher nutrient-efficient biofortified crops, for instance, enhance soil fertility and lower the need for outside inputs, supporting CA practices.

Artificial Intelligence and Digital Platforms: The dissemination of knowledge in conservation agriculture is changing as a result of mobile applications, AI tools, and decision-support systems. Farmers can access real-time information on pest outbreaks, soil moisture levels, and weather forecasts through digital platforms. Big data is analyzed by machine learning algorithms, which then suggest site-specific conservation measures to increase output while preserving resources (Wolfert *et al*., 2017). These platforms also encourage the adoption

of CA practices and enhance knowledge sharing between farmers.

Integration of Renewable Energy: To lessen dependency on fossil fuels, conservation agriculture is increasingly incorporating wind-powered systems, biogas digesters, and solar-powered irrigation pumps. In addition to reducing carbon emissions, renewable energy increases the economic viability of farming in rural areas. For instance, effective water resource use is ensured by solar irrigation and precision water management, which lowers the risk of soil erosion and salinization.

Contribution to Adaptation and Mitigation of Climate Change: Conservation agriculture's use of contemporary technologies helps with climate change adaptation and mitigation. While no-till equipment and residue retention lower greenhouse gas emissions through carbon sequestration, farmers can adjust cropping patterns to changing climates with the aid of remote sensing and AI-driven weather forecasts (Lal, 2015). Collectively, these technologies align conservation agriculture with global efforts for sustainable development and climate.

Conclusion

Modern technology plays an essential role in conservation agriculture. These innovations, which make CA more effective, scalable, and profitable, range from drones and precision farming tools to renewable energy and AI-based platforms. Technology integration with conservation agriculture provides a sustainable way forward as agriculture deals with issues like resource scarcity, climate change and soil degradation. However, adoption necessitates farmer training, supportive policies, and reasonably priced access to these technologies, particularly for smallholder farmers in developing nations. Modern technology has the power to close this gap and make conservation agriculture a widely accepted approach to sustainable food production.

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Role of GIS in Agriculture

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Introduction

For centuries, agriculture has been essential to human survival. The demand for food is rising quickly as the world's population is predicted to reach over 9 billion people by 2050. Farmers also have to deal with issues like water scarcity, soil degradation, climate change and shrinking farmland. These issues cannot be resolved by conventional farming methods alone; technology must be used. The Geographic Information System (GIS), which combines maps, spatial data, and analytics to assist farmers in making data-driven decisions, is one such potent tool. GIS is converting agriculture from a conventional method into an intelligent and sustainable system by fusing big data, GPS, and remote sensing. GIS facilitates "precision agriculture," sustainable land management, crop monitoring, resource optimization, risk assessment, and more when combined with remote sensing, GPS, IoT, and other technologies.

Why does GIS Matter and What is it?

The technology known as a GIS (Geographic Information System) collects, stores, processes, and displays data associated with particular places. GIS offers layers of data, such as crop health, irrigation networks, rainfall distribution, and soil type, all superimposed on a single digital map, in contrast to regular maps.

With this multi-layered strategy, farmers and legislators can:

- ✓ Determine trends in crop growth, water use, and soil fertility.
- ✓ Estimate market potential and yields.
- ✓ React promptly to hazards such as pest out-breaks, floods, and drought.

Key Applications of GIS in Agriculture

Precision Farming: GIS helps in applying fertilizers, pesticides, and water only where required. Farmers can prepare prescription maps that indicate the exact quantity of inputs for each section of the field. This reduces input costs and minimizes pollution. Example: In Punjab, India, GIS-based soil health cards have enabled farmers to reduce fertilizer use while improving yields.

Crop Health Monitoring: By integrating GIS with satellite imagery and drones, farmers can detect nutrient deficiencies, pest infestations, and water stress early. Color-coded maps show areas of healthy vs. stressed crops.

Soil and Land Use Mapping: Different soils require

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different crops. GIS-based maps help identify soil texture, organic matter, salinity, and erosion-prone zones. Farmers can select suitable crops and design crop rotation systems accordingly.

Irrigation and Water Resource Management: Water is one of the scarcest agricultural resources. GIS helps design irrigation networks by identifying high-water-demand and low-water-demand zones. It prevents over-irrigation, conserves groundwater, and reduces energy costs in pumping.

Risk Assessment for Disasters and Resources: Mapping areas vulnerable to flooding, drought, and soil erosion; incorporating climate change projections and facilitating preventative actions.

Climate and Risk Assessment: GIS integrates climate models, rainfall data, and temperature maps. Farmers can prepare for droughts, floods, and pest outbreaks in advance. Government agencies also use GIS to provide early warning systems to farmers. Example: In Sub-Saharan Africa, GIS is used to identify drought-prone areas and provide advice on drought-resistant crop varieties.

Advantages of GIS in Agriculture

Higher Productivity: By ensuring the right crop in the right soil.

Reduced Costs: Inputs like water and fertilizer are used efficiently.

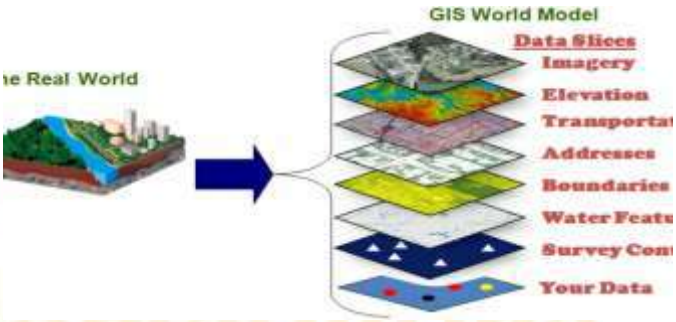
Environmental Sustainability: Less pollution and soil degradation.

Data-Driven Decisions: Farmers make choices backed by scientific data.

Food Security: Supports higher yields to feed growing populations.

Future of GIS in Farming

The future of agriculture lies in digital and precision technologies. With the integration of Artificial Intelligence (AI), Internet of Things (IoT), and Big Data, GIS will play an even greater role. Smart tractors, drones, and mobile apps linked with GIS can give farmers real-time updates on soil health, weather forecasts, and market prices right at their fingertips.



Difficulties

Data resolution and availability: High-quality soil maps, drone data, and high-resolution satellite imagery are not always accessible or reasonably priced.

Technical capacity: Farmers may lack the skills necessary to gather, process, and interpret GIS data; trained personnel are required.

Cost: The initial outlay for equipment (such as sensors, drones, and GIS software) may be substantial.

Integration with current practices: Farmers who are used to conventional techniques might find it challenging to embrace new technology.

Prospects for the Future

GIS integration with field-based real-time

data and Internet of Things sensors. Combining GIS layers with AI and machine learning to enhance predictive analytics (for weather extremes, yield, and pest risk).use of hyperspectral and other high-resolution drone and UAV imagery for fine-scale surveillance proved cloud and mobile GIS tools that are easier to use for extension agents and farmers expanding to encompass resource-poor environments, fragmented plots, and smallholder farms. Improved frameworks and regulations for training, data exchange, and technology subsidies for less wealthy farmers.

Conclusion

GIS is no longer just a mapping tool it is a decision-making partner for farmers. From precision farming to climate adaptation, GIS is helping agriculture become more profitable, sustainable, and resilient. As food demand rises, GIS will be one of the most powerful allies in achieving global food security and environmental balance. A useful tool in contemporary agriculture is GIS. By offering spatial insights into soil, crop, water, climate, and risk, it makes farming more accurate, effective and sustainable.

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Vertical Gardening: A Sustainable Urban Landscaping Element

Harshita Bora, Anamika Sajwan, Mukesh Kumar, Tanshu Chaudhary and Anju Pal

Introduction

Climate change has highlighted the importance of modifying our living environment for a better quality of life. Vertical gardening is an effective strategy for improving air quality, addressing urban heat issues and simultaneously enhancing the appearance of our homes. Paved and impermeable surfaces in urban areas absorb and retain more solar radiation than vegetation, leading to higher temperatures than in rural areas. The ambient temperature in urban area can be as much as 6ºC higher than the air in rural areas. Vertical gardens are increasingly being used in modern garden designs due to limited land space and the proliferation of high-rises that limit gardening opportunities. The idea of vertical garden began in 600 BC from Babylon's Hanging Gardens, but were not extensively used by later gardeners such as Persians, Mughals and Europeans. Vertical gardens are sometimes known as green walls, living walls or bio walls. A green wall is a wall that is entirely or partially covered with plants, sometimes with soil or an inorganic growing media and can be either free-standing or a part of a building. The history of greening outside walls of buildings shows that it increases insulation by keeping cool in the summer and warm in the winter, improves aesthetics, improves indoor and outdoor climate, reduces greenhouse gases such as carbon dioxide (CO_2), carbon monoxide (CO) and nitrogen dioxide (NO_2) and increases ecological values by providing habitat for birds and insects.

Classification of vertical gardens/green walls

Green walls are divided into two categories: green facades and living walls. Green facades are

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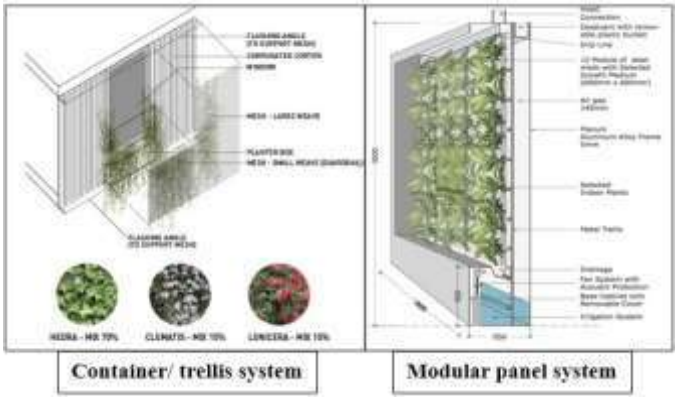
made up of climbing plants that grow directly on a wall or, more recently, on specifically constructed support structures. A living wall typically consists of modular panels composed of stainless-steel containers, geo textiles, irrigation systems, growing media and vegetation.

Container/ trellis system: Often referred to as "green facades". These are climbers and vines that emerge from the ground or from large containers at different points throughout the building and are held up by the wall or a supporting trellis or mesh. The wall-climbing method is the most prevalent and conventional green walls technique. Climbing plants can naturally cover a building's walls, but it is a time-consuming process. They are sometimes grown vertically with the help of a trellis or other supporting structures.

Modular panel system: The panel system, also referred to as a "living wall system". It is made up of vertical modules that contain growing soil and pre-planted panels that support plants that are affixed vertically to a structural wall or frame. The most recent concept is the module type. This system requires more complex design and planning before it is ready.

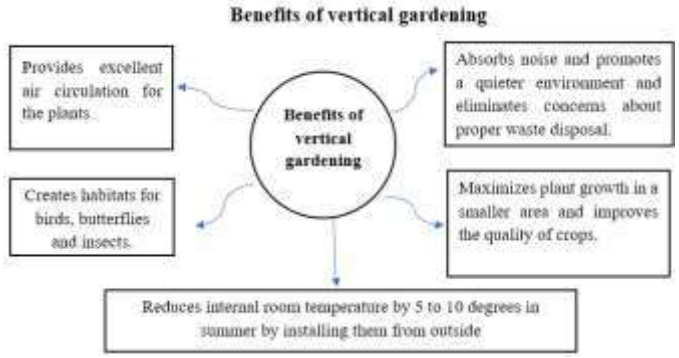


Container/ trellis system | Modular panel system

Steps involved in the preparation of vertical garden

- ✓ The vertical garden is made up of three layers: a metal frame, a PVC layer and a layer of felt.
- ✓ The metal frame can be wall-mounted or freestanding.
- ✓ PVC sheet with a thickness of 1.00 cm is riveted to the metal frame. This layer provides stiffness to the entire structure and makes it waterproof.
- ✓ A polyamide felt layer is stapled to the PVC. This felt is rot-proof and its high capillarity allows for even water distribution. Plant roots develop well on felt.
- ✓ Slits are cut into the outer felt covering to create pockets for the plants. Slits are cut in the outer felt covering to form pockets for the plants.
- ✓ Plants are planted on this felt layer as seeds, cuttings, or fully grown plants. The density is roughly 30 plants per square meter.
- ✓ The irrigation is delivered from the top and is supplemented with fertilisers. The fertilization and watering processes are automated.
- ✓ A pump and drip irrigation system deliver nutrient-rich water, which slowly cascades down the wall through the felt material layers until it reaches the bottom, where a collector collects the excess for reuse.
- ✓ The total weight of the vertical garden, including plants and metal structure is less than 25 kg per square meter.

Thus, the vertical garden can be installed on any wall, regardless of size or height.



Plants suitable for vertical gardens

Green facades

Hedera helix

Hydrangea petiolaris

Lonicera spp.

Jasminum officinale

Passiflora caerulea

Clematis spp.

Living wall

Bromeliads

Wisteria

Cordyline

Gardenia

Petunia

Nasturtium

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Challenges and Strategies in Managing Pests of Indian Medicinal Plants

Pooja Kumari, Kishor Kumar Yadav, Shakuntala and Saif Ali Khan

Introduction

India is a global hub for medicinal plants, with over 7500 species used in traditional healthcare systems like Ayurveda, Siddha, and Unani. In rural areas, traditional treatments with cost-free material assures health security to poor people. Besides, medicinal plants support livelihood of tribal communities since they collect raw material in wild and sell it in the local market. As demand for herbal products increases worldwide, the commercial cultivation of medicinal plants such as *Withania somnifera* (Ashwagandha), *Ocimum sanctum* (Tulsi) *Phyllanthus emblica* (Amla) and *Rauvolfia serpentina* (Sarpagandha) is expanding. However, the production of these valuable plants faces a major hurdle in the form of pests, which can drastically affect plant health, reduce yield, and compromise the quality of the medicinal compounds. Plant protection thus plays an important role to prevent or reduce the damages and produce healthy material.

Key challenges in pest management

Limited research and documentation: Most pest-related studies focus on food or cash crops, leaving a significant knowledge gap in medicinal plant protection. In many cases, pest species affecting these plants remain unidentified, and region-specific data is lacking.

Complexity of cultivation systems: Medicinal plants are often grown in mixed cropping or under agroforestry systems. This diversity complicates pest identification and control, as pest dynamics change based on plant combinations and ecological interactions.

Restrictions on chemical use: Due to the therapeutic purpose of these plants, synthetic pesticides are often avoided. Residues from chemical pesticides can alter the pharmacological properties of medicinal plants, making them unsuitable for use.

Climate change and pest incidence: Shifts in climate patterns, such as increasing temperatures and changing rainfall regimes, are enhancing the lifecycle and spread of pests. This is especially concerning for pests like mealybugs, aphids, and whiteflies, which thrive in warm, humid conditions.

Lack of farmer awareness: Smallholder farmers involved in medicinal plant cultivation may not have access to updated pest management practices or trained extension services. This leads to delays in pest detection and ineffective control measures.

Management of insect pests

Soil pests: The black cutworm (*Agrotis ipsilon*) cuts seedlings at the base and feeds on them.

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Common pests in medicinal plants in India

Plant Species	Common Pests	Impact
Ashwagandha (*W. somnifera*), Indian gooseberry (*Emblica officinalis*) and Blond psyllium/Isabgol (*Plantago ovata*)	Mealybugs, Red spider mites	Yellowing, stunted growth
Tulsi (*O. sanctum*)	Whiteflies, Aphids	Leaf curl, virus transmission
Sarpagandha (*R. serpentina*)	Leaf miners, Scale insects	Leaf damage, reduced alkaloid content
Senna (*Cassia angustifolia*)	Caterpillars, Pod borers	Defoliation, loss of marketable pods

Control measures include deep summer ploughing to expose larvae to birds, using 1-2 light traps or 20 pheromone traps per hectare to trap moths, and drenching the collar region of plants in the evening with chlorpyriphos 20 EC (2 ml l^{-1}) to kill larvae.

Sap sucking pests: In asparagus, high infestations of the red-colored bug *Brachytes bicolor* Westwood, an occasional pest, have been effectively managed through foliar application of profenophos (50 EC) at 2 ml per liter. In holy basil, both nymphs and adults of the tingid bug *Cochlochilo bullita* frequently attack the shoots and tender leaves by sucking sap, which can lead to plant death. This pest can be controlled with foliar sprays of 0.2% neem kernel oil or neem-based formulations containing 1000 ppm azadirachtin at 5 ml per liter, applied every two weeks until the pest population subsides. Indian gooseberry trees are attacked by three species of mealybugs (*Nipaecoccus viridis*, *N. vestator*, and *Ferrisia virgate*) which feed on the underside of leaves, leading to honeydew deposition that encourages sooty mold growth. Severe infestations can be managed by spraying 0.06% dimethoate (30 EC) or spinosad at 0.25 ml per liter. Additionally, in blond psyllium, the mealybug *Paracoccus marginatus* can be effectively controlled by removing infested plant parts during early infestation, followed by spraying 0.05% dimethoate (30 EC), 0.05% methyl demeton (25 EC), or 0.1% malathion (50 EC), and releasing coccinellid predators during later crop stages.

Defoliators: The grubs and adults of the epilachna beetle (*Henosepilachna vigintioctopunctata*) cause significant defoliation in blond psyllium by feeding on the leaves. Effective control involves manually collecting and destroying the pests, followed by spraying a mixture of 0.3% carbaryl (50 WP) and 0.2% wettable sulphur (50 WP). The hawk moth caterpillar (*Daphnis nerii*), a minor defoliator, can be managed by digging the soil to expose pupae, handpicking and destroying larvae, using one light trap per hectare, and planting *Nerium oleander* as a trap crop around the field. In *Withania somnifera* (Ashwagandha), gram caterpillars (*Helicoverpa armigera*) bore into fruits and feed on tender leaves. Management includes releasing *Trichogramma chilonis* at a rate of 100,000 eggs ha^{-1}, spraying *Bacillus thuringiensis* (Bt) at 0.5 kg ha^{-1} or Helicoverpa nuclear polyhedrosis virus (NPV) at 250 larval equivalents ha^{-1} and setting up 12 pheromone traps $hectare^{-1}$.

Stem/bark borers: The bark-eating caterpillar (*Indarbela quadrinotata*) is a common and persistent pest of Indian gooseberry. The larvae bore into the bark and stem, feeding while concealed under a protective gallery composed of silk, frass, and fecal

matter. Infested trees typically exhibit these galleries on the bark surface as a clear sign of attack. Maintaining orchard cleanliness and detecting infestations early are crucial in preventing severe outbreaks. During the initial stages of infestation, larvae can be killed mechanically by inserting an iron rod into the shelter holes. In more advanced cases, control can be achieved by placing cotton soaked in 0.025% dichlorvos (76 EC) into the holes or by spraying a 0.05% chlorpyriphos (20 EC) solution, followed by sealing the holes to trap the chemical inside.

Conclusion

Sustainable pest management in medicinal plant cultivation is essential not only for crop health but also to ensure the safety and efficacy of herbal medicines. India needs to invest more in research, farmer education, and policy support to develop region and crop-specific pest management solutions that align with the principles of eco-friendliness and health safety.

Success Story: Managing Chickpea Wilt and Root Rot with *Trichoderma viride*

Shakti Khajuria

Problem Statement

Chickpea is a staple pulse crop for millions, especially in semi-arid regions like Panchmahal. However, its productivity is severely constrained by wilt (*Fusarium oxysporum* f. sp. *ciceri*) and root rot (*Macrophomina phaseolina*), which thrive in dry and warm soils. These diseases can lead to up to 100% crop loss if not managed effectively. Traditional farmer practices include the use of unrecommended chemical pesticides, which are often ineffective and environmentally harmful. Additionally, these practices do not address the root cause-the soil-borne pathogens. The problem required a biological, sustainable solution that would not only control diseases but also maintain soil health. The FLD aimed to demonstrate that *Trichoderma viride*, as a biocontrol agent, could provide an effective alternative to reduce crop losses and improve chickpea productivity.

Intervention/Approach: During the *Rabi* season of 2020-21, ICAR-KVK Panchmahal conducted Frontline Demonstrations (FLDs) on managing wilt and root rot in chickpea across the fields of 12 selected farmers in Kalol Taluka. The demonstrated technology involved seed biopriming with *Trichoderma viride* (2×10^8 cfu g^{-1}) @ 50 g in 250 ml water per kg seed for 10 hours, followed by shade drying before sowing. Additionally, soil application of enriched farmyard manure (FYM) @ 1 ton ha^{-1}, prepared by mixing 10 kg of *Trichoderma viride* ton^{-1} of FYM, was applied.

All demonstrations were conducted using standard agronomic practices such as proper spacing, irrigation scheduling, and nutrient management. Data on disease incidence, crop yield, and economic returns were meticulously recorded. The participatory approach ensured active farmer involvement, which led to a clear comparison between the improved practice and local methods. The goal was to establish the technology's effectiveness and encourage its wider adoption for sustainable and profitable chickpea production in the region.

Results and Output: The frontline demonstration on managing chickpea wilt and root rot using *Trichoderma viride* significantly improved plant health and productivity in the 2020-21 *Rabi* season. The demonstrated technology, which included seed treatment and soil application of enriched manure, reduced disease incidence to 8.50% compared to 28.12% under local practices. This resulted in a substantial yield increase of 25.93%, with the demonstration plots recording 17.00 q ha^{-1} against 13.50 q ha^{-1} in farmer-managed plots. Economic analysis revealed notable advantages.

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The gross returns from demonstration fields were ₹51,000 ha^{-1}, compared to ₹40,500 ha^{-1} from local practices. Net returns stood at ₹28,000 ha^{-1} for demonstration plots, significantly higher than ₹19,000 ha^{-1} in farmer fields. The benefit-cost ratio (BCR) also improved from 1.88 to 2.22, indicating better profitability. These outputs demonstrate the effectiveness of bio-based disease management in chickpea and encou-rage wider adoption among farmers for sustainable crop production.

Table 1: Summary of Frontline Demonstration on Chickpea Wilt and Root Rot Management

Details	Information
Crop	Chickpea
Number of Farmers	12
Area Covered	2.00 hectares
Technology Demonstrated	Soil application of 1000 kg manure cultured with *Trichoderma viride* (10 kg ha^{-1}) + Seed treatment with *T. viride* @ 50 g kg^{-1} seed
Disease Incidence % (Demo/Local)	8.50/28.12
Yield in Demonstration Plot	17.00 q ha^{-1}
Yield in Local Check (Farmers' Practice)	13.50 q ha^{-1}
Increase in Yield	25.93%
Benefit-Cost Ratio (Demo/Local)	2.22 / 1.88

Table 2: Economic Comparison -Demonstration vs. Farmers' Practice

Parameter	Demonstration Plot	Farmer's Practice
Yield (q ha^{-1})	17.00	13.50
Cost of Cultivation (₹ ha^{-1})	₹23,000	₹21,500
Gross Returns (₹ ha^{-1})	₹51,000	₹40,500
Net Returns (₹ ha^{-1})	₹28,000	₹19,000
Benefit-Cost Ratio (BCR)	2.22	1.88

Outcome and Impact: The FLD program helped participating farmers realize the potential of *Trichoderma viride* as a reliable biological solution. They observed less disease**,** better plant growth**,** and higher pod formation**,** even under stress conditions. Farmers who were skeptical earlier now plan to adopt the technology in the next cropping cycle. Reduced reliance on chemical inputs also promoted soil and environmental health. On average, farmers using *T. viride* earned an additional ₹9,000/ha over those following traditional practices. The success has led to growing interest among neighboring farmers, creating a ripple effect. The results demonstrated that such interventions not only solve specific pest/ disease issues but also build farmer confidence in adopting sustainable agriculture practices.

Farmers' Feedback: The participating farmers were highly satisfied with the outcome of the technology. They reported a visible reduction in disease symptoms just a few weeks after germination. Most farmers had previously faced severe losses due to wilt and root rot, with very few plants surviving until harvest. With *Trichoderma viride*, they noticed vibrant plant growth**,** minimal disease and better yield. Some farmers mentioned they saved money on chemical pesticides, while others appreciated that this method was easy to use and safe for their soil and health. One farmer, Shri Ajab Singh of Kalol Taluka, shared:

"I was losing 30-40% of my crop every year. After using *Trichoderma*, the disease reduced a lot, and my yield increased. Now I will continue using this method in future."

This positive feedback encouraged neigh-boring farmers to try the same approach in the following season.

Learnings: This success story showed that biologic-

al disease management is not only effective but also economically beneficial. The demonstration proved that even small and marginal farmers can adopt scientific practices like seed biopriming and soil application of biocontrol agents without requiring expensive inputs. It also highlighted the importance of awareness and on-field training. Extension efforts like FLDs play a critical role in building farmer trust in newer technologies. The key learning was that sustainable agriculture solutions need to be simple, low-cost, and field-tested to ensure adoption. It also showed that combining traditional farming with modern biological tools can solve persistent problems without harming soil health.

Nano-Fertilizers in Indian Agriculture: Evaluating the Promise and Addressing the Gaps

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Abstract

India's agricultural sector faces a dual crisis of declining fertilizer efficiency and increasing environmental degradation, threatening both productivity and sustainability. This article evaluates the development and performance of nano-fertilizers, particularly nano Urea and nano DAP, based on over 75,580 field trials, which showed average yield increases of 5.5 per cent across the major crops. It suggests that while these inputs offer improved nutrient use efficiency and environmental benefits, their success depends on transparent regulation, region-specific extension, and farmer trust. In the future, targeted long-term studies and ethical promotion are vital to support safe and scalable adoption.

Introduction

A growing population that is expected to reach over 1.6 billion people by 2030 (Gupta and Ghosh, 2023) and the harsh realities of climate change and environmental degradation present an unprecedented dual challenge for India's agricultural sector, which is the foundation of its economy and the source of income for the majority of its citizens (Hussain *et al*., 2024). The initial achievements of the Green Revolution, which significantly boosted food grain output by using more fertilizer and high-yielding cultivars, are now confronting their limits (Pingali, 2012). Although they are essential, conventional fertilisers are notoriously ineffective. A large amount of applied nutrients is lost to the environment through leaching, runoff, volatilization, and soil fixation. Due to growing input costs and a strong reliance on subsidies, this places a tremendous financial strain on farmers and greatly increases environmental pollutants. At this crucial moment, nanotechnology provides a glimmer of hope. A paradigm change in nutrient management has occurred with the introduction of nano-fertilizers (NFs). These nutrient carriers possess unique physi-cochemical characteristics that enable unprecedented precision in nutrient delivery. Typically developed at the nanoscale (between 1 and 100 nm), they represent a significant advancement (Guru *et al.*, 2023). They embody the principle of "more crop per drop" and "more crop per input," promising to revolutionize how nutrients are supplied to plants (Malo, 2023).

What makes this particularly significant for India is the pioneering role played by indigenous

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organizations like the Indian Farmers Fertilizer Cooperative (IFFCO). IFFCO's development and widespread commercialization of Nano Urea Liquid, launched in June 2021 (Press Information Bureau, 2021), and Nano DAP Liquid, launched in April 2023 (IFFCO, 2023), have positioned India at the forefront of this global agricultural innovation. These products, gaining significant traction and government support, are becoming a global benchmark for efficient and sustainable nutrient solutions. The Indian government's proactive inclusion of Nano Urea and Nano DAP in its monthly fertilizer supply plans underscores their growing acceptance and strategic importance in transforming Indian agriculture (Press Information Bureau, 2023).

Indigenous Development

The journey of nano-fertilizers in India began with the pioneering efforts of the Indian Farmers Fertilizer Cooperative Limited (IFFCO), which has led the indigenous development and commercialization of these innovative inputs, significantly contributing to agricultural self-reliance.

Nano Urea: Nano Urea Liquid was developed by Dr. Ramesh Raliya and his team at IFFCO's Nano Biotechnology Research Centre in Gujarat. This product represents a revolutionary innovation in nutrient delivery, where a 500 ml bottle of Nano Urea, priced at ₹240, can effectively replace a conventional 45 kg bag of granular urea. Containing 400 ppm of nitrogen and 40,000 mg l^{-1} of nanoparticles, one bottle is sufficient for application on one acre of farmland (Chaurasiya and Singh, 2024). The Government of India approved Nano Urea on February 24, 2021. Commercial production was initiated shortly thereafter, with the first dispatch to Uttar Pradesh in June 2021. The world's first Nano Urea production facility was formally inaugurated at Kalol, Gujarat, by the Hon'ble Prime Minister Shri Narendra Modi on May 28, 2022 (Press Information Bureau, 2024).

Table 1: Key Differences between Nano Urea and Conventional Urea (Source: Kumar *et al.*, 2023)

Characteristics	Nano Urea	Conventional Urea
Year of Invention	2021	1823
Technology	Nano-technology	Conventional
Particle Size	32 nm	~1 mm
Use Efficiency (%)	85-90%	30-40%
Price	₹225/bottle (500 ml)	₹242/bag (45 kg)
Storage Space Requirement	Very Low	Very High
Pollution	None	Air, Water, Soil Pollution
Vaporization	No	Yes
Soil Residue	No	Yes
Effect on Soil	Improves Soil Quality	Causes Soil Acidification
Availability in Plants	Throughout Lifecycle	3-4 Days
Crop Maturity	On-Time	Often Early
Nutrient Uptake	Foliar (leaf absorption)	Root absorption
Application Method	Foliar Spray Only	Soil & Foliar Application

Nano DAP: Building on the success of Nano Urea, IFFCO developed Nano Di-Ammonium Phosphate (DAP) Liquid, a novel formulation supplying both nitrogen and phosphorus in a highly efficient manner. Nano DAP is engineered to correct nutrient deficiencies and boost plant uptake, while being biologically safe, eco-friendly, and well-suited for residue-free green farming. The Ministry of Agriculture and Farmers Welfare officially notified Nano DAP under the Fertilizer Control Order on March 2,

2023. IFFCO began establishing Nano DAP production facilities in September 2021, and Union Home Minister and Minister of Cooperation Shri Amit Shah in New Delhi held the commercial launch on April 26, 2023. While IFFCO and its Nano Biotechnology Research Centre were pivotal in developing Nano DAP, Dr. Ramesh Raliya, also the lead innovator of Nano Urea, played a key role in its research and formulation. Notably, other fertilizer companies, including Coromandel International Limited (CIL), have also entered the space, launching their versions of Nano DAP and contributing to a broader R&D ecosystem. A conventional DAP bag is priced at ₹1350, whereas a 500 ml bottle of Nano DAP is available at ₹600 (IFFCO, 2023), making it a more cost-effective and sustainable option for farmers.

Field Evaluation across Crops and Regions: Extensive field studies have been undertaken across India to evaluate the effectiveness of nano-fertilizers, particularly Nano Urea, in enhancing crop productivity and nutrient use efficiency. The IFFCO spearheaded a large-scale, all-India trial program to test Nano Urea across different agro-climatic zones and crop categories. A total of 75,580 field trials were conducted covering a wide spectrum of crops, including cereals, pulses, oilseeds, vegetables, fruits, spices, and plantation crops. The aggregate data from these trials demonstrated an average yield increase of 5.5 per cent when Nano Urea was used either as a substitute or supplement to conventional urea in farmers' practices. Among horticultural crops, the most notable yield improvements were observed in Dioscorea (12.5%), Cashewnut (10.82%), Peach (9.60%), Safflower (9.18%) and Pineapple (8.90%). Major cereals also responded positively, with wheat (24,770 trials) and paddy (10,025 trials) exhibiting yield increases of 5.01 and 5.39 per cent, respectively. Vegetables such as tomato, potato, onion, brinjal and cabbage consistently showed productivity gains ranging from 5 to 7 per cent, while spices and plantation crops like turmeric, cardamom, tea, and coffee recorded yield increases between 4 and 8 per cent. These results reinforce the role of Nano Urea in improving nutrient efficiency and overall crop performance across diverse production systems (Source: IFFCO, https://www.iffco.in/en/crop-wise-nano-urea).

In addition to IFFCO's nationwide trials, focused farmer field experiments were carried out in Rajasthan and Uttar Pradesh during 2019-20, to assess the impact of nano-fertilizers on both crop yields and economic returns (Kumar *et al.*, 2021). The application of nano-nutrients (Nano-N, Nano-Zn, and Nano-Cu) alongside a 50 per cent reduction in nitrogen fertilizer showed positive results across multiple crops. These trials provide strong empirical evidence supporting the effectiveness of nano-fertilizers, especially when integrated into low-nitrogen fertilization strategies. The most pronounced benefits were observed in high-response crops such as urdbean, chickpea, maize, and potato, underlining the economic and agronomic potential of nano-fertilizer technologies in sustainable agriculture.

Promotional Efforts: The promotion and scaling up of nano-fertilizers in India, particularly Nano Urea and Nano DAP, have been driven by coordinated efforts from the Government of India, fertilizer companies, and research institutions under the Fertilizer Control Order (FCO) of 1985. Specific standards have been notified for nano-fertilizers produced by approved manufacturers, facilitating their regulated production and distribution across the country.

Production Capacity and Institutional Support: To support large-scale production, six Nano Urea plants with an annual capacity of 26.62 crore (500 ml) bottles and four Nano DAP plants with a combined annual capacity of 10.74 crore bottles have been established nationwide. To further augment production, the Department of Fertilizers has directed Public Sector Undertakings (PSUs) such as National Fertilizers Limited (NFL) and Rashtriya Chemicals & Fertilizers Limited (RCF) to set up additional Nano Urea plants. Memoranda of Understanding (MoUs) have been signed between IFFCO, NFL, and RCF to facilitate technology transfer and boost indigenous nano-fertilizer production. These MoUs are seen as a step toward reducing government subsidies and empowering Indian farmers (Press Information Bureau, 2021).

Outreach and Awareness Campaigns

A range of awareness and extension initiatives has been launched to promote the adoption of Nano Urea and Nano DAP:

Field-Level Engagement: Demonstrations, awareness camps, Kisan Sammelans, and *nukkad nataks* (street plays) have been organized to showcase nano-fertilizer benefits directly to farmers.

Digital and Regional Communication: Regional language videos and webinars have been used to reach a diverse and multilingual rural audience.

PM-KSKs Integration: Nano Urea and Nano DAP are stocked and distributed through Pradhan Mantri Kisan Samridhi Kendras (PMKSKs), ensuring last-mile availability.

Inclusion in Monthly Allotments: The Department of Fertilizers has integrated nano-fertilizers into its monthly allocation plans for seamless supply.

ICAR's National Campaign: The Indian Institute of Soil Science (ICAR), Bhopal, launched a campaign titled "Efficient and Balanced Use of Fertilizer (including Nano Fertilizers)" to promote nutrient stewardship.

'NaMo Drone Didi' Scheme: In a gender-inclusive approach, 15,000 women-led Self Help Groups (SHGs) were targeted for drone-based nano-fertilizer spraying. As of now, 1,094 drones have been provided by fertilizer companies under this initiative.

Maha Abhiyan for Nano DAP: A national-level campaign, covering all 15 agro-climatic zones, has been launched by the Department of Fertilizers and fertilizer companies to promote Nano DAP through consultations and field trials (Press Information Bureau, 2024).

Research Trials and Regulatory Approval: Nano DAP was officially notified under the FCO on March 2, 2023, after extensive toxicological and bioeffic-

acy testing. Approved manufacturers include IFFCO, Coromandel International Limited (CIL), and Zuari Farm Hub Limited. Field trials, conducted by ICAR institutes and State Agricultural Universities, indicated that Nano DAP, when used as a foliar spray and seed treatment, could partially replace conventional granular DAP.

Market Overview

The nano-fertilizer industry is witnessing the active participation of several prominent players, both from India and internationally. In India, the Indian Farmers Fertilizer Cooperative Limited (IFFCO) is a leading force, having pioneered the development and commercialization of Nano Urea and Nano DAP. IFFCO has further expanded its innovation capacity through its dedicated subsidiary, IFFCO-Nanoventions Private Limited (NVPL), which is engaged in advanced research and development of nano-based agri-inputs. In addition to IFFCO, Coromandel International Limited, and Zuari Farm Hub Limited have also received approval to manufacture Nano DAP, indicating a growing industrial base for nano-fertilizer production within the country. Other notable Indian public-sector organizations in the fertilizer domain include National Fertilizers Limited, Rashtriya Chemicals & Fertilizers Limited, Hindustan Insecticides Limited (HIL), and the Fertilizers and Chemicals Travancore Limited (FACT), all of which play critical roles in the broader agri-input ecosystem. On the international front, the Organization of Brazilian Cooperatives and the Cooperative Federation of Argentina, along with INAES (Instituto Nacional de Asociativismo y Economía Social), have emerged as significant stakeholders in the nano-fertilizer landscape, reflecting growing global interest and investment in sustainable agricultural innovations (TechSci Research, 2023).

From a market segmentation perspective, nano-fertilizer usage is categorized by crop type and regional application. By end-user, nano-fertilizers are utilized across food crops, cash crops, horticultural crops and plantation crops. Geographically, their market spans several key regions, including North America, Europe, Asia Pacific, and South America (TechSci Research, September 2023).

Production and Sales Performance: Despite considerable installed capacity, actual production and sales of nano-fertilizers remain underutilized during 2024. IFFCO's Kalol Plant, with the highest capacity of 600 lakh bottles, produced only 177.06 lakh bottles. Other players such as Zuari Farm Hub Ltd (Bathinda) and CIL Kakinada, with capacities of 24 and 140 lakh bottles respectively, also showed modest production levels. Overall, only 262.44 lakh bottles were produced out of a total capacity of 764 lakh, and 181.25 lakh bottles were sold (Press Information Bureau, 2024).

Regional Sales Trends: The adoption of Nano DAP has shown wide regional variation. Maharashtra and Goa led with 35.39 lakh bottles sold, followed by Madhya Pradesh (18.75 lakh), Karnataka (13.17 lakh), and Andhra Pradesh (10.57 lakh). In contrast, states like Jharkhand (0.71 lakh), Jammu & Kashmir

(0.73 lakh), Assam and Northeast (1.42 lakh), Kerala (0.33 lakh), and Himachal Pradesh (0.83 lakh) registered comparatively lower sales. This suggests the need for more targeted extension strategies to increase awareness and trust in nano-fertilizer technologies in underperforming regions.

Media Coverage and Public Reception: Despite the strong governmental push and promotional efforts, the adoption of nano-fertilizers in India, particularly in states like Punjab, has remained limited. *The Tribune* (July 22, 2024) reported that farmers in Punjab continue to resist nano-fertilizers such as Nano Urea, expressing skepticism over their efficacy. Many view the 500 ml nano bottles as inadequate substitutes for the traditional 45 kg urea bags. Field trials conducted by the Punjab Agricultural University, Ludhiana and IFFCO have shown only marginal yield benefits, reinforcing farmers' doubts and leading to poor adoption. Adding to the concerns, a research study published in *Down to Earth* (August 27, 2024) reported a significant decline in yield and plant growth associated with the use of nano DAP. The 2022-2023 study by Rajeev Sikka, Jeevanjot Dhaliwal, and Mandeep Kaur indicated a 16.1 per cent reduction in wheat grain yield when two sprays of nano DAP were applied without the recommended dose of conventional phosphorus fertilizers. Yields dropped to 47.61 quintals per hectare with nano DAP compared to 56.75 q ha^{-1} using traditional DAP. The studies focused on nano DAP manufactured by Coromandel International Ltd., one of the three companies licensed to produce it alongside Zuari Farm Hub and IFFCO.

Farmer dissatisfaction was further exacerbated by reports of coercive sales practices. *The Indian Express* (July 14, 2025) highlighted Union Minister Shivraj Singh Chouhan's directive to all Chief Ministers to halt the forced sale of nano-fertilizers and biostimulants. He emphasized that purchasing such products, a precondition for buying subsidized fertilizers like urea or DAP, is illegal. This followed widespread farmer complaints across states. The *Financial Express* (May 29, 2025) reflected on the four-year progress since Nano Urea's launch in June 2021. It revealed that, despite trials suggesting potential benefits such as a 28 per cent reduction in solid fertilizer use and 5.7 per cent yield increase in designated "nano villages", actual adoption remained sluggish. In FY 2024-25, only 26.5 million bottles were sold, which equates to roughly 3.4 per cent of conventional urea usage. The slow uptake has been attributed to low farmer awareness and skepticism, although IFFCO remains optimistic and is expanding outreach, launching new micronutrient products, and setting up its first international nano plant in Brazil.

Farmer unrest also surfaced in Sirsa, Haryana, where *The Tribune* (June 21, 2025) reported a protest led by the Bharatiya Kisan Ekta. Farmers accused IFFCO and cooperative retailers of forcing them to buy bundled products, such as nano urea, nano DAP, IFFCO's "Sagarika," and even non-agricultural items like tea, alongside essential fertili-

zers. Allegations of black-marketing and hoarding further fueled tensions. In response, the Agriculture Department initiated inspections, suspended non-compliant dealers, and formed a special committee to investigate the bundling of "Sagarika" and other practices.

Conclusion

Nano-fertilizers, particularly Nano Urea and Nano DAP, represent a significant technological breakthrough in India's journey toward sustainable and resource-efficient agriculture. Backed by proactive government support and spearheaded by key players like IFFCO, Zuari Farm Hub Limited, and Coromandel International, India has taken pioneering steps in developing and scaling nano-based agri-inputs. The market for nano-fertilizers is expanding across multiple crop types and regions, with increasing global interest from organizations in Brazil and Argentina, signifying their growing relevance beyond national borders. Despite the promise, adoption among Indian farmers remains limited. Field evidence, media reports, and independent research studies highlight ongoing skepticism, inconsistent yield benefits, and farmer resistance to replacing conventional bulk fertilizers with nano alternatives. Controversies around forced bundling of nano-products with traditional fertilizers and slow uptake despite extensive outreach reflect critical trust and awareness gaps. Furthermore, concerns regarding the efficacy and safety of nano-fertilizers, such as reported yield declines with exclusive nano DAP application, emphasize the need for cautious scaling. To realize the full potential of nano-fertilizers, a multi-pronged and evidence-based approach is essential. Long-term agronomic, toxicological, and environmental impact studies must be prioritized to validate claims and dispel doubts. Regulatory frameworks must be strengthened to ensure transparent marketing, prevent unethical sales practices, and safeguard farmers' interests. Most importantly, extension systems must focus on need-based, location-specific demonstrations, farmer capacity building, and clear communication of use protocols, rather than coercive promotion. As India and other nations move towards greener agri-input systems, nano-fertilizers can be an important part of the solution, if implemented judiciously. A calibrated, research-backed, and farmer-centric strategy will be key to ensuring that these innovations contribute meaningfully to productivity, sustainability, and climate resilience in agriculture.

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The Impact of AI on Livestock Health Monitoring and Management

Devshree D. Panchbhai, Priya P. Satwadhar and Bhavna Sharma

Introduction

Artificial Intelligence (AI) is revolutionizing various sectors, and livestock farming is no exception. With a growing global population and an increasing demand for animal-derived food products, ensuring livestock health and productivity is paramount. AI offers innovative solutions that enable precise health monitoring, early disease detection, and efficient management practices, paving the way for sustainable and profitable livestock farming (Barkema *et al.,* 2015). AI-powered systems can analyze various data points, including animal behaviour, vital signs, and environmental conditions, to identify potential health issues before they escalate. This leads to more efficient and timely interventions, reducing the need for reactive treatments and improving animal well-being.

AI in Livestock Health Monitoring

Traditionally, livestock health monitoring relied on manual inspections, which were labor-intensive and prone to human error. AI has transformed this process by introducing automated systems that monitor animal health continuously and with greater precision (Morota *et al.*, 2018).

Wearable Sensors: Smart sensors attached to animals collect real-time data on vital parameters such as heart rate, body temperature, activity levels, and rumination. AI algorithms analyze this data to identify early signs of illness, stress, or abnormal behaviour, allowing for timely interventions. For example, wearable devices like Cow Manager provide actionable insights into dairy cattle health and fertility, improving herd productivity.

Image Recognition Systems: Advanced AI-powered cameras monitor animal behaviour, gait, and posture. Computer vision algorithms detect lameness, injuries, or signs of discomfort that may not be visible to the naked eye. These systems enhance animal welfare and reduce treatment costs by addressing issues before they escalate.

Voice Analysis: AI-driven audio analysis tools assess vocalizations to detect distress or health issues. For instance, pig farms have implemented systems that analyze pig squeals to detect respiratory infections early.

AI in Livestock Management

AI also supports decision-making in livestock management, optimizing resources while ensuring animal welfare.

Feeding Optimization: AI-based feeding systems use data on animal weight, health, and production levels to customize feed rations. This reduces feed wastage and ensures animals receive optimal nutrition for growth and productivity.

Reproductive Management: AI tracks reproductive cycles and identifies optimal breeding times.

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This improves conception rates and reduces the costs associated with missed breeding opportunities or reproductive disorders.

Disease Outbreak Prediction: AI models analyze environmental data, historical disease records, and animal health data to predict potential disease outbreaks. This allows farmers to implement preventive measures and minimize losses. For instance, AI tools have successfully predicted foot-and-mouth disease outbreaks by correlating climatic and movement data.

Case Studies and Real-World Applications

Dairy Industry: In Europe, AI-powered robotic milking systems not only milk cows but also monitor under health, milk quality, and cow behaviour.

Poultry Farming: AI systems monitor broiler chickens' growth and detect diseases like avian flu early, ensuring rapid containment.

Beef Cattle: Companies like CattleEye use AI-powered video analytics to monitor cattle health and body condition scores, aiding in early disease detection (CattleEye, 2024).

Challenges and Future Directions

While the benefits of AI in livestock farming are immense, challenges such as high initial costs, lack of technical expertise, and data privacy concerns remain. Additionally, farmers in developing regions may face hurdles in accessing these technologies. To overcome these challenges, governments and private stakeholders must invest in training programs and subsidies to make AI tools accessible to all farmers. Research should also focus on developing low-cost, user-friendly solutions tailored to small-scale farms.

Conclusion

AI is transforming livestock health monitoring and management, enabling more precise, efficient, and sustainable farming practices. By leveraging AI, farmers can enhance animal welfare, improve productivity, and meet the growing demand for animal products. As the technology continues to evolve, its integration into livestock farming will undoubtedly play a crucial role in shaping the future of agriculture.

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A Comprehensive Pest Management in Sericulture

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India is the world's largest buyer of raw silk and silk fabrics and the world's second-largest producer of raw silk, after China. According to a study of global silk production trends, sericulture has a better chance of expanding in emerging nations than in developed ones. Temperate nations such as Japan, South Korea, the USSR, and others are experiencing a steady decline in silk production. This decline is caused by a combination of factors, including high labor costs and heavy industrial-ization, as well as climatic restrictions that limit the availability of mulberry leaves to two cocoon crops annually. Because of its tropical environment, India has the unique advantage of being able to practice sericulture year-round, producing a stream of roughly four to six crops. Sericulture is a living culture as well as a heritage in India. It is a labor-intensive, farm-based, and lucrative economic activity that is classified as cottage and small-scale. Due to its minimal investment requirements and potential for comparatively larger returns, it is especially well-suited for farmers, business owners, and craftspeople in rural areas. It gives the rural poor, particularly small-scale farmers, as well as the weaker and disadvantaged segments of society, jobs and income. Sericulture has the highest benefit-cost ratio among similar agricultural crops, according to several socioeconomic research. The Indian silk industry has had remarkable expansion during the past 60 years, both vertically and horizontally. This situation has benefited from the plans and programs put in place by federal and state organizations as well as the tireless efforts of thousands of committed individuals working in the domains of research and extension. For example, multivoltine × bivoltine and bivoltine hybrids have supplanted the long-standing multivoltine hybrids. The production of raw silk has skyrocketed in the sericulture sector. In recent years, the average yield of 25 kg of cocoons per 100 dfls has increased, and at the moment, the average yields fall between 60 and 65 kg/100 dfls. In addition to increasing yields, the new approach has improved the quality of cocoon manufacturing with significantly lower renditta and has also helped break the climate barrier. Given that India is the world's second-largest producer of raw silk, its 4-5% market share in the global silk trade is considered insignificant. This is due to India's sizable domestic market for silk products, which accounts for almost 85% of total production. Nonetheless, about 15% of India's total

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production of silk goods, including those with added value, is exported. Indian silk exports include finished goods like fabrics, makeup, and ready-made clothing as well as furnishings including carpets, curtains, bed spreads, and pillow coverings. The export of silk products has been showing a steady growth and the export earnings showed a rapid increase during the last decade but due to the insect pest problems created for production of silk.

Pests of silkworm

Pests of silkworm include insects that attack silkworm larvae in rearing room and grainages.

Rearing room pests

Uzifly: *Exorista bombycis,* Tachinidae, Diptera

Ants: Fire ants, *Solenopsis geminata*, Formicidae, Hymenoptera

Straw itch mile: *Pyemotes ventricosus,* Acarina, Pyemotidae, Arachnida.

Rodents like rate, squirrels, lizards etc.

Grainage pests

Dermestid beetle: *Dermestes ater* - Dermestidae, Coleoptera

Earwig: *Labia arachidis* - Labidae, Dermoptera

Uzi fly: *Exorista bombycis* Tachinidae, Diptera

Uzi fly is an endo-larval parasitoid of the silkworm. It causes loss to an extent of 10-20% to the sericulture industry. It occurs throughout the year with maximum incidence during July-November.

Symptoms of damage

- ✓ Presence of eggs and / or black scar on the larval body.
- ✓ Presence of maggot emergence hole in cocoons.
- ✓ Silkworms are generally attacked from 3rd instar onwards by uzi flies. Silkworms parasitized in early instars are get killed. While that parasitized in late fifth instar, spin weak cocoons and uzi maggots pierce through the cocoon and emerges out. (Uzi pierced cocoons are unfit for reeling).

Integrated management of Uzi fly

Cultural

- ✓ Collect and destroy the uzi infested silkworms.
- ✓ Remove the uzi maggots and pupae in rearing rooms and market centers.
- ✓ Keep the rearing room free from crevices / holes
- ✓ Destroy the uzi infested cocoons.

Physical

All the windows and ventilators are to be fitted with Uzi Nets (Nylon mesh). Provide 'Ante room' at the entrance of the rearing hall to exclude Uzi flies.

Chemical

Uziflay trap: It is a Chemo-trap to attract and kill the Uzifly adults. Uzi tablet (2.5 g) is dissolved in one litre water and the resultant yellow color solution is kept in a light coloured flat containers. The Uzi traps are to be placed near the windows in the rearing houses from 3rd instar onwards. It is effective in reducing the damage by 36.0%.

Uzizide (Benzoic acid): It is an ovicidal formulation. It is sprayed on the body of silkworm from 2nd day of III instar through 4th / 6th day of V instar. Dose: 4- 5 liters / 100 dfl

Mode of action: Ovipositional deterrent and ovicidal action.

Uzi powder: It is an ovicidal dust applied on the body of the silkworm larvae on 2nd day of III instar, 2nd and 4th day of IV instar and on 2nd, 4th and 6th day of V instar worms. Dose: 4-5 kg / 100 dfl.

Mode of action: Dislodges the eggs from the body of silkworm

Biological: Parasitoids of uzifly (Hyper parasitoids) are used for the biological control. Several natural enemies have been reported on uzifly which include, *Nesolynx thymus, Exoristobia philippinensis, Trichopria sp: Tetrastiches howardi* and *Dirhinus sp.* Among the hyper parasitoids, *N.thymus* is highly effective indigenous ecto-pupal parasitoid of Uzi fly. *N. thymus* is mass multiplied and used in the control of uzilfy. Release one lakh adults of *N. thymus* @ 8,000 during IV instar, 16,000 during Vinstar and 76,000 at one or two days after cocoon harvest.

Release the parasitoids in the rearing house, places of mountage storage, near manure pits and cocoon markets.

Diseases of mulberry silkworm

Protozoan: Pebrine - *Nesema bombycis*

Viral diseases: NPV, CPV, IFV and DNV

Bacterial diseases

- ✓ **Flacherie:** *Bacillus, Serratia, Streptococcus, Staphylococcus spp.*
- ✓ **Sotto:** *Bacillus thuringiensis*

Fungal diseases

- ✓ **White muscardine:** *Beaveria bassiana,*
- ✓ **Green muscardine:** *Metarhizium anisopliae*
- ✓ **Aspergillosis:** *Aspergillus flavus*

Pebrine: *Nosema bombycis,* Nosematidae, Protozoa

Pathological symptoms: Observed in egg, larval, pupal and adult stages.

Eggs

- ✓ Poor egg number
- ✓ "Pebrinized eggg laying" - eggs are loosely adhered to substratum
- ✓ Irregular laying - lack of uniformity in laying and more of unfertilized eggs
- ✓ Poor and irregular hatching

Larva

- ✓ Poor appetite, retarded growth, irregular size/ moulting and sluggishness.
- ✓ Presence of pepper like spots
- ✓ Body wrinkled with rusty brown colouration
- ✓ Transversally infected larvae die before III moult.

Pupa: Flabby pupae; swollen, lusterless pupae with softened abdomen and poor emergence

Adult: Delayed emergence; clubbed wings; distorted antennae; improper mating; sclales easily come off; lay eggs without glue.

Course of the disease: Chronic infection

Diagnosis: Spores are oval, glistering light blue under light microscopy.

Viral diseases

Grasserie: NPV, *Borrelina bombycis,* Baculo-viridae

Pathological symptoms: Swollen segments; milky white body colour; movement of the larvae along the periphery of rearing trays and wandering movements and characteristic 'hanging down' symptom.

Diagnosis: Polyhedral bodies in haemolymph are hexahedron in shape.

Cytoplasmic polyhedrosis, Smithea virus, Reoviridae

Pathological symptoms: Empty headed, diarrhoea, motionless, irregular faeces and chain of whitish green excreta. Rectal protrusion is a prominent symptom in advanced stages.

Bacterial diseases: Flacherie caused by *Streptococcus sp, Staphylococcus sp, Serratia mascescens, Bacillus sp etc.,*

Symptoms: Decreased appetile; sluggish movements; straightened body; swollen thorax; shrinkage of abdominal segments; vomiting and bead like faces; loss of clasping power of legs; body becomes soft and discoloured emitting foul smell on eruption.

Sotto: *Bacillus thuringiensis*

Symptoms: Loss of appetite; convulsionsion; lifting of head; spasms; tremors; paralysis, diastress; sudden collapse and death. Shortly after death body is outstretched and corpse is hard to touch with a hooked head. Body turns brownish black with foul smelling dark brown fluid.

Fungal diseases

- ✓ White muscardine */Calcino disease* - *Beaveria bassiana,*
- ✓ Green muscardine - *Metarhizium anisopliae*
- ✓ Aspergillosis - *Aspergillus flavus*

Muscardines

General symptoms

- ✓ Appearance of moist specks on the body
- ✓ Loss of appetite and inactive
- ✓ Body becomes limp; loss of skin elasticity

Diagnosis

- ✓ If body is covered with while mycelial growth, spores are colourless, globular and porcelain, it is due to white - *White muscardine*
- ✓ When body is covered with light greenish mycellia, slightly pointed light green oval shaped and irregularly branched conidium, it is due to *Green muscardine*.

Aspergillosis: *Aspergillus flavus*

Symptoms

- ✓ Infects mainly first and second instar larvae of silkworm
- ✓ Stop feeding; lethargic, show body tension
- ✓ Restlessness; vomiting with extended head and thorax
- ✓ Body is covered with black colored conidia and hyphae.

Integrated management of silkworm diseases

Prevention of diseases: As pebrine is trans-ovarially transmitted it requires preventive measures such as mother moth examinations and scientific method of disease free egg production.

Maintenance of hygiene

- ✓ Sun drying of rearing appliances.
- ✓ Regular disinfection of rearing room and appliances with 5% bleaching powder
- ✓ Ensure proper ventilation for aeration and maintenance of optimum temp and humidity and aeration.
- ✓ Disinfection of rearing room, trays and discarding of diseased worms.

Healthy rearing practices

- ✓ Provide adequate bed spacing
- ✓ Provide nutritious mulberry leaves
- ✓ Collect infected larvae, faecal matter and bed refuse and burn
- ✓ Early diagnosis and rejection of infected lots
- ✓ Keep the rearing bed thin and dry at the time of moulting.
- ✓ Apply bed disinfectants like Vijetha / RKO / Sakthi Seri Dust @ 4 kg / 100 dfl on the larva after each moult ½ hour before resumption of feeding.
- ✓ Spray 1.0% extract of *Psoralea corylifolia* on mulberry leaves once during third instar to contain grasserie disease.
- ✓ Apply mancozeb @ 3 kg / 100 dfl when muscardine incidence is noted.
- ✓ Apply antibiotics like *Streptomycin / Tetracyclin* to contain bacterial diseases.
- ✓ Avoid spraying commercial BT insecticides nearby mulberry field.
- ✓ Surface-disinfect the layings in 2% formalin for 10 minutes before incubation.
- ✓ Disinfect the rearing the layings in 2% formalin for 10 minutes before incubation.

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Strawberry Cultivation: Good Source of Nutrients and Vitamins

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The term "strawberry" is believed to have originated from the producers' technique of covering their plants with a coating of straw when the berries started to form. Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most popular soft fruit. Among the fruits strawberry gives the quickest returns in the shortest possible time. Rich in vitamins, proteins, minerals like P, K, Ca and Fe and best natural sources of antioxidant. The strawberry is a short-day plant that contains ellagic acid, an antioxidant, anti-inflammatory, anti-neurodegenerative and anti-cancer compound (Katel *et al.,* 2022). The fruits of cultivated strawberry are considered for diarrhea, gout, stomachache, and kidney stones. The fruits are used as astringents, diuretics and mild laxatives. Strawberries contain high quantities of ellagic acid which inhibit cancer and function as antioxidants and free- radical scavengers. Strawberry is a delicious light sour sweet fruit. Strawberry is a tasty, healthy red fruit whose flavour is influenced by three substances viz.sugar (0.5%), acid (0.90-1.85%), and aromatic components (Sahana *et al.,* 2020). Strawberries are grown in many areas of India. Kashmir's climate, with bright sunshine and moderate rainfall, is ideally suited to strawberry cultivation. This is the first fruit which comes after winter here and it is very good for health. The strawberries were not grown in large quantities few years back but with the gradual demand for table varieties as well as from processing units; numbers of farmers have taken up this activity.

Soil: Strawberry can be cultivated in almost every fertile land, but sandy loam soil is beneficial for good yield**.** Strawberry ripens somewhat earlier on sandy soil than on clay soil. The ideal condition for strawberry cultivation is sandy loam to loamy soil with pH 5.7-6.5 and a proper water drainage system. Strawberry is not much sensitive to soil reaction. However, it prefers a slight acidic soil. At higher pH, there is less root growth. The land on which tomato, potato, chilli, brinjal was grown in the previous crop should not be cultivated for strawberry.

Climate: Strawberry thrives best in temperate climate. It is a short day plant, which requires exposure to about 12 days of less than 8 hours sunshine for initiation of flowering. Each cultivar may have a different day length and temperature requirement. The strawberry plants are strongly affected by the environmental parameters like temperature, photoperiod and light intensity. Strawberry cultivation is

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possible in almost every climate but it can be grown successfully in sub-tropical and temperate climates, both of which have plants that behave like annuals and small perennial herbs, respectively (Salentijn *et al.*, 2003). It requires optimum day temperature of 22 to 25ºC and night temperature of 7 to 13ºC. Good air drainage and covering the row with plastic mulch can reduce frost damage.

Propagation: Strawberry is propagated through runners that are formed after the blooming season. Although the runner produces the correct type of plant, viral diseases are often transmitted through the runner itself. Hence a separate bed should be used for runner production. Thus for runner production, a separate bed should be used. The site and soil where the strawberry had not been grown for at least 3 to 4 years should be selected. Planting should be done at a distance of 1.2 x 1.2 m or 1.8 x 1.8 m. Generally, 30-40 runners per plant is considered a satisfactory rate of production. The rate of runner production can be increased by spraying GA_3 @ 50-100 ppm (Chadha, 2019).

Land preparation and Planting: Strawberry cultivation requires friable soil. The soil is made friable by ploughing. It can be cultivated well in beds raised 15 cm from the surface. Sustainable quantities of organic manure should be incorporated in the soil before plating. Planting should be done after washing the roots thoroughly with the help of water. Strawberry can be planted on flat beds, in the form of hill rows or matted rows, or it can be planted on raised beds. In irrigated areas, planting on ridges is advised. The planting distance should be 45 cm from plant to plant and 70 to 85 cm. from row to row. In the hills, Transplanting is done in March-April, September-October, but in the plains, the months of January-February may be utilized for this purpose. Light irrigation is necessary after planting (Chadha, 2019).

Varieties: Varieties like Premier, Pusa Early Dwarf, Sujata, Majestic, Fanil, Cardinal, Cambridge Favourite, Tioga, Talisman, TriStar, Olympus, Shuxon, Chandler Confucura, Laguna, Douglas, Gorella, Camarosa, Pajarón, Fern, Domanil, Addie, Festival, Brighton, Belrubi, Dana and Eatna etc. are different cultivars of strawberry (Sharma and Singh, 2009). The Camarosa variety is one of the most promising varieties of strawberry which was introduced from California that have best quality of firm flesh and even provide opportunities for the distant marketing. 'Winter Dawn' which is day neutral variety which produce fruits from March up to May when planted in last week of January or first week of October.

Manures and Fertilizers: In sub-tropical areas, 20-50 tons of well decomposed cow dung, one-third of Nitrogen (100 kg), full dose of Phosphorous (70 kg) and Potash (150 kg) per hectare are applied at the time of field preparation before planting and remaining quantity of nitrogen is given by drip method after planting in equal quantity at an interval of 10 to 15 days (Chadha, 2019).

Irrigation: Strawberry being a shallow-rooted plant requires more frequent but less amount of water for

each irrigation. Irrigation should be applied in furrows between the rows.Strawberry plants produce optimum growth when the soil moisture tension is maintained at less than 1.0 atmosphere. Under normal conditions, irrigation is necessary at an interval of 10-15 days in autumn and 5-7 days in summer. Excessive irrigation is, however, detrimental which encourages growth of leaves and stolens at the expense of fruits and flowers. To obtain better fruit size and quality, it should be irrigated judiciously during harvesting.

Plant growth regulators: Application of GA_3 @ 25 ppm enhances foliar spray, fruit weight, TSS, ascorbic acid and yield (Ingle *et al.,* 2001). At the rate of 50 ppm, GA_3 inhibits flowering and promotes runner development (Dennis and Bennet, 1969; Paroussi *et al.,* 2002). El-Shabashi *et al.,* 2008 reported that application of 100 ppm GA_3 increases flower production.

Weed control: Weed control is considered one of the most expensive management practices. Herbicides like simazine @ 3 kg ha^{-1} and pendimethalin @ 330 g l^{-1} can be used to keep the weeds under control. Black plastic mulch is used for weed control in India (Chadha, 2019).

Mulching: Light and loose mulching material is appropriate. Commonly used mulching materials include white straw, marsh hay, and saw dust. Mulching with black polythene material gives good control of weeds. Mulching reduces winter damage, weed growth and soil erosion.

Harvesting and Post-Harvest Management:

Strawberries are typically picked when between half and three-quarters of the skin has turned color. Berries with a tiny steam part adhering should be picked. It is best to pick in the morning. The yield of the suggested cultivars is typically between 250 and 500 g $plant^{-1}$. According to Chadha (2019), strawberries can be kept in cold storage for up to ten days.

Plant protection

Insect-Pest

- ✓ White grubs (*Phyllophaga spp.*)
- ✓ Thrips (*Scirtothrips dorsalis*)
- ✓ Red spider mite (*Tetranychus urticae*)

Diseases

- ✓ Botrytis rot (*Botrytis cinerea*)
- ✓ Powdery mildew (*Sphaerotheca macularis*)
- ✓ Leaf spot (*Mycosphaerella fragariae*)
- ✓ Anthracnose (*Colletotrichum spp.*)
- ✓ Verticillium wilt (*Verticillium alboatrum*)

Integrated Pest Management strategies

- ✓ Collect fallen infested fruits and destroy them.
- ✓ Field release of natural enemies *Opius compensates* and *Spalangia philippines.*
- ✓ Apply well rotten sheep manure @ 4 t $acre^{-1}$ in two splits or poultry manure in 2 splits Control ants and dust which can give the scale a competitive advantage.
- ✓ Field release of ladybird beetle.
- ✓ Spray of Cypermethrin (6.6 g a.i ha^{-1}) and Deltamethrin (2.25 g a.i ha^{-1}) decrease the occurrence of thrips and the quantity of deformed fruits.

- ✓ The application of Carbofuran (6-10 kg ha^{-1}) can effectively control the white grub.

Disease Management

- ✓ Proper sanitation of field by periodical removal of fallen debris and checks further spread of the disease.
- ✓ Maintaining plant vigour with proper irrigation and fertilization.
- ✓ Spraying twice with Carbendazim (0.1%) or Mancozeb (0.2 %) or combination of Carbendazim 12 % + Mancozeb 63 % @ 0.1 % at 15 days interval during flowering to control blossom infection and twice during pea nut stage to prevent fruit infection.
- ✓ Alternate sprayings of Carbendazim and Mancozeb to avoid development of resistance in pathogen to fungicides.
- ✓ Dusting with sulphur at 15 days interval are quite efficient at controlling the infection.

Future prospects: Strawberries may now be grown anywhere thanks to the advancement of new technologies. Strawberries are unique among temperate fruits. It is rich in minerals and vitamins. Farmers can profit greatly from producing it on their land because it is sold at a very high price.

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Vertical Farming: The Future of Urban Agriculture

Mahendra Kumar Seemar, Saroj and Rohit Sharma

Introduction

As cities expand and farmland shrinks, feeding the growing urban population has become a global challenge. By 2050, nearly 70% of the world's population will live in urban areas. Traditional farming, which requires vast amounts of land, water, and labor, cannot keep pace with this demand.

Vertical farming has emerged as a revolutionary solution. It involves growing crops in vertically stacked layers, often inside buildings, warehouses, or shipping containers. By integrating hydroponics, aeroponics, and aquaponics with advanced technologies like LED lighting, sensors, and artificial intelligence, vertical farming brings food production directly into the heart of cities.

What is Vertical Farming?

Vertical farming is a method of growing crops in controlled indoor environments where plants are cultivated in multiple layers. Unlike traditional agriculture, it does not depend on soil, seasons, or large open fields.

Key techniques used

Hydroponics: Plants grown in nutrient-rich water solutions without soil.

Aeroponics: Roots are suspended in the air and sprayed with nutrient mist.

Aquaponics: A combination of aquaculture (fish farming) and hydroponics, where fish waste nourishes plants.

Advantages of Vertical Farming

Space Efficiency: Multiple layers mean higher productivity per square meter.

Water Conservation: Uses up to 90% less water than traditional farming.

Year-Round Production: Indoor control allows crops to grow independent of seasons.

Reduced Transportation: Farms within cities lower "food miles" and ensure fresher produce.

Pesticide-Free Farming: Controlled environments minimize pests, reducing chemical use.

Climate Resilience: Protected from droughts, floods and extreme weather.

Challenges of Vertical Farming

High Energy Use: LED lighting and climate control consume significant electricity.

High Initial Cost: Infrastructure, automation, and technology require heavy investment.

Limited Crops: Currently more suited for leafy greens, herbs, and strawberries rather than staple grains like wheat or rice.

Technical Expertise: Requires trained staff for monitoring and managing systems.

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Global Examples of Vertical Farming

Japan: After the 2011 tsunami, vertical farms became popular. Companies like Spread Co. run automated indoor lettuce farms producing thousands of heads daily.

USA: AeroFarms (New Jersey) and Plenty (California) are pioneers in large-scale vertical farming, supplying supermarkets with fresh greens.

Singapore: With limited land, the government supports vertical farms like Sky Greens, producing vegetables in multi-tiered rotating towers.

UAE: Emirates Airlines invested in the world's largest vertical farm to supply fresh produce for in-flight meals.

Vertical Farming in India

India is gradually adopting vertical farming in metro cities like Delhi, Mumbai, and Bengaluru. Startups are experimenting with hydroponic and rooftop farming to provide fresh, pesticide-free vegetables directly to consumers. Given India's rising urban population and land constraints, vertical farming has strong potential for the future.

Role of Technology in Vertical Farming

Artificial Intelligence (AI): Optimizes nutrient levels, growth cycles, and harvest timing.

Internet of Things (IoT): Sensors monitor humidity, temperature, and pH.

LED Lighting: Provides specific wavelengths to maximize photosynthesis.

Robotics and Automation: Reduce labor needs and enhance efficiency.

Future Prospects

Vertical farming is expected to become a major part of urban food systems. Research is underway to expand crop varieties, reduce energy costs with solar power, and integrate vertical farms into smart cities. Some experts even predict vertical farms will be used in space missions and colonies on Mars.

Conclusion

Vertical farming is more than just an agricultural innovation it is a vision of future cities producing their own food sustainably. While challenges like cost and energy use remain, its potential benefits for food security, climate resilience, and urban sustainability are immense. As technology advances and investments grow, vertical farming will play a vital role in feeding the world's urban population in the decades to come.

Innovation in Dairy Farming for Higher Milk Production

Jagruti Singh

Dairy farming has always been a key part of agriculture, supplying nutritious milk and milk products to millions of people. As the need for dairy products grows around the world, farmers are working hard to increase milk production while keeping animals healthy and farming sustainable. New technologies and methods in dairy farming are changing the way things are done, helping to make milk production more efficient and higher than before.

Better Breeding Methods: Farmers use selective breeding and artificial insemination to create better dairy cows. Techniques like genomic selection and cross breeding help develop cows that are healthier, more fertile, and stronger against diseases, leading to more and better milk production each time.

Smart Farming Technologies: Tools like sensors, automatic milking machines, and wearable devices are changing how farmers manage their herds. These tools track cow health, eating patterns, and milk quality in real time, helping farmers make better decisions to improve productivity.

Improved Nutrition: Feeding cattle the right mix of protein, minerals, and vitamins is important for getting more milk. Using Total Mixed Rations (TMR), growing fodder with hydroponics, adding probiotics, and using bypass protein feed helps cows digest food better and produce more milk.

Comfortable Housing: Cow happiness plays a big role in milk production. New housing ideas like controlled temperature barns, rubber flooring, water sprinklers, and automatic fans help keep cows relaxed and healthy. Comfortable living conditions help improve milk output and herd performance.

Automated Milking Systems: Robotic milking machines allow cows to be milked on their own schedule, which reduces stress and increases milk production. These machines also keep things clean, track milk quality, and lower labor costs, making dairy farming more efficient.

Health and Disease Control: Modern vet care, regular vaccinations, and early disease detection with biosensors keep cattle healthier. Managing mastitis, keeping hooves in good shape, and controlling parasites help improve milk quality and yield.

Eco-Friendly Practices: Using biogas plants, managing cow waste, and recycling water not only help protect the environment but also give farmers extra income. These practices ensure dairy farming stays profitable and sustainable for the long term.

Conclusion: Innovation is essential for meeting the growing demand for milk and dairy products worldwide. By using better breeding, smart technology, improved food, and eco-friendly methods, farmers can increase milk production without harming animals or the environment.

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Role of Plant Introduction in Diversifying and Improving Fruit Genetic Resources

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Plant Introduction

- ✓ It consists of taking a genotype or group of genotypes into a new environment where they have not been grown before.
- ✓ The introduction may involve introducing new varieties of the crop already grown in the area, wild relatives of the crop species or a totally new crop species for the area.
- ✓ It can be done within the country or from other countries of continents.

Types

Introduction can be categorized as:

- ✓ Primary Introduction
- ✓ Secondary Introduction

Primary Introduction

- ✓ An introduction is said to be primary introduction when the introduced variety is well suited for newenvironment.
- ✓ It is released for commercial cultivation without any alteration in original genotype.
- ✓ In floricultural crops, the commercial varieties of rose, carnation, gerbera etc. which are presently being grown for commercial cut flower production or export have been introduced from different parts of the world.

Secondary Introduction

- ✓ The introduced variety may not be suitable for direct cultivation and can be subjected to selection to isolate a superior variety suitable for a particular area.
- ✓ The introduced variety may also be hybridized with local variety to transfer one or two characters from it to local variety.

Plant Introduction Agencies

- ✓ A centralized plant introduction agency was initiated in 1946 at IARI, New Delhi.
- ✓ The agency began a plant introduction scheme in Division of Botany and was funded by ICAR.
- ✓ Subsequently in 1961 it was made on independent division and subsequently called as National Bureau of Plant Genetic Resources in 1976.

Other plant introduction agencies are:

- ✓ NBPGR (National Bureau of Plant Genetic Resources, New Delhi)
- ✓ FRI (Forest Research Institute, Dehradun)
- ✓ The Botanical Survey of India
- ✓ Central Research Institutes for different crops.

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Achievements of Introduction

Scientific Achievement	Significance	Examples
Widening Genetic Base	Introduction of wild relatives and new genotypes to enhance disease resistance, drought tolerance, and other beneficial traits.	Tomato and wheat: Wild relatives used to improve resistance and yield.
Development of High-Yielding Varieties (HYVs)	HYVs are developed using introduced genotypes to improve yield, quality, and disease resistance.	IR8 rice from introduced semi-dwarf varieties in the Philippines. Indian wheat and rice varieties developed from introduced materials.
Improved Resistance to Pests and Diseases	Resistance genes from wild or introduced species enhance pest and disease resistance in crops.	Wheat rust resistance via genes from rye. Coffee rust resistance from African wild coffee relatives.
Crop Diversification and Climate Adaptability	Introduction promotes new crops, leading to crop diversification and adaptation to changing climates.	Rubber introduced to Southeast Asia and India from Brazil. Oil palm, cocoa, and cinchona introduced to Asia and Africa.
Vegetative Propagation & Clonal Selection	Clonal propagation of elite genotypes for uniformity and quality.	Grapevines and apple cultivars introduced from Europe to India and the USA.
Source Material for Biotechnology & Breeding	Biotechnology and molecular breeding using introduced genetic material to improve crops.	Bt cotton developed using genes from *Bacillus thuringiensis*. CRISPR gene-editing using introduced or wild germplasm.
Conservation of Rare and Threatened Germplasm	Gene banks preserve introduced and rare species to maintain biodiversity.	Svalbard Global Seed Vault preserves global plant diversity. NBPGR in India conserves native and introduced species.
Economic and Commercial Benefits	Introduction of new crops leads to economic growth, especially in export-oriented crops.	Tapioca from South America now a key crop in southern India. Coffee from Arabia became a major crop for export in India.
Facilitating International Collaboration	International exchange of germplasm strengthens global cooperation in agricultural research and development.	CGIAR centers (e.g., IRRI, CIMMYT) use introduced germplasm for global crop improvement.

✓ NRC Orchids, Gangtok, Sikkim

Plant introduction is one of the oldest and very effective methods of plant breeding. The main function of plant introduction is to make available the germplasm that can bebe utilized in plant breeding programme.

Introduction consists of various steps

✓ Procurement
✓ Quarantine
✓ Cataloging
✓ Evaluation
✓ Multiplication

Procurement of germplasm

✓ The new germplasm is procured through NBPGR, New Delhi.
✓ Scientists, individuals and institutions can submit their requirement to Director, NBPGR, Pusa Complex, New Delhi.
✓ If the bureau is unable to meet the request from its own stock or from known source it attempts to procure them from the counterparts in other countries.
✓ Generally the material is obtained through correspondence as gifts or exchange of germplasm in consideration of past gifts to the Bureau or in anticipation of future gifts.
✓ The Bureau participation in the activities of NBPGR aims at free exchange of germplasm and is helpful in arranging supply of needed germ-plasm.
✓ The plant part depending on the crop species e.g. seeds; tubers; suckers, bulbs or cuttings etc. can

be procured.

Quarantine

- ✓ It is to keep the material in isolation to prevent spreading of diseases etc.
- ✓ All introduced material is thoroughly inspected for contamination with diseases, weeds and insects. Plants that are suspected to be contaminated are fumigated or are given other isolation for treatments and observed for insect pests and disease.
- ✓ The entire process is known as quarantine and the rules which are used for this are known as Quarantine rules.
- ✓ It is essential that all the material being introduced must be accompanied by an authentic phytosanitary certificate.
- ✓ The plant material being introduced or exported must confirm to certain quarantine regulations and quarantine control is exercised by NBPGR at different points of entry.
- ✓ The phytosanitary certificate is thoroughly inspected and returned back to the sender or owner.

Cataloging: All the plant material which is introduced is given an entry number and information regarding agency, place of origin, adaptation etc and is well documented.

Plant material is classified in three categories

- ✓ Exotic collection (EC)
- ✓ Indigenous collection (IC)
- ✓ Indigenous wild collection

Evaluation: The plant material is sent to sub stations of the bureau and evaluated with respect to various characters to assess the potential of new introductions.

Acclimatization

- ✓ It is the process that leads to the adaptation of a variety to a new environment.
- ✓ Variability must be present in original population so that natural selection could lead to acclimatization. The extent of acclimatization is determined by range of genetic variability in original population and duration of life cycle of crop.
- ✓ Cross pollination leads to far more gene recombination than self pollination. The greater the initial variation the more is acclimatization.

Multiplication and distribution: Plant material which is introduced is to be multiplied and further tested at various locations. The suitability of cultivation in different regions of the country should be assessed before using it as a commercial variety.

Merits and Demerits of Plant Introduction

Merits

- ✓ It provides entirely new crop plants to a place.
- ✓ Superior varieties may be originated directly or after selection or hybridisation.
- ✓ Germplasm collection, maintenance and protection of genetic variability
- ✓ It is the most quick and economical method of crop improvement when introduced material can be used directly.
- ✓ Introduction of some varieties to newer areas may protect them from some diseases.

Demerits

- ✓ The weeds like Argemone, Eichhornia, Lantana have been introduced from other countries.
- ✓ The fungal diseases like late blight of potato, flat smut of wheat, coffee rust, bunchy top of banana have been introduced in India along with plant materials.
- ✓ Many insect pests like potato tuber moth, woolly aphis of apple, were introduced in India.

Agri-Entrepreneurship in India: Pathways, Policies and Opportunities

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Abstract

Agriculture in India, traditionally a source of subsistence and food security, has undergone a significant transformation over the past two decades, evolving towards commercialization, innovation, and entrepreneurship. Agri-entrepreneurship, which integrates farming with business practices, value addition, technology, logistics, and marketing, has emerged as a key strategy for enhancing rural livelihoods. Supported by government initiatives such as the Agriculture Infrastructure Fund (AIF), Agri-Clinics and Agri-Business Centres (AC&ABC), RKVY-RAFTAAR, and the Prime Minister Formalisation of Micro Food Processing Enterprises (PMFME) (MoFPI, 2024; NABARD, 2024), it enables farmers to diversify incomes and adopt modern practices. This paper examines the primary drivers of agri-entrepreneurship in India, explores various entrepreneurial pathways, and assesses emerging opportunities and associated risks. Case studies of innovative agri-startups such as DeHaat, Ninjacart, and Stellapps illustrate the transformative potential of novel business models. The findings highlight that agri-entrepreneurship not only enhances farmer incomes but also strengthens food security, promotes climate resilience, and accelerates India's integration into global agricultural markets.

Introduction

Agriculture remains the backbone of the Indian economy. It provides jobs for nearly 44% of the population and contributes about 18% to the Gross Domestic Product (GDP) (Department of Agriculture & Farmers Welfare [DA&FW], 2025). Besides its economic importance, agriculture supports social and cultural systems, ensures food supply, and fosters national development. The Green Revolution of the 1960s helped India become self-sufficient in food grains. However, challenges persist, including fragmented landholdings, unstable markets, post-harvest losses, and increasing risks from climate change. Agri-entrepreneurship is increasingly regarded as a solution. This approach views agriculture as a complete business system that includes production, storage, processing, marketing, and export. It uses technology, innovation, and teamwork to boost productivity and profits (NABARD, 2024). This method creates opportunities for rural youth, women entrepreneurs, and small farmers. It also aligns with India's goals of doubling farmers' income and meeting the Sustainable Development Goals (SDGs) of zero hunger,

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decent work, and climate action.

The Rationale and Relevance of Agri-Entrepreneurship Today

Agri-entrepreneurship in India is becoming increasingly important due to various structural, economic, and environmental changes. Several factors show why promoting it is urgent and essential.

Demographic Pressures: The average operational holding size is only 1.08 hectares, and over 85% of farmers are considered small or marginal (DA&FW, 2024). This limits the ability to achieve economies of scale through traditional farming. As a result, farming is becoming less viable. A large and young rural population is turning to entrepreneurship in related sectors like dairy, poultry, horticulture, and fisheries to diversify and stabilize their incomes (ICAR, 2024).

Policy Environment: Supportive government policies are encouraging agri-entrepreneurship. The establishment of 10,000 Farmer Producer Organisations (FPOs) aims to strengthen collective bargaining power. Programs like the Agriculture Infrastructure Fund (AIF) are improving storage and supply chain facilities. The PM Formalisation of Micro Food Processing Enterprises (PMFME) scheme provides subsidies to food processing micro-units (MoFPI, 2024).

Digital Transformation: Technology is changing Indian agriculture. Platforms like the National Agriculture Market (e-NAM) and private agritech companies such as DeHaat, AgroStar, and Ninjacart are making it easier to access quality inputs, credit, and markets. By 2023, India had over 2,800 agritech startups, significantly transforming rural economies and entrepreneurial chances (Invest India, 2025).

Climate Change Adaptation: More erratic rainfall, rising temperatures, and extreme weather have made farming riskier. This situation has opened doors for climate-smart agri-entrepreneurs who offer solutions like IoT-based sensors, renewable energy-powered irrigation pumps, and precision farming tools. These tools are vital for building resilience (DAHD, 2025).

Global Demand: India's agricultural exports are growing quickly, especially in organic produce, Geographical Indication (GI)-tagged goods, and millets. The International Year of Millets (2023) acted as a global catalyst, increasing demand. Agencies like APEDA are helping agri-entrepreneurs access international markets (APEDA, 2024).

Pathways for Agri-Entrepreneurs

Agri-entrepreneurship in India is growing as a key area for rural development and economic diversification. Various pathways offer unique chances for creating value throughout the agricultural ecosystem.

Farm Services and Inputs: Custom hiring centers are becoming crucial in tackling the problem of fragmented landholdings. They allow farmers to rent machinery, drones, and other modern tools at affordable rates. The Agri-Clinics and Agri-Business Centres (AC&ABC) scheme trains agri-graduates to provide services like soil testing, crop advice, and farm mechanization support. This helps improve

productivity and cut input costs (NABARD, 2024).

Post-Harvest and Food Processing: India loses almost 20 to 30% of its agricultural produce each year due to poor storage, ineffective logistics, and a shortage of processing facilities (MoFPI, 2024). Agri-entrepreneurs who invest in cold chains, warehouses, grading, and processing units are essential for reducing waste and increasing farmers' incomes. The PM Formalisation of Micro Food Processing Enterprises (PMFME) scheme has especially empowered rural women to start small businesses producing pickles, millet-based snacks, jams, and packaged foods. These efforts not only enhance the value of primary produce but also create local jobs.

Digital Platforms and Agritech Solutions: Technology-driven ventures are changing the agricultural scene by connecting farmers, markets, and service providers. For example, DeHaat offers AI-based crop advice, credit, and market connections to over 1.8 million farmers. Ninjacart simplifies supply chains by linking farmers directly to retailers, which significantly cuts inefficiencies and price distortions. Similarly, AgroStar uses mobile apps for last-mile delivery of inputs, making sure farmers have timely access to seeds, fertilizers, and pesticides (Invest India, 2025). These digital solutions improve transparency, enhance market access, and provide farmers with real-time information**.**

Export-Oriented Ventures: Increasing global demand for Indian agricultural products creates chances for export-focused entrepreneurship. With support from the Agricultural and Processed Food Products Export Development Authority (APEDA), businesses export goods such as Basmati rice, Darjeeling tea, organic spices, and millet products. Small companies in states like Karnataka and Rajasthan have effectively promoted millet-based snacks in European and Middle Eastern markets, showcasing the potential for niche agri-products in global value chains (APEDA, 2024).

Institutional and Financial Support: Strong institutional support and financial incentives are boosting the environment for agri-entrepreneurs. The Agriculture Infrastructure Fund (AIF) has approved projects worth over ₹30,000 crore, especially for warehouses, logistics hubs, and processing units. Moreover, RKVY-RAFTAAR incubators at ICAR institutions are fostering innovations in biotechnology, precision irrigation, and smart farming systems (ICAR, 2024). These initiatives provide financial help and technical guidance, allowing startups to grow sustainably.

Opportunities Ahead

Agri-entrepreneurship in India offers significant chances for economic growth and rural change. Farmer Producer Organisations (FPOs) are becoming strong allies by bringing together small farmers, improving their bargaining power, and achieving economies of scale (DA&FW, 2024). Agri-fintech startups like Samunnati are closing gaps in credit and insurance access. This reduces risks and allows farmers to invest confidently in new projects. Sectors like dairy, fisheries, and poultry are important for

growth. Dairy alone contributes nearly 23% to agricultural GDP (DAHD, 2025). The rising consumer demand for safe, healthy, and specialty products is driving the growth of organic exports, which surpassed $1 billion in 2023 and 2024. Markets for medicinal plants, GI-tagged spices, and millets are also expanding (APEDA, 2024). At the same time, climate-smart businesses that offer solar-powered cold storage, efficient irrigation, and waste-to-energy solutions are attracting investors and promoting long-term sustainability (ICAR, 2024). Together, these opportunities make agri-entrepreneurship a key driver for income diversification, job creation, and strong rural development.

Challenges and Risks

Despite the promising opportunities, agri-entrepreneurship in India continues to face significant challenges that constrain its full potential. Climate uncertainty and unstable weather patterns tend to bring about lower yields and unstable farm revenues, rendering entrepreneurship risky by nature (DAHD, 2025). Finance is still a major obstacle since a large number of small entrepreneurs find it difficult to access collateral-free credit despite schemes such as the Agriculture Infrastructure Fund (NABARD, 2024). Regulatory intricacies, such as FSSAI licensing, GST regulations, and APEDA certification, further increase barriers to entry and operational expenses for startups (MoFPI, 2024). Gaps in infrastructure also exist, with fewer than 15% of perishables moving through cold chains, leading to post-harvest losses and value addition constraints (DA&FW, 2024). Additionally, a lack of business management and marketing competencies among potential entrepreneurs presents further bottlenecks. While programs such as Agri-Clinics and Agri-Business Centres (AC&ABC) do offer training, there is a much higher demand for capacity-building programs than they currently cover (NABARD, 2024). Minimizing these risks is the key to developing a strong ecosystem in which agri-entrepreneurship can flourish sustainably.

Government Support and Future Outlook

India's policy environment offers a strong support system for the development of agri-entrepreneurship via varied institutional and financial arrangements. Agri-Clinics and Agri-Business Centres (AC&ABC) program provides agri-graduates with entrepreneurial and technical competencies to build service-oriented enterprises (NABARD, 2024). The Agriculture Infrastructure Fund (AIF) provides low-interest financing for storage, warehousing, and logistics, lowering post-harvest losses (DA&FW, 2024). In the same manner, the PM Formalisation of Micro Food Processing Enterprises (PMFME) scheme enhances rural food enterprises with credit-linked subsidies, with the emphasis placed squarely on women-dominated microenterprises (MoFPI, 2024). Programs such as Startup India and the Department for Promotion of Industry and Internal Trade (DPIIT) promote agritech innovation, while RKVY-RAFTAAR incubators located within ICAR institutions mentor and upscale potential agri-startups (ICAR, 2024).

At the international level, APEDA ensures exports through certification, branding, and market connections, allowing Indian agri-entrepreneurs to compete globally (APEDA, 2024). Collectively, these strategies build a multi-tiered system that consolidates agri-businesses throughout the value chain. In the times to come, the agri-entrepreneurship business of the future will be pioneered by innovation, inclusivity, and sustainability. AI-driven digital agriculture, big data, and IoT are making precision farming, predictive analytics, and intelligent use of resources a reality (Invest India, 2025). Blockchain technology is offering higher transparency and traceability in supply chains, particularly for export-oriented products. Increased youth and female participation will bring dynamism, enhance rural incomes, and help achieve gender equality in the agricultural sector (MoFPI, 2024). In addition, sustainability will continue to be central because agri-entrepreneurship itself aligns squarely with the UN Sustainable Development Goals (SDGs), especially those on zero hunger, climate action, and responsible consumption. With the support of robust policy and new technology opportunities, agri-entrepreneurship will emerge as an important catalyst for resilient, inclusive, and sustainable rural change.

Conclusion

Agri-entrepreneurship is becoming a key impetus for rural change in India. Through the combination of technology, innovation, and enabling policy support, it is transforming agriculture from conventional subsistence farming into a globally competitive and remunerative business. With the help of government programs, online platforms, and climate-resilient management systems, agri-entrepreneurship can raise farmers' incomes, create jobs, and ensure sustainable development. When India develops its farm sector, agri-entrepreneurs will play a crucial role in making farming transition into a dynamic and vibrant business culture, adding to rural wealth and national growth.

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Natural Farming: An Eco- Friendly Alternatives to Modern Agriculture

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Introduction

An Ecological Path for the Hills of Uttarakhand is Natural Agriculture. Agriculture, which has long been the lifeblood of the state, provides direct or indirect employment for around 70-78% of Uttarakhand's population. However, achieving agricultural prosperity and stability has proven to be extremely difficult for the state, particularly in its hilly regions. Rough terrain, erratic weather, poor irrigation systems, and deteriorating soil health are examples of ongoing challenges. These issues are made worse by the growing consequences of climate change, which have an impact on the livelihoods of many indigenous farmers. Eco-friendly & nature-based agricultural practices have gained popularity in an attempt for making traditional farming environmentally friendly (FAO, 2017; HLPE, 2017). The Indian government established the National Mission of Natural Farming (also known as NMNF) in 2023 to incentivize farmers to transition to chemical-free farming practices. In this sense, natural farming became a beacon of hope, especially for the hilly areas of Uttarakhand. The mountainous areas need a low-input, ecologically responsible approach that coexists together with the environment, as compared to the lowlands, wherever automated farming and extensive irrigation systems are more feasible.

Natural farming, which emphasizes organic inputs, biodiversity, and minimal soil disturbance, is ideally suited to the traits and constraints of hill agriculture. It reduces dependency on artificial pesticides and fertilizers, boosts resilience to climate shocks, and enhances soil fertility through natural composting (Economic Survey, 2019). It also encourages the preservation of traditional knowledge systems and indigenous agricultural kinds, which are often better adapted to the local microclimates. Natural Farming's characteristics and limitations are perfectly matched with natural farming, which places an emphasis on organic inputs, biodiversity, & little soil disturbance. In addition to strengthening resilience to climate shocks, it increases soil fertility by natural composting. A few examples of organic inputs that have been used to increase the amount of organic matter in soil are green manures, animal dung, and straw (Panagos *et al*., 2015). Additionally, because indigenous agricultural types are frequently better suited to the local microclimates, it promotes the safeguarding of traditional knowledge systems. The steep areas of Uttarakhand may set the benchmark for sustainable agriculture by adopting natural farming, which would guarantee food security, protect the environment, and support the local agricultural community financially. While the low-lands can still benefit from traditional approaches,

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ches, the hills provide a unique opportunity to create a resilient and regenerative agricultural paradigm.

Agroecological Conditions of Hilly Regions of Uttarakhand: Natural farming is encouraged by the unique agroecological conditions provided by Uttarakhand's steep hills. The areas of Rudraprayag, Uttarkashi, Pithoragarh, and Chamoli are renowned for their rich wildlife, varied microclimates, and steep slopes. The foundation for sustainable agriculture is laid by traditional terrace farming, which regulates water flow and prevents soil erosion. The fertility and structure of the soil are gradually improved by natural farming practices including mulching, composting, and mixed cropping, despite the fact that the soils are frequently shallow and prone to erosion. Uttarakhand fully approved 23% of its total land for organic farming in 2019 and became the first Indian state to pass a state-level Organic Agriculture Law, according to the APEDA, 2021 report. Rain-fed agriculture predominates in the highlands and there is minimal irrigation infra-structure. Natural farming works well under these conditions because it promotes moisture retention and reduces dependency on external inputs. Crops that are resilient to climate variability and demand minimal resources, like pulses, millets, horticultural crops, and indigenous medicinal herbs, thrive at these elevations. Cultural preservation and ecolo-gical balance are further supported by the incorporation of livestock and regional seed varieties. The hilly topography naturally supports the ideas of natural farming, despite logistical hurdles.

Natural farming has a cutting-edge strategy to enhance conventional and contemporary farming methods with the goal of protecting communities, the environment, and public health (Mishra, 2013). India's vast traditional knowledge and varied agroclimatic conditions.

Agroecological Conditions of Plain Areas: India's lowlands, particularly the coastal regions, the Brahmaputra valley, and the Indo-Gangetic plains, have extremely advantageous agroecological conditions for farming. These areas sustain long growing seasons & several cropping cycles because to their flat terrain, deep & fertile alluvial soils, & sub-humid to humid climate. Widespread irrigation is made possible by an abundance of water resources from rivers including Ganga, Yamuna, and Brahmaputra. While coconut, spices, & horticulture are also supported in coastal plains, the predominant crops are wheat, rice, maize, sugarcane, pulses, & oilseeds. Because of the level terrain and intensive farming practices that frequently rely on large inputs of pesticides and fertilizers, mechanization is common. They are essential for maintaining rural livelihoods in a variety of climatic zones and guaranteeing national food security due to their agroecological diversity.

Why Natural Farming Suits Hilly Areas as compared to Plain Areas of Uttarakhand?

Uttarakhand's hilly regions are better suited for natural farming than its plains because of the state's topography, climate and ecology. Mechani-zation is limited by steep slopes and dispersed land-

holdings on hills, which makes low-input, organic approaches perfect. In districts includes Chamoli, Uttarkashi, and Pithoragarh, terrace farming is popular, and natural farming promotes soil fertility and reduces erosion. Additionally, climate-resilient crops that thrive at high elevations, such as pulses and millets, are encouraged. Conversely, because of their level topography and easy access to irrigation, plains support intensive, chemical-based agriculture, but they also run the danger of degrading the soil. The implementation of natural agricultural practices by farmers in India was examined using a descriptive research approach. It concentrated on common customs such as Dashparni, Agniastra, Neemastra, Stale Seedbed preparation, Beejaamrit, Ghanajivamrita and Jeevamrit, Green Manuring, Trap cropping, Biological Control, Transparent Mulch, Cover Crop, Mulching, Vermicomposting, Intercropping, Crop Rotation, NADEP Compost, Kunapjal, Panchgavya, Basam Rasayan and Aloevera Rasayan. A combination of both quantitative and qualitative data collection approaches was used in a mixed-methods approach (Aulakh *et al*., 2022). A thorough semi-structured interview plan was created to collect data on the use of various natural farming techniques. To improve the clarity and validity of the results, a chosen sample of respondents was used to test the preliminary versions of both closed-ended and open-ended questions. The quantitative data was then processed through a comprehensive exploratory data analysis.

Natural Farming: "Hilly areas vs Plain areas"

A clear comparison table showing why natural farming is more suitable for hilly areas than plain areas is given below Table 1.

Case Study: Natural Farming in Uttarkashi, Uttarakhand

Background: Uttarkashi is primarily an agrarian district with precipitation-fed crops, mountainous terrain, and delicate soils. It is situated in the Garhwal Himalayas. Long-standing local communities have been supported by traditional farming methods, but agricultural viability is now seriously threatened by rising climatic variability, soil degradation & youth movement. Initiative: Natural farming methods were embraced by farmers in villages including Bhatwari and Dunda with assistance from NGOs such as the Himalayan Environmental Studies and Conservation Organization (HESCO) and the State Government's Natural Farming Mission. Among these were mixed cropping, mulching, Jeevamrit usage, zero-budget natural farming ("ZBNF"), and the revival of native seeds.

Results: Enhanced soil fertility and decreased soil erosion in terraced fields. Increased agricultural diversity through the use of medicinal herbs, pulses, and millets. Reduced input costs and greater farmer independence. Enhanced regional food systems and less reliance on chemicals.

Challenges: Lack of Irrigation, Restricted Market Access, and the requirement for ongoing training continue to be obstacles. However, Sustainable Hill Agriculture is a viable concept for Natural Farming

Table 1: Comparative between hilly areas and plains areas

Aspects	Hilly areas	Plain Areas
Farm size	Small fragmented land holding	Large, continuous land holding
Use of fertilizer	less use	extreme use
Biodiversity	Rich in indigenous crops, horticultural crops, medicinal crops etc.	Less biodiversity
Economic aspects	Low costs, self- reliant, reduce dependency on external inputs	High cost, high inputs
Erosion	Less erosion	High erosion
Water availability	More water resources	Less water resources
Soil conditions	Deep fertile soil	Shallow and less fertile soil, suitable for intensive farming
Soil degradation	Less soil degradation	High soil degradation
Productivity	Long term productivity	Short term productivity
Soil organic carbon	Naturally higher due to less human disturbance	Often depleted of organic carbon due to intensive, conventional farming
Water management	Natural slopes provide excellent drainage	Requires extensive artificial drainage system
Natural pest control	Presence of diverse flora and fauna provides natural predators	Lack of natural predators due to monoculture and pesticide use
Nutrient cycling	Natural decomposition of diverse plant and animal matter enriches the soil	Nutrient cycling is often disrupted, requiring synthetic fertilizers to replenish nutrients.
Carbon sequestration	Higher potential for long-term carbon storage due to undisturbed soils and diverse plant life	Lower potential for carbon storage
Self-sufficiency	The natural abundance of resources and a focus on minimal external inputs make farms more self-sufficient	A high dependency on external inputs like fertilizers, pesticides and hybrid seeds.
Labor and mechanization	Less reliance on heavy machinery	Relies heavily on large, fuel-consuming machinery
Water purity	Access to cleaner water from mountains, springs and streams	Water resources are often contaminated by chemicals
Tradition and local knowledge	Natural farming aligns with many traditional farming practices passed down through generation	Conventional farming has often replaced traditional methods leading to loss of valuable local knowledge
Resource efficiency	Efficient use of natural resource like rainwater, biomass	High consumption of water and non-renewable resources like fossil for fuels for machinery and fertilizers

because it is ecologically compatible with Uttarkashi's topography.

Conclusion

Uttarakhand's hilly regions are particularly ideal for natural farming due to its unique agroecological characteristics and traditional farming practices. Because of the uneven terrain, dispersed landholdings, and inadequate irrigation infrastructure, traditional, mechanical agriculture is impractical. By contrast, natural farming flourishes in these circumstances by focusing on organic, low-input practices that improve soil fertility, lessen erosion, and foster biodiversity. In areas like Chamoli, Uttarkashi, and Pithoragarh, the climate and topography make techniques like terrace farming, mulching and composting, and producing native seeds ideal. Additionally, climate-resilient crops that thrive in high-altitude microclimates, such as medicinal herbs, pulses, and millets, are supported by natural farming. By lowering their need on additional resources and chemical inputs, it also encourages farmers to become more self-sufficient. Cultural preservation and ecological balance are further supported by the merging of livestock to

traditional knowledge systems. Uttarkashi case studies show how natural farming can improve soil health, lower input costs, and increase crop diversity. The hilly areas present a favorable setting for sustainable agriculture, notwithstanding obstacles like market accessibility and training requirements. These regions might set the standard for regenerative practices that guarantee food security, environmental preservation and financial stability for mountain communities by embracing natural farming. An inherent advantage for promoting sustainable agriculture is that practically every family in hilly regions has an indigenous cow. Without the use of synthetic pesticides, natural farming makes use of cow-based inputs such as Jeevamrit and Gaumutra (cow urine), these increase soil fertility and microbial activity. Unlike buffaloes, that are more common in the plains yet less suitable for generating these bio-enhancers, cows provide a steady flow of essential materials for regeneration processes. Its zero-budget natural farming principles are naturally compatible with hilly areas due to this historically and biologically based livestock pattern. By using cow-based inputs and local biodiversity, farmers in these regions can grow flexible, chemical-free crops while maintaining soil health and reducing costs. As a result, the makeup of cattle in hilly areas encourages an autonomous, ecologically conscious agricultural model and increases the potential for natural farming.

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Towards Oil Security for India: Sunflower as the Anchor Crop

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Abstract

India relies on imports to meet more than 60% of its edible oil needs, of which a large proportion is sunflower oil. Hence, there is an urgent need to enhance domestic production of sunflower for oil security New generation hybrids with early maturity (85-120 days), higher productivity, drought-tolerant and better resistance to pests and diseases, such as TilhanTec-SUNH-1, KBSH-85, RSFH-700, COH-4, PDKV Suraj, and TilhanTec-SUNH-3, have been developed and released to increase oil productivity. However, the sunflower crop is affected by several biotic and abiotic constraints including climate stress, pests and diseases, fluctuating market prices, and poor infrastructure, among others. These challenges must be addressed to increase the adoption of the crop by farmers. Interventions related to improving the seed system, providing assured minimum support prices (MSPs), crop insurance, irrigation support, and market linkages along with appropriate intercropping practices and utilization of rice-fallow areas have the potential to significantly expand the area under sunflower. Integrating genetic gains with policy support can make sunflower a game-changer for India's edible oil security.

Introduction

India is the world's second-largest consumer of edible oils, but it still relies largely on imports, with roughly two-thirds of its demand being fulfilled by international markets (Manivannan *et al*., 2017; Chakraborty *et al.*, 2022). India imports more than 60% of its edible oil needs, including a large share of sunflower oil from Ukraine, Russia, and Argentina. This makes the country vulnerable to international price shocks and supply disruptions. To achieve this potential challenge and reduce India's heavy reliance on edible oil imports, the country must overcome many production hurdles that have resulted in a long-term drop in sunflower cultivation (Singh *et al.*, 2009). This significant reliance not only stresses the economy, but also exposes the country to global price volatility. Strengthening domestic oilseed production is thus not only an agricultural priority, but also a national food security concern.

The potential of sunflower cultivation in India

Crop adaptation to local environment: The crop has significant adaptability to varied environments,

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being highly photosensitive and suitable for year-round cultivation throughout many agro-climatic zones and seasons in India (*Kharif, Rabi* and *Zaid*).

Short growth duration: The sunflower cultivation, with short duration (85-120 days) hybrids/varieties, is easily incorporated into a variety of crop rotation and intercropping systems, including peanuts, soybean, and pigeon pea. This flexibility enables farmers to make better use of their land while increasing their annual revenue.

Drought tolerance: Sunflowers exhibit considerable drought tolerance owing to their extensive root system, that makes them suited to rain-fed regions.

High-quality oil: Sunflower seeds contain 35-45% oil, making them a high-quality oil for consumption loaded with unsaturated fatty acids and vitamin E. It is a widely utilized heart-healthy cooking oil in India, particularly in the southern and western regions.

Lucrative for farmers: New generation high-yielding hybrid/ varieties, have a substantial production potential, climate resilient and improved oil content, resulting in increased profitability for farmers.

Contribution to biodiversity: Sunflowers attract pollinators like bees, which can improve overall agricultural biodiversity and provide beekeepers with an additional source of income.

The New Age of Sunflower Hybrids

The new-age sunflower hybrids developed by ICAR institutions, state agricultural universities, and seed companies have been carefully bred to address the obstacles that previously made sunflower cultivation difficult (Table 1.). Recent releases such as TilhanTec-SUNH-1, KBSH-85, RSFH-700, COH-4, PDKV Suraj, TilhanTec-SUNH-2, SUNH-3, and KBSH-90 are giving farmers a reliable edge (Meena *et al.*, 2023; Selvakumar *et al.*, 2022). These hybrids have been carefully bred with the following strengths:

SUNH-3 (IIOSH-434): Developed by ICAR-Indian Institute of Oilseeds Research (IIOR) in Rajendra-nagar, this high-yielding hybrid is suitable for both rainfed and irrigated conditions and excels in both *Kharif* and *Rabi* seasons.

KBSH-78: Released by the University of Agricultural Sciences (UAS), Bangalore, this hybrid is particularly beneficial for rainfed areas in southern India, showing improved drought tolerance and profitability.

TilhanTech-SUNH-1 & SUNH-2: These are early-maturing hybrids, with SUNH-1 maturing in about 90-100 days and SUNH-2 maturing even faster (84-87 days), allowing for quicker harvest and more efficient land use.

COH 3: This hybrid is noted for its high oil content and high yield potential, providing strong economic returns for farmers.

DRSH-1 and KBSH-44: These are recommended for all-India cultivation and other specific regions, contributing to broad productivity**.**

PDKV Suraj (PDKVSH 964): This high-yielding hybrid is specifically recommended for cultivation in Maharashtra.

Challenges to anchoring sunflower as a core oil-

Table 1: List of new age sunflower hybrids released in past five years (2021-2025)

Hybrids	Year of release	Maturity	Yield (kg ha^{-1})	Oil content (%)	Salient features	Areas of Adaptation/ Recommended ecology
TilhanTec-SUNH-1	2021	95-100	2000-2650	39-41	Resistant to downy mildew and moderately resistance to leafhoppers	Uttarakhand and Jammu & Kashmir, Gujarat, Maharashtra and Northern Karnataka, Andhra Pradesh, Southern Karnataka, Tamil Nadu and Telangana
KBSH-85	2021	90-100	1500-1900 (R) 2200-2600 (I)	35-37	Resistant to downy mildew and moderately resistance to leafhoppers	Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and Telangana State
RSFH-700	2022	90-95	1893-2434	38-40	Tolerant to viral sunflower necrosis disease, *Alternaria* blight and Powdery mildew diseases	Karnataka
COH-4 (CSFH-15020)	2023	90-95	1800-2200	40-42	Moderately resistant to powdery mildew, *Alternaria* leaf blight and sucking pest and leaf feeders	Tamil Nadu
KBSH-88	2024	86-88	1500-2000	34-36	Resistant to downy mildew disease and moderately resistant to leafhoppers	Uttarakhand and Jammu & Kashmir, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and Telangana
PDKV SURAJ (PDKVSH-964)	2024	89-90	1750-2000	39.3	Moderately resistant to *Alternaria* leaf spot and leafhopper	Maharashtra
TilhanTec-SUNH-2 (IIOSH-460)	2024	89-91	1519-1657 (R) 2000-2600 (I)	37-40	Resistant to downy mildew disease and moderately resistant to leafhoppers	Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and Telangana
TilhanTec-SUNH-3 (IIOSH-434)	2025	87-90	1500-2000 (R) 2000-2600 (I)	37-39	Resistant to downy mildew disease and moderately resistant to leafhoppers	Uttarakhand and Jammu & Kashmir, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and Telangana
KBSH-90	2025	82-85	1700-1800 (R) 2000-2400 (I)	36.6	Resistant to downy mildew disease	Uttarakhand and Jammu & Kashmir, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and Telangana

R=Rainfed I=Irrigated

seed crop

Significant production-consumption gap: Sunflower oil is very popular, but India does not produce much of it. In 2023-2024, India imported about 250,000 metric tons of sunflower oil each month. This makes India the biggest importer of sunflower oil in the world.

Climate-related issues: Irregular rainfall and severe weather conditions, such as terminal heat stress, can adversely affect crop yields, especially in areas

dependent on rain for irrigation.

Pests and diseases: Sunflower crop prone to various pests (e.g., leafhoppers and birds) and diseases (e.g., downy mildew, powdery mildew, alternarira and necrosis viral disease), which can be leading to severe crop losses.

Market volatility and pricing: Farmers face significant price fluctuations for their produce. Low or unstable prices, along with competition from cheaper imported oils, make sunflower cultivation a less appealing option.

Inadequate support infrastructure: Key constraints include the high cost and inconsistent availability of quality seeds and inputs, limited irrigation facilities in some regions, and weak market linkages, storage, and processing infrastructure.

Farmer knowledge gap: Many farmers lack sufficient knowledge of modern cultivation techniques, hybrid varieties, and effective pest management strategies.

Strategic interventions for oil security

To successfully anchor sunflowers as a key component of India's oil security, the government and industry must implement a multi-pronged strategy.

Improve seed supply and technology

Research and development: Continue to invest in developing high-yielding, short-duration, and climate-resilient hybrid seeds with higher oil content.

Seed distribution: Strengthen seed distribution systems to ensure farmers have timely and affordable access to quality certified seeds.

Strengthen market and financial support

Price support schemes: Guarantee a stable and attractive Minimum Support Price (MSP) for sunflower seeds through schemes like PM-AASHA to protect farmers from market volatility.

Crop insurance: Extend comprehensive crop insurance to cover climate-related risks, protecting farmers from financial loss due to uncertain weather.

Expand irrigation and modern practices

Micro-irrigation: Promote the adoption of efficient irrigation techniques, such as drip and sprinkler systems, through subsidies, especially in dry and rain-fed areas.

Technological extension: Utilize agricultural extension services, like Krishi Vigyan Kendras (KVKs), to train farmers on best practices for cultivation, integrated pest management, and post-harvest handling.

Invest in value chain infrastructure

Processing capacity: Encourage public-private partnerships to increase domestic processing and refining capacity for sunflower oil.

Market linkages: Establish better linkages between farmers, farmers' producer organizations (FPOs), and oil mills to reduce reliance on middlemen and ensure fair prices.

Encourage crop diversification

Intercropping benefits: Actively promote sunflower cultivation as part of diverse cropping systems to improve soil health and provide additional income.

Utilize fallow land: Capitalize on the potential of

cultivating oilseeds like sunflowers in rice-fallow areas, as identified by NITI Aayog.

Summary: The decline sunflower cultivation area, yield production variability, and price fluctuations continue to be significant challenges. The next-generation hybrids will empower farmers with stability, profitability, while enhancing the country's journey towards edible oil self-sufficiency. Newer hybrids have brought a renewed hope. However, Adoption is uneven. Without better policy support, a robust seed system, irrigation management, and farmer incentives, sunflower risks staying a niche oilseed rather than becoming a cornerstone of India's edible oil security plan.

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Segregating Populations Used for Gene Mapping in Plant Breeding

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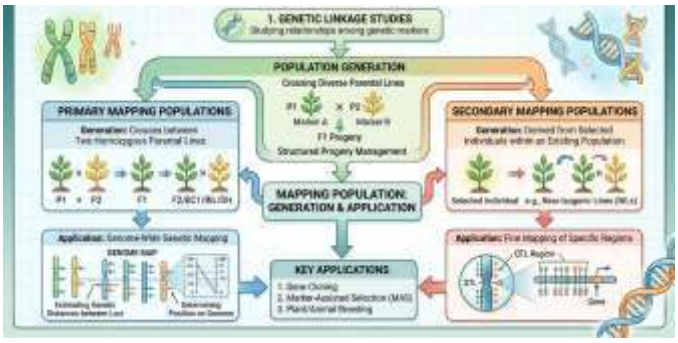
Abstract

A mapping population refers to a group of individuals specifically developed for studying the linkage relationships among genetic markers. It is produced by crossing two or more genetically diverse parental lines and managing the resulting progeny in a structured manner. Such populations are essential for estimating genetic distances between loci or genes and for determining their positions on the genome. Mapping populations are broadly classified into two types: primary and secondary. Primary mapping populations are generated through crosses between two homozygous parental lines that differ in traits of interest. In contrast, secondary mapping populations are derived from selected individuals within an existing mapping population and are primarily used for fine mapping of specific genomic regions.

Primary mapping populations can be categorized into several types, including: (1) F_2, (2) F_2-derived F_3 (F_2:F_3), (3) backcross (BC), (4) backcross inbred lines (BILs), (5) doubled haploids (DHs), (6) recombinant inbred lines (RILs), (7) near-isogenic lines (NILs), (8) chromosomal segment substitution lines (CSSLs), (9) immortalized F_2, (10) advanced intercross lines, (11) recurrent selection backcross (RSB) populations and (12) interconnected populations.



F_2 Population: F_2 mapping population consists of individuals obtained by selfing or sib-mating the F_1 generation derived from a cross between selected parental lines. The F_1 plants are heterozygous at all loci where the parents differ, and each F_2 individual carries a distinct combination of parental linkage blocks. This variation enables the detection of linkage between loci. Because the F_2 generation results from a single meiotic event in the F_1, only one round of recombination occurs between any two loci. Consequently, recombination frequency estimates from F_2 populations are often used as a baseline. In this population, dominant markers typically segregate in a 3:1 ratio, while codominant markers follow a 1:2:1 ratio. F_2 populations are particularly useful for initial mapping of markers and genes with major effects (oligogenes). They also allow estimation of additive, dominance, and epistatic components of genetic variance and they incorporate recombination contributions from both male and female parents of

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the F_2 individuals.

F_2-derived F_3 ($F_{2:3}$) Population: An $F_{2:3}$ population is developed by selfing individual F_2 plants for one generation and collecting seeds separately from each plant, so that each F_2 plant is represented by its own F_3 family. Genotyping can be done using DNA from individual F_2 plants or from bulked samples of multiple plants within each F_3 family, which represent the genotype of the original F_2 plant. These populations are particularly useful for mapping traits controlled by recessive genes and quantitative trait loci (QTLs), as evaluation across multiple plants within each family helps reduce sampling error

Backcross (BC) Population: Backcross populations are produced by crossing F_1 individuals with one of their parental lines. For effective genetic analysis, the F_1 is usually backcrossed to the recessive parent, a process known as a testcross (often denoted as BC_2). This results in a 1:1 segregation ratio for the trait phenotype and for dominant markers in coupling phase, as well as for co-dominant markers. However, dominant markers in repulsion phase do not segregate. Backcrossing to the dominant parent leads to different segregation patterns.

Doubled Haploids (DHs): Doubled haploid lines are produced by doubling the chromosome number of haploid plants, typically derived from anther or pollen culture of F_1 plants. Chemicals like colchicine are used for chromosome doubling. Each DH line is completely homozygous, and markers segregate in a 1:1 ratio regardless of dominance. DH populations are suitable for replicated trials and mapping both qualitative and quantitative traits, though they only allow estimation of additive genetic effects and are not suitable for studying heterosis.

Recombinant Inbred Lines: RILs are developed by repeated selfing of F_2 individuals over several generations (usually more than eight), often using the single seed descent (SSD) method. This process results in a set of homozygous lines with a 1:1 ratio of parental alleles. RILs are widely used for linkage mapping, QTL analysis and studying both qualitative and quantitative traits. They are also valuable for integrating genetic and molecular maps.

Immortalized F_2 (IF_2) Population: IF_2 populations are created by intercrossing pairs of RILs to produce single-cross hybrids. These populations mimic the genetic composition of an F_2 generation, including heterozygosity, but allow repeated evaluation across environments. IF_2 populations are useful for detecting QTLs, including those related to heterosis, and for studying epistatic interactions.

Near-Isogenic Lines: NILs are pairs of nearly identical homozygous lines that differ only at a specific gene or genomic region. They are typically developed through repeated backcrossing of a donor parent carrying the target gene with a recurrent parent, followed by selection. NILs are valuable for fine mapping, functional genomics, and precise evaluation of gene effects.

Chromosomal Segment Substitution Lines (CSSLs): CSSLs consist of a series of lines where each line carries a distinct chromosomal segment from a donor parent in the genetic background of a

recurrent parent. They are developed through repeated backcrossing and marker-assisted selection. CSSLs are powerful tools for mapping both major genes and QTLs, detecting small-effect loci, and developing improved breeding lines.

Backcross Inbred Lines (BILs): BILs are developed by backcrossing an F_1 hybrid to one parent followed by repeated selfing to achieve homozygosity. These lines tend to have a higher proportion of alleles from the recurrent parent. They are useful for mapping studies, especially when the recurrent parent possesses desirable traits.

Advanced Intercross Lines (ALLs): AIL populations are created by repeated intermating among individuals of the F_2 and subsequent generations. This increases recombination events and improves mapping resolution of QTLs. Compared to F_2 populations, AILs can significantly reduce confidence intervals for QTL positions.

Recurrent Selection Backcross (RBS) Population: RSB populations are developed by repeated backcrossing to a recurrent parent while selecting individuals with superior trait values. This approach enhances recombination and allows high-resolution mapping of QTLs. Changes in heterozygosity at marker loci can help pinpoint QTL locations.

Interconnected Mapping Populations: These populations are formed by crossing multiple parental lines in such a way that different crosses share common parents. They may include F_2, backcross, RIL, or DH populations. Joint analysis of such populations improves QTL detection, provides more generalizable results, and helps assess interactions between QTLs and genetic backgrounds

Multiparent Advanced Generation Intercross (MAGIC) Populations: MAGIC populations are developed by intercrossing multiple parental lines followed by inbreeding to produce RILs. They combine the advantages of linkage and association mapping, offer high genetic diversity, and are useful for high-resolution mapping and genomic selection studies.

Nested Association Mapping (NAM) Population: NAM populations are created by crossing several diverse founder lines with one or more common parental lines, followed by development of RILs. This design integrates the strengths of linkage and association mapping, enabling efficient dissection of complex traits and better utilization of genetic diversity.

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Genetic Enhancement for Alternaria Blight (*Alternaria brassicae*) Resistance in Mustard

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Introduction

Rapeseed-mustard (*Brassica* species) is the second most important group of oilseed crops in India, contributing about 23.91% of total acreage and 27.19% of production, next only to soybean.

The major cultivated species include *Brassica rapa* (2n = 20), comprising ecotypes such as yellow sarson, brown sarson, and toria; *Brassica juncea* (2n = 36), commonly known as Indian mustard; and *Eruca sativa* (2n = 22), known as taramira. Among these, Indian mustard accounts for more than 80% of the total rapeseed-mustard cultivation area in the country. The breeding system of a crop largely depends on its mode of pollination. Therefore, plant breeders must understand the extent and nature of genetic variability, the role of wild relatives, reproductive behavior, environmental adaptation, and suitability to different cropping systems. The efficiency of selection improves significantly when genetic variability is well characterized and reliable screening techniques are available. This discussion primarily focuses on breeding Indian mustard (*Brassica juncea*) for resistance to Alternaria blight caused by *Alternaria brassicae*.

Breeding Objectives

The primary objective of crop improvement is to enhance seed yield with acceptable quality and ensure yield stability across environments. This stability is achieved by incorporating resistance or tolerance to major biotic and abiotic stresses.

Key diseases affecting rapeseed-mustard include Alternaria blight (*Alternaria brassicae*), white rust (*Albugo candida*), powdery mildew (*Erysiphe cruciferarum*), and Sclerotinia stem rot (*Sclerotinia sclerotiorum*). Important insect pests include mustard aphid (*Lipaphis erysimi*), painted bug (*Bagrada hilaris*), sawfly (*Athalia lugens*), pea leaf miner (*Chromatomyia horticola*), and flea beetle (*Phyllotreta cruciferae*). Additionally, crops face parasitic weeds such as broomrape (*Orobanche*) and abiotic stresses like frost, drought, heat, and salinity.

Alternaria blight is one of the most destructive diseases, reported worldwide and capable of causing yield losses of up to 47%. In India, three isolates of *A. brassicae* highly virulent (A), moderately virulent (C), and avirulent (D) have been identified. Although no complete resistance source is

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available in Indian mustard, several tolerant genotypes have been identified. Resistance sources have also been reported in related and wild species such as *Sinapis alba*, *Camelina sativa*, *Capsella bursa-pastoris*, and *Eruca sativa*. Inheritance studies indicate that tolerance is polygenic, involving additive and partial dominance effects.

Inter-specific Variation: Wild and weedy relatives of *Brassica* serve as valuable reservoirs of disease resistance genes. Traits such as lesion size, number, and type are commonly used as selection criteria for Alternaria resistance.Among cultivated species, *B. carinata* and *B. napus* show relatively higher resistance, followed by *B. nigra*, *B. juncea*, and *B. rapa*. Some related species exhibit strong resistance due to biochemical defenses such as phytoalexin production, which inhibits fungal growth. However, gene transfer from wild species is often limited by pre- and post-fertilization barriers. Techniques like embryo rescue can help overcome these barriers and facilitate the transfer of resistance genes.

Genetics of Resistance: Resistance to Alternaria blight is complex and involves multiple mechanisms. It is governed by polygenic inheritance with additive, dominant, and epistatic gene interactions. Both inter- and intra-specific crosses have demonstrated the importance of additive gene effects, along with interactions such as additive × additive and dominance × dominance. Intermating among tolerant plants enhances resistance levels by accumulating favorable genes (gene pyramiding). Traits like epicuticular wax, reduced stomatal density, and biochemical factors (e.g., phenolics, catalase, and polyphenol oxidase activity) contribute to resistance.

Breeding Approaches for Resistance

Given the predominance of additive gene action, breeding methods such as reciprocal recurrent selection and diallel mating are effective for improving resistance. Selection should preferably be practiced in intermated populations rather than early segregating generations to minimize linkage effects and enhance recombination of favorable genes. Repeated intermating among resistant genotypes increases the frequency of desirable alleles, improving the chances of developing lines with durable and multiple disease resistance.

Genetic Engineering Approaches

Due to the lack of strong resistance within crossable germplasm, genetic engineering offers promising alternatives. Several genes have been successfully introduced into *B. juncea* to enhance resistance against *Alternaria brassicae*. Examples include: Osmotin and glucanase genes, which delay disease development and reduce lesion size, Antimicrobial peptide genes (e.g., *msrA1*) that inhibit fungal growth, Thaumatin-like proteins that suppress pathogen development and Chitinase genes that degrade fungal cell walls. These transgenic approaches have shown significant improvement in resistance under pathogen pressure.

Screening Techniques

Standardized screening methods are essential for evaluating resistance. According to AICRP guidelines:

Artificial Inoculation: Plants are inoculated at flowering and pod formation stages using a conidial suspension (~10^5 spores ml^{-1}) of *Alternaria brassicae*. Disease severity is recorded at 90 days after sowing and before harvest.

Observations

- ✓ Date of first disease appearance
- ✓ Disease severity or incidence (on leaves and pods)
- ✓ Separate recording for cotyledon and pod infection
- ✓ Data collected from randomly selected plants using a 0-9 scale
- ✓ Statistical analysis using ANOVA after trans-formation

Disease Rating Scale (0-9)

- ✓ 0: No symptoms (immune)
- ✓ 1: Highly resistant (<5% infection)
- ✓ 3: Resistant (5-10%)
- ✓ 5: Moderately resistant (11-25%)
- ✓ 7: Susceptible (26-50%)
- ✓ 9: Highly susceptible (>50%)

Conclusion

Although complete resistance to Alternaria blight in Indian mustard is not yet available, significant progress has been made through conventional breeding, interspecific hybridization, and biotechnological approaches. Integration of these strategies, along with efficient screening and molecular tools, will be crucial for developing durable and high-yielding resistant varieties.

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