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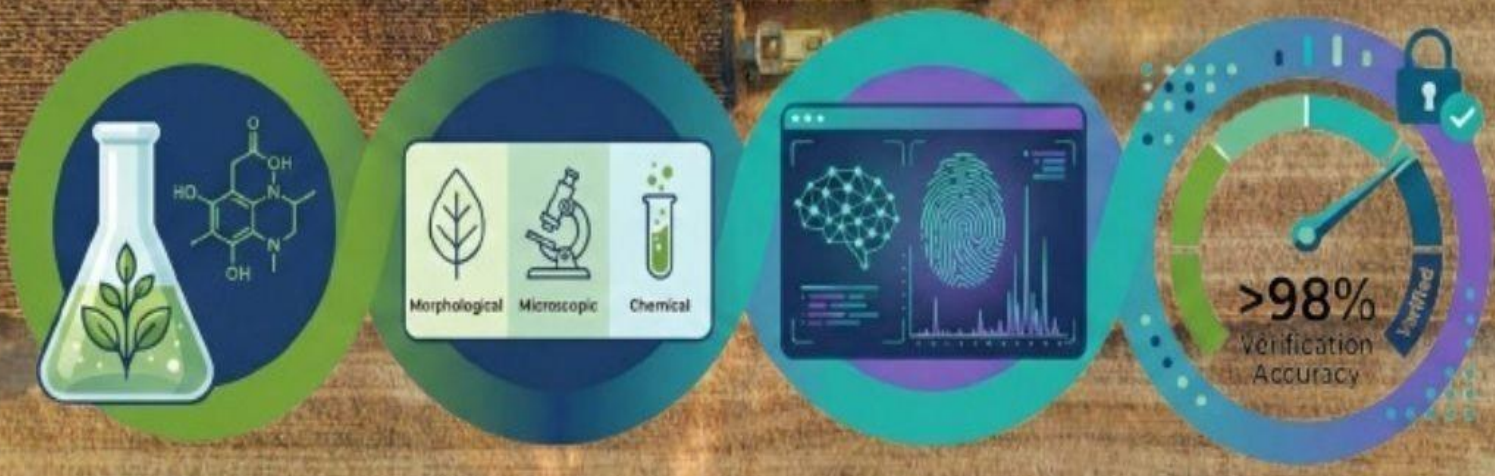

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From Fields to Formulation: A Technical Nexus Between Medicinal Plant Cultivation and Pharmaceutical Development

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Introduction

Medicinal and aromatic plants (MAPs) represent a unique intersection between agronomic sciences and pharmaceutical technology. These plants are repositories of diverse secondary metabolites such as alkaloids, flavonoids, glycosides and essential oils, which form the basis of both traditional and modern drug products (Chatterjee, 2002). In India's context, the supply chain from field cultivation to raw drug quality assurance to standardized extraction to final formulation development demands precision at every stage so that bioactive compounds retain efficacy, safety and stability.

1. Field Production: Agronomic and Phytochemical Precision

1.1 Good Agricultural and Collection Practices (GACP)

Medicinal plant cultivation begins with adherence to Good Agricultural and Collection Practices (GACP), which emphasize correct species selection, genotype verification, soil fertility, irrigation scheduling and pest management calibrated to maximize bioactive compound accumulation (Chatterjee, 2002). Secondary metabolites such as withanolides in *Withania somnifera* or menthol in *Mentha arvensis*, are strongly influenced by agronomic inputs and phenological stage at harvest.

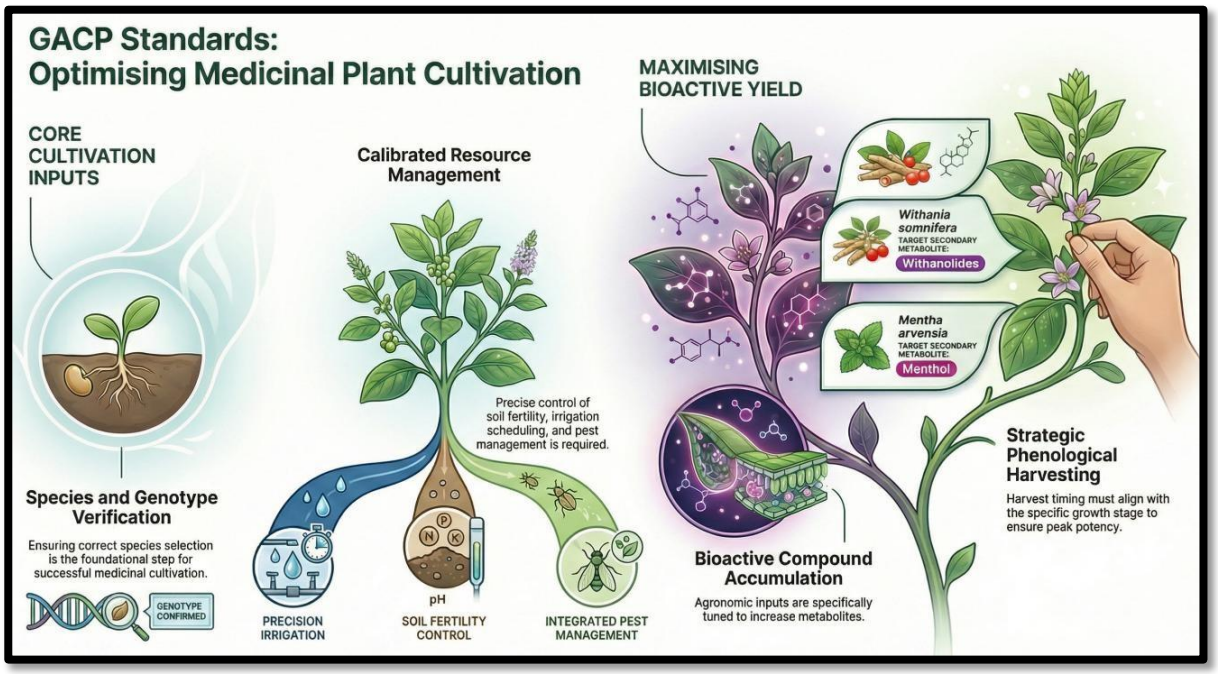


Figure 1: GACP Standards

1.2 Harvest & Post-Harvest Protocols

Deviation in harvest time alters quantitative phytochemical profiles, impacting downstream pharmacokinetics. For instance, premature harvesting of *Cymbopogon flexuosus* can yield essential oils with suboptimal citral content, rendering them unsuitable for standardized formulations. Controlled drying and storage under inert conditions are essential to preventing oxidative degradation of labile compounds.

2. Authentication & Quality Control: Analytical Rigor

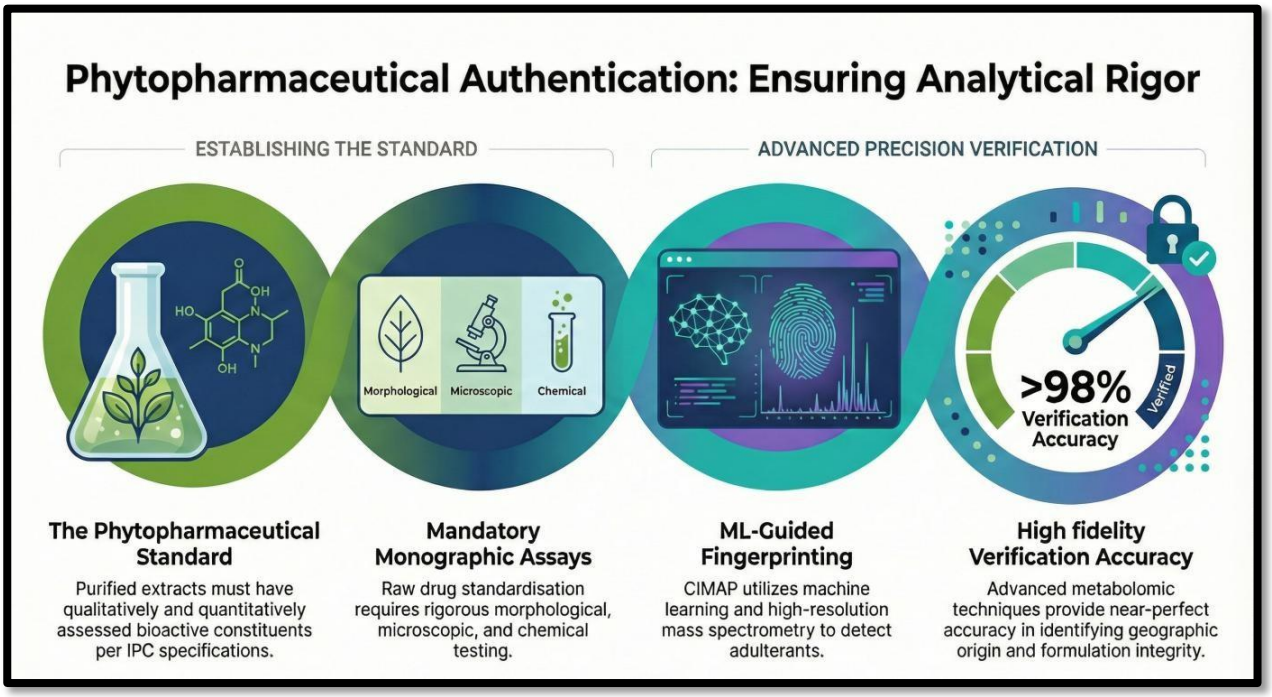
2.1 Pharmacognosy and Monographs

National and international pharmacopoeias require raw drug standardization via morphological, microscopic and chemical assays. The Indian Pharmacopoeia Commission defines phytopharmaceuticals as purified extracts with quantitatively and qualitatively assessed bioactive constituents, backed by monographic specifications (Indian Pharmacopoeia Commission, 2025).

2.2 Advanced Authentication Techniques

Institutions such as CSIR-Central Institute of Medicinal and Aromatic Plants (CIMAP), Lucknow, have pioneered *machine learning-guided metabolomic fingerprinting* combined with high-resolution mass spectrometry to detect adulterants and geographic origin, achieving >98% accuracy in sample verification—crucial for safeguarding formulation integrity before extraction (CIMAP researchers, 2025).

Figure 2: Authentication and Quality Control



3. Standardized Extraction & Formulation Science

3.1 Extraction Methodologies

Extraction protocols—such as supercritical fluid extraction, solvent partitioning and fractionation must be calibrated to optimize yield and purity of target compounds. For example, selective partitioning using gradient solvents isolates polar glycosides separately from non-polar terpenoids, which is essential for reproducible formulation inputs.

3.2 Formulation Development

Post-extraction, pharmaceutical sciences engage in formulation design, involving excipient compatibility, dose uniformity, stability profiling and delivery mechanisms (oral, topical, etc.). Techniques like spray drying, lyophilization and nanoparticle encapsulation are increasingly applied to MAP extracts to enhance bioavailability and controlled release.

4. Leading Institutional & Industry Ecosystem in India

4.1 Research & Development Hubs

Directorate of Medicinal and Aromatic Plants Research (DMAPR, ICAR) focuses on cultivar improvement, GAP development, and germplasm conservation of species such as *Aloe barbadensis, Withania somnifera* and *Plantago ovata* (DMAPR, n.d.). Aromatic and Medicinal Plants Research Station (AMPRS), Odakkali, Kerala, serves as a Regional Analytical Laboratory for phytochemical quality testing and varietal trials.

4.2 Industry Examples & Value Chain Integration

Pharmaceutical and herbal product industries such as Dabur, Patanjali Ayurveda, Himalaya and Shree Baidyanath integrate MAP extracts into standardized formulations ranging from adaptogens to dermatological ointments and nutraceuticals (FirstHope, n.d.).

A notable collaborative model involves a tripartite MoU in Himachal Pradesh among the state government, Indian Army and Shree Baidyanath Ayurved to train farmers in MAP cultivation, supply quality plant material, and ensure assured procurement—*directly linking production to formulation needs and market assurance* (Times of India, 2026).

Another example is the 'Swasth Dhara' initiative involving Patanjali Organics Research Institute, Indian Agricultural Research Institute (IARI), and Ministry of AYUSH focusing on soil health and sustainable cultivation of MAPs, reinforcing field quality as the foundation for therapeutic formulations (Times of India, 2025).

4.3 Value-Added Product Development

CIMAP has licensed multiple herbal products such as herbal shampoo (Habisoft) and aromatherapy oils (Relaxomap) to industry partners, showcasing applied formulation outcomes derived from scientifically authenticated and standardized raw botanical materials (Times of India, 2025).

5. Policy & Quality Assurance Frameworks

5.1 Regulatory Standards for Phytopharmaceuticals

India's regulatory ecosystem, including monographs in the Indian Pharmacopoeia and AYUSH clinical safety guidelines, mandates rigorous identity, purity, and potency testing

before integrating plant extracts into pharmaceutical products (Indian Pharmacopoeia Commission, 2025).

5.2 International Standards

Globally, MAP-derived products must satisfy WHO guidelines for herbal medicines, ensuring conformity in marker compound specifications, limit tests for contaminants (heavy metals, pesticides), and validated analytical methods.

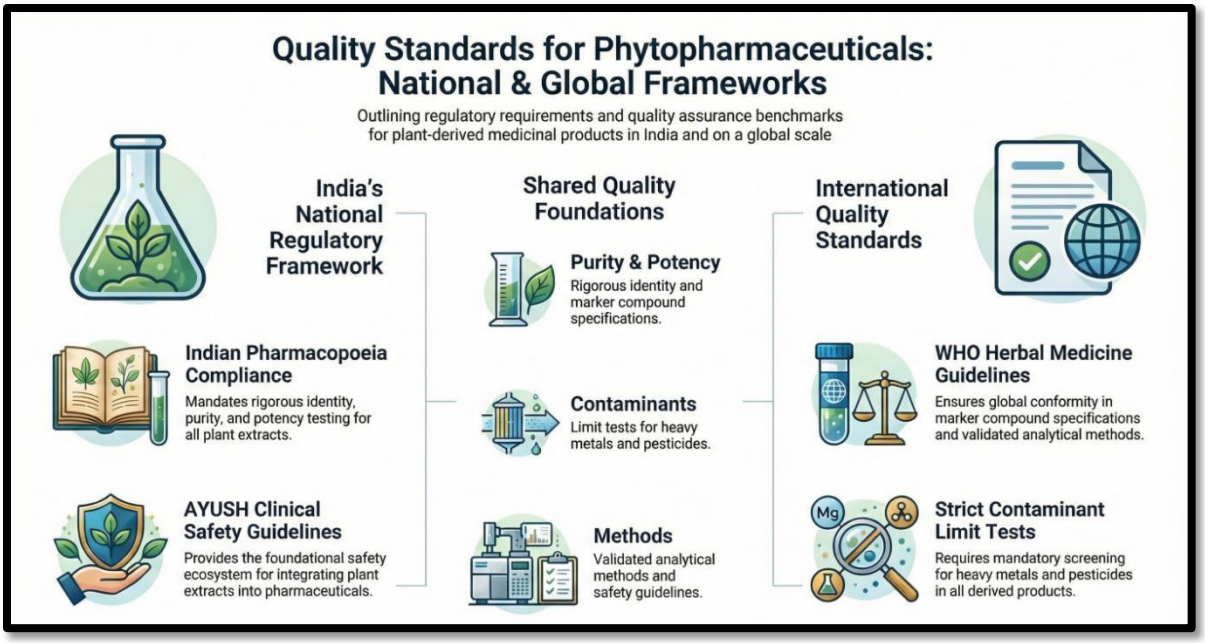


Figure 3: Policy & Quality Assurance Frameworks

Conclusion

The pathway from agricultural fields to sophisticated pharmaceutical formulations is inherently interdisciplinary, requiring tight synergy among agronomic precision, phytochemical authentication, analytical standardization, and drug formulation sciences. India's institutional frameworks and industry collaborations exemplify how scientific rigor at each stage enhances both farmer livelihoods and therapeutic product reliability. For future advances, deeper integration of omics technologies, AI-guided metabolomics, and standardized extraction protocols will only strengthen the MAP value chain, enabling more efficacious and globally competitive phytopharmaceuticals.

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SHAPING THE FUTURE OF POSTHARVEST MANAGEMENT WITH NANOTECHNOLOGY

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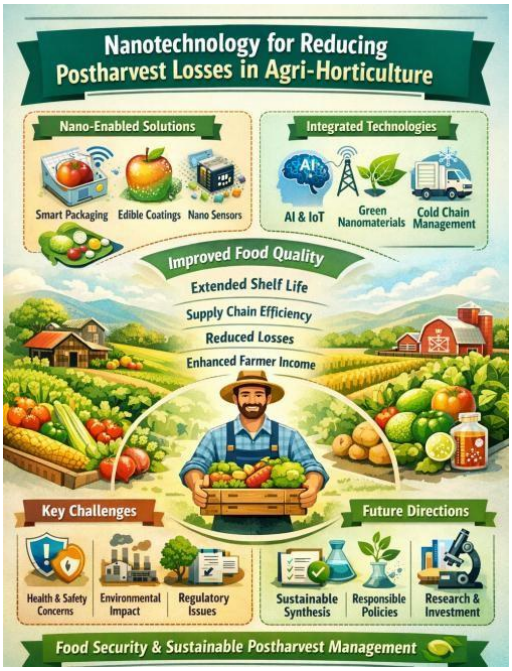
Abstract

Nanotechnology offers an effective approach to reduce postharvest losses by enhancing food quality, shelf life, and supply chain efficiency through nano-packaging, coatings, nanosensors, and smart cold-chain systems. Its integration with AI, IoT, and sustainable materials enables intelligent postharvest management, though challenges related to safety, cost, and regulation remain. With strong research and policy support, nanotechnology can improve food security, farmer income, and sustainability.



Keywords: Nanotechnology; Postharvest management; Nano-packaging; Edible nano-coatings; Shelf-life extension; Smart packaging.

Introduction

Postharvest management is critical for ensuring food quality, safety, and availability, yet losses remain alarmingly high, particularly in developing countries due to poor storage, handling, microbial spoilage, and inefficient transportation (Anusha et al. 2024). Globally, nearly one-third of agri-horticultural produce is lost or wasted, posing serious economic and food security challenges, especially as the world population is projected to reach 9.7 billion by 2050 (Satheeshkumar et al. 2025). In India alone, postharvest losses amount to about 49.9 million tonnes annually, causing an economic loss of approximately ₹1.53 trillion (NABCONS, 2022) and the government aims to reduce these losses to below 5% by 2047 (Ministry of Agriculture, 2025). Nanotechnology offers promising solutions at the nanoscale (1–100 nm) through nano-packaging, edible nano-coatings and nanosensors, which enhance barrier properties, inhibit microbial growth, and enable real-time quality monitoring, thereby significantly extending shelf life and improving supply-chain efficiency (Revathi et al.2025; Chang et al. 2025; Ghosh et al. 2025).

Figure 1. Postharvest losses at different stages

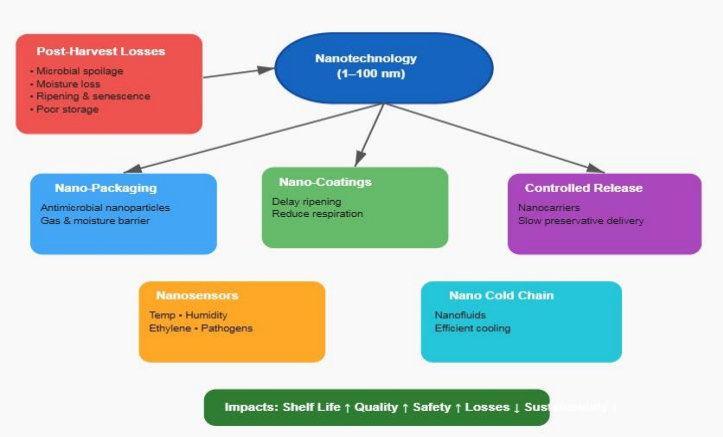


Figure 1.1 Uses of Nanotechnologies in Postharvest Management

Concept of Nanotechnology in Post-Harvest Agriculture

Nanotechnology involves the application of materials at the nanoscale (1-100 nm) to improve the safety, quality, and shelf life of agri-horticultural produce. In postharvest management, it offers advanced solutions to reduce losses and maintain freshness by controlling microbial spoilage, moisture loss and oxidative deterioration (Satheeshkumar et al. 2025). The use of nano-coatings, nanocomposite packaging, and nanosensors enhances barrier properties, antimicrobial activity and real-time quality monitoring during storage and transportation (Revathi et al. 2025; Chang et al. 2025; Ghosh et al. 2025). Owing to their high surface area and unique functional properties, nanomaterials effectively extend shelf life while preserving nutritional and sensory quality. Thus, nanotechnology enables the development of smart, sustainable postharvest management systems that reduce losses and strengthen food security.

Role of Nanotechnology in Post-Harvest Management

Nanotechnology offers innovative solutions to reduce postharvest losses and improve the quality, safety and shelf life of agri-horticultural produce through advanced packaging, surface coatings, smart sensing and cold-chain optimization (Satheeshkumar et al. 2025; Chang et al. 2025). Nano-packaging systems incorporate antimicrobial nanoparticles and intelligent nanosensors to inhibit microbial growth and enable real-time monitoring of storage conditions. Nano-enabled edible coatings based on nanochitosan, nanocellulose and lipid nanoparticles improve barrier properties, delay ripening and maintain firmness and visual quality (Ashaq et al. 2025; Ghosh et al. 2025). Nanocarriers such as liposomes and nanoemulsions allow controlled release of preservatives and bioactive compounds, enhancing efficacy while reducing chemical usage. In addition, nanosensors integrated with IoT platforms enable rapid, on-site monitoring of quality and safety parameters, while nanofluids improve cold-chain efficiency by enhancing heat transfer and reducing energy consumption (Revathi et al. 2025; Satheeshkumar et al. 2025).

Impact on Food Quality and Shelf Life

Nanotechnology significantly improves the quality and shelf life of agri-horticultural products by controlling microbial spoilage, moisture loss, oxidative damage and rapid senescence. Nano-packaging and nano-coatings enhance barrier properties against oxygen, carbon dioxide and water vapor, thereby slowing respiration, delaying ripening, and maintaining firmness, color and sensory quality (Satheeshkumar et al. 2025; Ashaq et al. 2025). The incorporation of antimicrobial nanoparticles and nanoemulsions inhibits microbial growth, while nanocarriers enable the controlled release of preservatives, antioxidants and bioactive compounds for sustained protection with minimal residues (Revathi et al. 2025; Postharvest Biology and Technology, 2025). In addition, smart packaging with nanosensors enables real-time monitoring of storage conditions, helping prevent quality deterioration. Collectively, these nano-enabled technologies improve nutritional retention, preserve sensory attributes, and significantly extend the shelf life of perishable produce (Ghosh et al. 2025).

Emerging Advancements in Nanotechnology for Post-Harvest Management

Recent advances are shifting nanotechnology from conventional packaging toward intelligent, precision-based systems for improved food quality, safety, monitoring, and preservation. Nano-biosensors based on gold nanoparticles, quantum dots, and graphene enable ultra-sensitive, real-time detection of pathogens such as *E. coli*, *Salmonella* and *Listeria*, strengthening food safety management (Chang et al. 2025; Ghosh et al. 2025). Stimuli-responsive smart packaging releases antimicrobial and antioxidant agents only under spoilage conditions, improving preservation efficiency while minimizing chemical usage (Revathi et al. 2025; Satheeshkumar et al. 2025). The integration of nanosensors with AI and IoT enables predictive shelf-life modelling, automated spoilage detection, and optimized cold-chain logistics, thereby reducing postharvest losses (Ghosh et al. 2025). Nanostructured ethylene scavengers delay ripening in climacteric fruits, while green synthesis using plant and microbial systems improves the environmental compatibility of nanomaterials (Ashaq et al. 2025; Satheeshkumar et al. 2025). In addition, self-healing nano-coatings and electrospun nanofibers with controlled-release properties further enhance barrier performance and active packaging efficiency (Revathi et al. 2025; Ghosh et al. 2025).

Economic and Environmental Benefits

The adoption of nanotechnology in postharvest management offers substantial economic and environmental benefits by extending the shelf life of fruits, vegetables, dairy, and meat products. Nano-enabled packaging, coatings, and sensors reduce postharvest losses, increase marketable yields and improve profit margins while lowering costs by minimizing preservatives, chemical treatments, and energy intensive storage (Satheeshkumar et al. 2025; Chang et al. 2025; Revathi et al) here by lowering greenhouse gas emissions and the ecological footprint of food supply chains (Ghosh et al. 2025; Ashaq et al. 2025). Overall, nano-enabled postharvest technologies support both economic viability and environmental sustainability.

Challenges and Safety Concerns

Despite the promising role of nanotechnology in postharvest management, several challenges hinder its large-scale adoption. The potential human health risks associated with the ingestion and long-term exposure to nanoparticles are not yet fully understood, necessitating comprehensive toxicological evaluations. Environmental concerns also arise from the accumulation of nanomaterials in soil and water systems which may disrupt microbial balance and biodiversity. Furthermore, the lack of standardized regulatory frameworks, safety guidelines and labeling norms limits commercial application and consumer acceptance. In addition, high production costs, technical complexity and limited accessibility restrict the adoption of nano-enabled technologies, particularly among small and marginal farmers in developing countries.

Future Prospects and Research Directions

Nanotechnology shows strong potential in postharvest management by enabling smart, sustainable, and precision based solutions through biodegradable nanomaterials, intelligent nanosensors, and controlled release bioactive systems. Future research priorities include safety and toxicological assessments, development of eco-friendly materials, IoT-enabled real-time monitoring and cost-effective scalable technologies for smallholder farmers. With continued interdisciplinary research and regulatory harmonization, nanotechnology is expected to play a key role in efficient and sustainable postharvest management worldwide (Satheeshkumar et al. 2025; Ghosh. 2025).

Conclusion

Nanotechnology offers a powerful solution to reduce postharvest losses in agri-horticultural systems through advanced packaging, nano-coatings, nanosensors, controlled bioactive release and improved cold-chain management. Its integration with AI, IoT and green synthesis supports intelligent, sustainable and environmentally responsible postharvest solutions aligned with global sustainability goals. However, issues related to safety, regulation, cost, and accessibility must be addressed for responsible adoption. With strategic research, policy support, and stakeholder collaboration, nanotechnology can significantly enhance food security, farmer incomes, and supply chain resilience.

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Urban Agriculture as an Adaptation Strategy in India: Assessing the Role of Policy and Planning Frameworks

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Abstract

Rapid urbanisation in India has intensified challenges related to food security, environmental degradation, climate change, waste management and urban livelihoods. Urban agriculture encompassing kitchen gardens, rooftop farming, community gardens, vertical farming, hydroponics and peri-urban cultivation has emerged as a viable strategy to address these interconnected challenges. This article examines the impact of policy frameworks on the practice of urban agriculture in India and analyses how policies shape adaptation practices in urban settings. It highlights the role of urban planning policies, food security initiatives, environmental and climate policies, livelihood programmes, and technology-driven Smart City missions in enabling or constraining urban agriculture. The study shows that policy recognition enhances adaptive capacity by improving access to land, water, institutional support and innovation, while restrictive zoning laws and regulatory ambiguities limit long-term sustainability. The article further demonstrates that integrated policies linking urban agriculture with waste recycling, water management, livelihood generation and technological innovation strengthen socio-economic and environmental resilience. Overall, the paper argues that coherent and inclusive policy integration is essential for mainstreaming urban agriculture as an effective adaptation strategy and for building sustainable, climate-resilient, and food-secure Indian cities.

Introduction

India is witnessing rapid urbanisation, with a growing proportion of its population residing in cities. This transformation has intensified challenges related to food security, environmental sustainability, waste management, unemployment, and public health. Urban agriculture, the practice of cultivating crops and rearing livestock within urban and peri-urban

areas, has emerged as a promising response to these challenges (Orsini *et al.,* 2013; Zezza & Tasciotti, 2010). It includes kitchen gardens, rooftop farming, community gardens, vertical farming, hydroponics, and peri-urban cultivation.

Climate change has a socio-political dimension with significant impacts on economies. The extent of damage associated with climate-induced events depends largely on social, political, and economic vulnerabilities of individuals and communities (Padgham *et al.,* 2015). For instance, devastation caused by floods is often more severe in populations with weak economic systems and inadequate policy frameworks related to basic social amenities (Thompson & Scoones, 2009).

Despite its potential, urban agriculture in India has historically remained outside formal policy frameworks. Urban planning policies have largely prioritised housing, infrastructure, and industrial growth, often neglecting food production systems within cities (Mukherji & Morales, 2010). However, in recent years, growing concerns over climate change, nutrition insecurity, and sustainable cities have encouraged policymakers to reconsider the role of urban agriculture. Government policies, urban development missions, environmental regulations, and livelihood programmes now increasingly influence how urban agriculture is practiced, supported, or constrained in India (FAO, 2016; Government of India, 2015).

1. Policy Recognition

Urban agriculture has long lacked formal recognition in city master plans and municipal regulations. Most urban development policies classify land strictly into residential, commercial, or industrial zones, leaving little room for agricultural activities (Mukherji & Morales, 2010). However, emerging policy initiatives, such as draft urban agriculture policies in cities like Delhi, seek to integrate food production into urban planning (Dubbeling *et al.,* 2010).

Impact:

- Lack of recognition restricts land access and tenure security for urban farmers (Zezza & Tasciotti, 2010).
- Policy inclusion enables allocation of vacant lands, rooftops, and community spaces for farming (Dubbeling *et al.,* 2010).
- Institutional recognition improves access to municipal support and technical guidance (FAO, 2016).

2. Food Security and Nutritional Outcomes

Urban agriculture policies play a crucial role in strengthening local food systems. Cities depend heavily on distant rural areas for food, making them vulnerable to supply disruptions and price volatility (Zezza & Tasciotti, 2010). Policy support for urban farming can shorten supply chains and enhance availability of fresh, nutritious food (FAO, 2016).

Impact:

- Improved access to fresh vegetables and fruits in low-income urban areas (Orsini *et al.,* 2013).
- Reduction in transportation losses and food waste (FAO, 2016).
- Support to school nutrition programmes and community feeding initiatives (Dubbeling *et al.,* 2010).

3. Environmental Sustainability and Climate Policies

Urban agriculture aligns closely with national and municipal sustainability goals. Policies related to climate change, waste management, and green infrastructure directly influence its growth (Government of India, 2015). Integrating urban agriculture with composting and wastewater reuse policies promotes circular urban economies and climate-resilient cities (Padgham *et al.,* 2015).

Impact:

- Reduction in the urban heat island effect through increased green spaces (Orsini *et al.,* 2013).
- Recycling of organic waste into compost for urban farms (FAO, 2016).
- Enhanced biodiversity and improved air quality (Padgham *et al.,* 2015).

4. Livelihood Generation and Social Inclusion

Policies linked to urban livelihoods significantly affect the expansion of urban agriculture. When integrated with programmes such as the National Urban Livelihoods Mission (NULM), urban farming can generate employment and supplementary income, especially for women, migrants, and informal workers (Government of India, 2015; Zezza & Tasciotti, 2010)

Impact:

- Income generation through sale of produce and value-added products (Zezza & Tasciotti, 2010).
- Empowerment of women and marginalised groups (Dubbeling *et al.,* 2010).
- Strengthening of community bonds through collective farming initiatives (FAO, 2016).

5. Technological Innovation and Smart City Policies

Smart City initiatives and digital agriculture policies encourage the adoption of advanced technologies such as vertical farming, hydroponics, precision irrigation, and sensor-based systems (Government of India, 2015). These innovations allow efficient food production in space-constrained urban settings and enhance adaptive capacity to climate stress (Orsini *et al.,* 2013).

Impact:

- Higher productivity with minimal land and water use. (Orsini *et al.,* 2013).
- Promotion of start-ups and agri-entrepreneurship (FAO, 2016).
- Enhanced resilience against climate variability (Padgham *et al.,* 2015).

Analysis of link between Policy Framework and Adaptation Practices in urban Agriculture in India

Urban agriculture in India has emerged as an important adaptation strategy in response to rapid urbanisation, climate change, food insecurity, and environmental degradation (Padgham *et al.,* 2015). The effectiveness of urban agriculture as an adaptation practice is strongly influenced by the policy framework, which acts as either an enabler or a constraint (Dubbeling *et al.,* 2010).

1. Policy Recognition and Adaptive Capacity

Formal recognition of urban agriculture within urban planning and development policies directly enhances adaptive capacity by encouraging investment in rooftop gardening, community farming, and peri-urban cultivation (FAO, 2016). In contrast, lack of recognition keeps urban agriculture informal and limits innovation (Mukherji & Morales, 2010).

2. Land-Use Policies and Spatial Adaptation

Urban land-use policies determine access to land, which is critical for adaptation. Policies allowing the use of vacant land, public spaces, rooftops, and institutional premises support spatial adaptation to land scarcity (Dubbeling *et al.,* 2010).

3. Water, Waste, and Environmental Policies

Adaptation practices such as rainwater harvesting, wastewater reuse, and composting are closely linked to environmental policies. Integrated policy approaches promote climate-resilient urban agriculture by improving resource efficiency (Padgham *et al.,* 2015; FAO, 2016).

4. Livelihood and Social Protection Policies

Smart City and innovation-oriented policies promote adaptive technologies such as vertical farming and hydroponics, helping urban agriculture respond to space, water, and climate constraints (Government of India, 2015; Orsini *et al.,* 2013).

5. Technology and Innovation Policies

Smart City initiatives and innovation-oriented policies encourage adaptive technologies such as vertical farming, hydroponics, and precision irrigation. These technologies help urban agriculture adapt to constraints like limited space, water scarcity, and climate variability. However, limited policy support for affordability and training can restrict widespread adoption.

Conclusion

Policies play a decisive role in shaping the practice and potential of urban agriculture in India. Where urban planning, sustainability, livelihood, and technology policies align, urban agriculture contributes significantly to food security, environmental resilience, and social inclusion (FAO, 2016; Dubbeling *et al.,* 2010). However, challenges persist due to limited recognition, regulatory ambiguities, and weak institutional support. Strengthening policy integration, ensuring access to land and water, promoting innovation, and raising public awareness are essential to unlock the full potential of urban agriculture in building sustainable and resilient Indian cities (Padgham *et al.,* 2015).

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Trade Liberalisation vs. Protectionism in Agricultural Markets

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Article ID: 22004

Introduction: The Buzz Behind India's Sweet Revolution

Agricultural trade has long been a sensitive and strategic component of national economies. Unlike industrial goods, agriculture is deeply linked to food security, farmer livelihoods, rural employment, and socio-political stability. In recent decades, global agricultural markets have been shaped by two contrasting policy approaches, trade liberalization, which promotes open markets and reduced trade barriers, and protectionism, which emphasizes safeguarding domestic agriculture through tariffs, subsidies, and trade restrictions. The ongoing debate between these approaches has intensified in the context of climate change, global price volatility, geopolitical conflicts, and post-pandemic economic recovery. (FAO, 2019)

Concept of Trade Liberalization in Agriculture

Trade liberalization in agriculture refers to the reduction or removal of tariffs, quotas, export restrictions, and subsidies to facilitate freer movement of agricultural commodities across borders. International institutions such as the World Trade Organization (WTO) advocate liberalization to improve market efficiency, encourage competition, and enhance global food availability. (WTO, 2020)

Liberalized agricultural trade allows countries to specialize based on comparative advantage, leading to improved productivity and consumer access to diverse and affordable food products. Export-oriented nations benefit from expanded market access, foreign exchange earnings, and technological spillovers. For developing economies, agricultural trade liberalization can stimulate investment, improve supply chains, and integrate farmers into global value chains. (Krugman, 1991)

Protectionism in Agricultural Markets

Protectionism in agriculture involves policy measures such as import tariffs, export bans, minimum support prices (MSP), domestic subsidies, and non-tariff barriers to shield local farmers from international competition. Governments often justify these measures on grounds of food security, income stability for farmers, and rural development. (FAO, 2019)

In many developing countries, agriculture supports a large proportion of the population, making sudden exposure to global competition risky. Protectionist policies help stabilize domestic prices, reduce vulnerability to global market shocks, and ensure self-sufficiency in

staple crops. Developed nations also practice protectionism through heavy subsidies, which distort global markets and disadvantage farmers in low-income countries.

Trade Liberalization vs Protectionism: Key Areas of Conflict

The central conflict between liberalization and protectionism lies in balancing efficiency and equity. While liberalization improves overall market efficiency and consumer welfare, it may expose small and marginal farmers to price volatility and unfair competition from subsidized imports. On the other hand, excessive protectionism can reduce competitiveness, discourage innovation, and burden government finances.Export bans during food crises, such as those imposed on cereals or pulses, highlight this tension. Although such measures protect domestic consumers in the short run, they disrupt global supply chains and damage a country's credibility as a reliable trading partner. (Anderson & Nelgen, 2012)

Indian Perspective

India presents a unique case where both approaches coexist. On one hand, India promotes agricultural exports through policy reforms, trade agreements, and initiatives like value-added agri-exports. On the other hand, the government frequently uses protectionist tools such as MSP, export restrictions, and import duties to protect farmers and ensure food security. India's challenge lies in gradually integrating into global agricultural markets while strengthening domestic infrastructure, risk-management systems, and farmer institutions like Farmer Producer Organizations (FPOs). A rigid stance on either extreme, complete liberalization or excessive protectionism, can undermine long-term agricultural sustainability. (FAO, 2019)

Case Study: India's Wheat Export Ban (2022) (Anderson & Nelgen, 2012)

In 2022, India imposed a ban on wheat exports following a sharp rise in domestic prices, heatwave-induced production losses, and concerns over national food security. This decision

came at a time when global wheat markets were under stress due to the Russia–Ukraine conflict, which had disrupted major export supplies. From a protectionist perspective, the export ban aimed to stabilize domestic prices, ensure sufficient availability for India's Public Distribution System (PDS), and protect low-income consumers from inflation. Given wheat's importance as a staple food crop, the policy reflected the government's priority of food security over trade commitments. However, from a trade liberalization standpoint, the ban drew criticism for undermining India's credibility as a reliable agricultural exporter. Several importing countries, particularly in Africa and Asia, were affected, and global wheat prices experienced additional volatility. Exporters and farmers who could have benefited from high international prices faced income losses, highlighting the opportunity cost of restrictive trade policies. (FAO, 2019)

This case study illustrates the core tension between trade liberalization and protectionism in agri-markets. While protectionist measures can provide short-term domestic stability, they may disrupt global markets and reduce long-term trade competitiveness. The Indian wheat export ban underscores the need for a balanced and predictable trade policy, supported by buffer stocks, crop insurance, and targeted subsidies rather than abrupt trade restrictions. (Anderson & Nelgen, 2012)

Way Forward: A Balanced Trade Strategy

The future of agricultural trade lies in adopting a calibrated and flexible approach. Selective liberalization, combined with targeted protection for vulnerable farmers, can ensure inclusive growth. Investments in technology, storage, market intelligence, and crop diversification can enhance competitiveness without compromising food security. (FAO, 2019)

International trade rules must also address subsidy imbalances and support developing countries in transitioning toward resilient agricultural systems. Sustainable trade practices, climate-smart agriculture, and fair-trade mechanisms can bridge the gap between efficiency and equity.

Conclusion

The debate between trade liberalization and protectionism in agricultural markets is not a binary choice but a continuum requiring strategic balance. While trade liberalization offers opportunities for growth and global integration, protectionism remains essential for safeguarding farmer welfare and national food security. A pragmatic, context-specific approach that aligns global engagement with domestic priorities is crucial for achieving sustainable and inclusive agricultural development. (FAO, 2019).

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Salicornia: The Green Gold of Saline Lands

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Introduction

The agricultural landscape of the 21st century stands at a precarious crossroads. We are witnessing a convergence of crisis: the rapid depletion of freshwater aquifers, the salinization of arable lands due to climate change and anthropogenic mismanagement and the rapidly increasing nutritional demands of a growing global population. Conventional crops such as rice, wheat and maize are highly sensitive to salinity stress, resulting in yield losses and land degradation. In this context, halophytes which are the plants naturally adapted to saline environments, are gaining attention as alternative crops for sustainable agriculture. Among them, *Salicornia* spp., commonly known as glasswort, sea asparagus or pickleweed, has emerged as a promising climate-resilient plant with multiple agricultural, nutritional and environmental benefits. The shift from viewing saline soils as "wastelands" to regarding them as "opportunity landscapes" requires a paradigm shift. *Salicornia* represents the vanguard of this shift as it is a plant that drinks sea water and yields food, fuel and fodder.

1. Botanical Characteristics and Distribution

Salicornia spp. is a succulent, leafless annual halophyte belonging to the family Amaranthaceae. The plant typically grows up to 25–35 cm in height and is characterized by jointed, fleshy green stems that turn reddish during maturity due to increased salt accumulation. It is widely distributed across coastal regions of Europe, Asia, North America, Africa, and the Mediterranean basin, thriving in salt marshes, estuaries, and saline flats where most conventional crops fail to survive (Patel, 2016; Abd El-Maboud, 2023).

Unlike glycophytes, *Salicornia* requires salinity for optimal growth and can tolerate extremely high salt concentrations, sometimes exceeding 1,000 mM NaCl. This unique physiological adaptation makes it an ideal candidate for cultivation in degraded and salt-affected soils (Katel et al., 2023).

2. Physiological Adaptations to Salinity

The exceptional salt tolerance of *Salicornia* is attributed to several adaptive mechanisms, including ion compartmentalization, osmotic adjustment and enhanced antioxidant defence systems. The plant stores excess sodium ions in vacuoles, thereby preventing cellular toxicity and maintaining metabolic stability. Additionally, the accumulation of osmolytes and antioxidant compounds helps mitigate oxidative stress induced by salinity (Dzhoglova et al., 2024).

These mechanisms not only enable survival under harsh conditions but also result in the synthesis of valuable bioactive compounds, enhancing the plant's nutritional and medicinal value.

3. Nutritional Composition and Bioactive Properties

Glasswort is increasingly recognized as a functional food due to its rich nutritional profile. The tender green shoots are edible and contain essential minerals such as sodium, potassium, calcium, magnesium and iron. The plant is also a good source of dietary fiber, polyunsaturated fatty acids, vitamins, and phytochemicals including phenolic compounds and flavonoids (Castagna et al., 2022).

Several studies have reported strong antioxidant, anti-inflammatory, antimicrobial, and hepatoprotective activities of *Salicornia* extracts. These bioactivities are primarily linked to the presence of polyphenols, saponins, sterols, and flavonoids, which are produced in higher concentrations as adaptive responses to environmental stress (Dzhoglova et al., 2024; Patel, 2016).

Traditionally, *Salicornia* has been used in folk medicine to manage conditions such as diabetes, hypertension, obesity, and liver disorders. Recent research also highlights its potential role in developing nutraceuticals, functional foods, and herbal pharmaceuticals.

4. Agricultural and Economic Potential

From an agricultural perspective, *Salicornia* represents a non-conventional crop suitable for seawater agriculture. It can be cultivated using saline water, brackish water or even aquaculture effluents, thereby reducing pressure on freshwater resources. Experimental studies indicate that moderate salinity levels (200–400 mM NaCl) enhance biomass production and branching in *Salicornia*, making it economically viable (Abd El-Maboud, 2023).

The crop has multiple uses:

- ***Vegetable:*** Fresh shoots are consumed as salads, pickles, or cooked vegetables.
- ***Oilseed:*** Seeds contain high-quality edible oil rich in linoleic and oleic acids.
- ***Animal feed:*** Biomass can be used as a salt-tolerant fodder supplement.
- ***Industrial use:*** Historically used in glass and soap making due to high soda content.

With increasing interest in alternative livelihoods for coastal and arid communities, *Salicornia* cultivation offers new income opportunities while utilizing otherwise unproductive lands.

5. Role in Climate-Smart and Sustainable Agriculture

Soil salinization is projected to affect nearly 50% of irrigated agricultural land by 2050, posing a serious threat to global food security. In this scenario, *Salicornia* fits well within the framework of Climate-Smart Agriculture (CSA). Its cultivation contributes to land reclamation, carbon sequestration, biodiversity conservation, and reduced greenhouse gas emissions (Katel et al., 2023).

Moreover, *Salicornia* plays a significant role in phytoremediation, as it can accumulate salts and heavy metals, helping to restore degraded ecosystems. Its use in intercropping systems

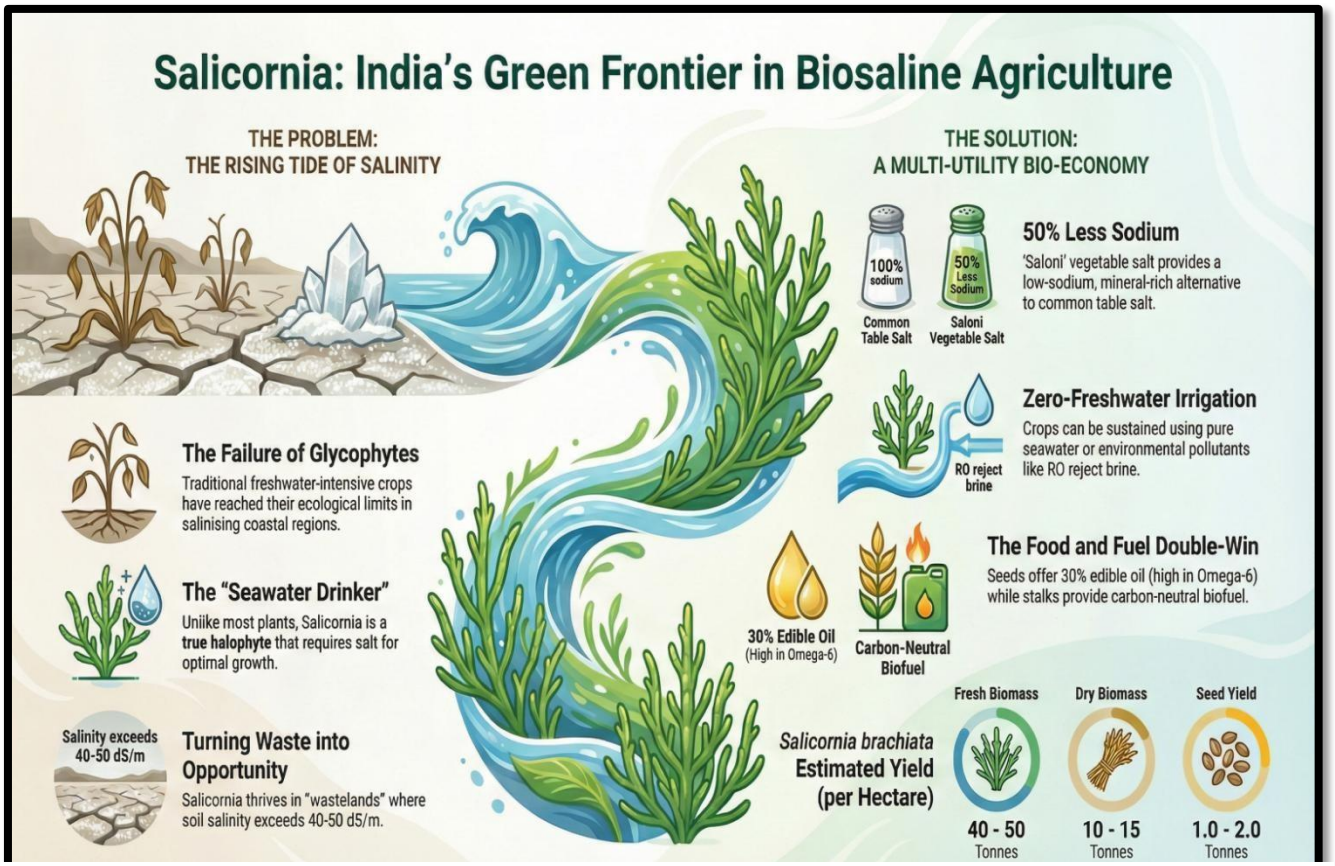

Figure 1: ***Salicornia- India's Green frontier in Biosaline Agriculture***

has also shown potential to improve soil conditions and productivity of salt-sensitive crops grown alongside it (Castagna et al., 2022)..

6. Future Prospects

Despite its immense potential, large-scale adoption of *Salicornia* is still limited by gaps in agronomic practices, market awareness, and processing technologies. Future research should focus on developing improved cultivars, optimizing cultivation techniques, and promoting value-added products to enhance farmer adoption.

In conclusion, *Salicornia* stands out as a future crop capable of addressing the intertwined challenges of salinity, climate change, and food insecurity. By integrating this halophytic plant into mainstream agriculture, especially in coastal and arid regions, sustainable and resilient food systems can be developed for the coming decades.

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FPOs: FARMER PRODUCER ORGANISATIONS IN INDIA

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Abstract:

Farmer Producer Organisations (FPOs) are cooperative structures formed by small and marginal farmers to improve their access to inputs, credit, markets, and value-added services. This article explores the role of FPOs in India, focusing on their benefits, challenges, and the impact of the government's "Formation & Promotion of 10,000 FPOs" scheme. Studies indicate that effective FPOs can enhance farmer income, reduce risks, and strengthen rural livelihoods. Drawing insights from recent research, it highlights the benefits of collective farming, constraints to sustainability, and policy recommendations to enhance the effectiveness of FPOs.

Keywords: Farmer Producer Organisation, FPO, marginal farmers, government scheme, value addition.

Introduction:

Agriculture in India is predominantly practiced by small and marginal farmers who face numerous challenges, including fragmented land holdings, limited access to credit, low bargaining power, and difficulties in marketing their produce. These constraints often result in low income and heightened vulnerability. FPOs have emerged as an innovative solution to these problems. By forming legally registered entities, farmers can pool resources, purchase inputs collectively, aggregate their produce, add value, and market products more effectively. FPOs aim to shift farmers from subsistence production to organized business participation.

The Government of India has supported FPO growth through the "Formation & Promotion of 10,000 FPOs" scheme, launched in 2020. This initiative seeks to create 10,000 FPOs across the country by providing financial assistance, technical support, capacity building, and credit guarantees

Understanding Farmer Producer Organisations (FPOs):

FPOs are legally registered entities formed by a group of farmers with a common objective to improve their agricultural business operations. These organisations can take the form of producer companies, cooperatives, or societies. They aim to enhance farm incomes by

providing access to inputs, technology, finance, and markets.

According to Nikam et al. (2019), FPOs enable small farmers to reduce transaction costs, negotiate better prices, and achieve economies of scale, which are otherwise not possible individually. By collectively handling production, procurement, and marketing, FPO members gain a stronger voice in the market and increased opportunities for value addition.

Factors Contributing to FPO Success:

Research indicates that several key factors determine how well an FPO performs:

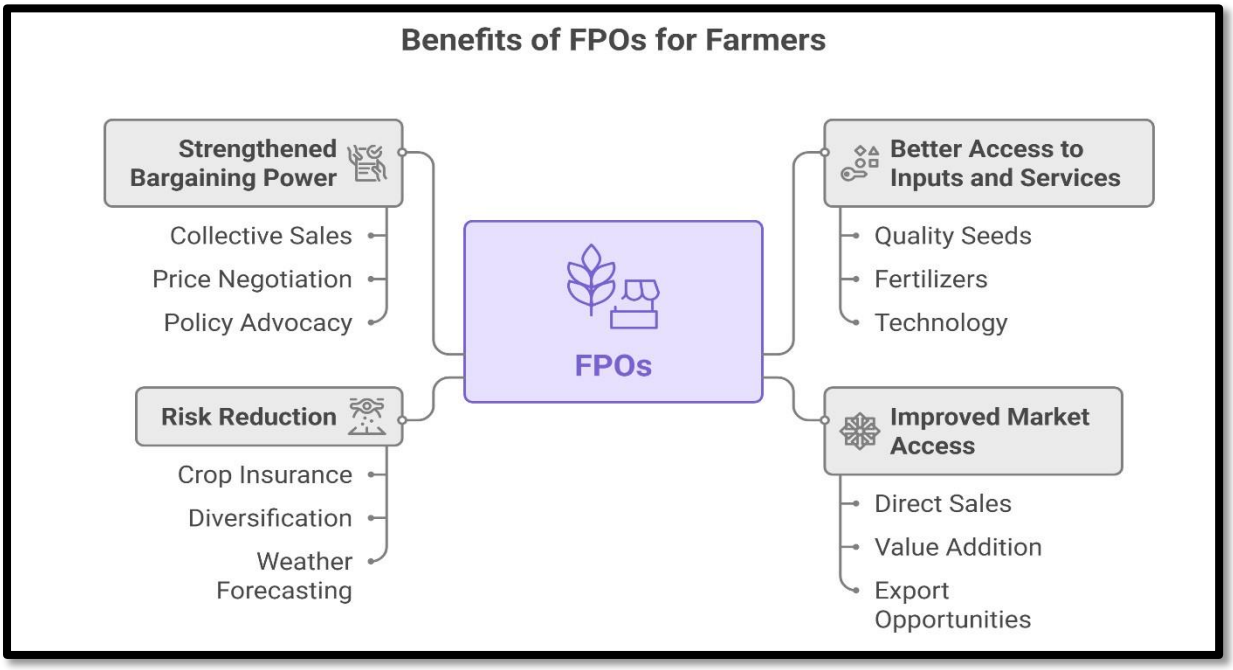
- **Size and membership**: Larger FPOs with more active members and higher paid-up capital tend to perform better. Studies of 125 FPOs across India show that organisations with more members and experienced leadership achieve higher turnover (Kumar et al., 2023).
- **Diversified activities**: FPOs that engage in multiple functions—such as input supply, production aggregation, processing, and marketing—tend to be more successful. Anand et al. (2023) found that FPOs active for more than five years with diversified business activities had effectiveness rates of 60–68%, compared to 50–56% for less diversified, younger FPOs.
- **Legal structure and governance**: A professional management structure, clear governance policies, and strong external linkages with markets, buyers, and support agencies are essential for sustainability (Patel et al., 2025).
- **Access to finance**: Adequate capital and financial support allow FPOs to invest in infrastructure, working capital, and value-added processes.

In short, FPOs are more likely to succeed when they have a solid member base, good management, diversified activities, and financial support.

Benefits of FPOs for Farmers:

FPOs offer multiple advantages to their members:

- **Better access to inputs and services**: By pooling demand, FPOs can procure seeds, fertilizers, machinery, and other inputs at lower costs. They also provide training and technical support (Nikam et al., 2019).
- **Improved market access**: Collective marketing ensures better price realization and reduces dependence on middlemen. Studies in Andhra Pradesh indicate that FPO members received 2–5% higher prices for crops and an increase of 30–40% in overall income.
- **Risk reduction**: FPOs help share production and market risks among members, providing more stability.
- **Strengthened bargaining power**: Members can negotiate better with buyers, input suppliers, and service providers.



These benefits highlight that FPOs are not just cooperative groups but strategic business units that empower small farmers.

Challenges Faced by FPOs:

Despite their potential, FPOs face several barriers:

- **Marketing difficulties**: Limited market access, price fluctuations, lack of storage, and weak buyer linkages restrict profitability (Banik et al., 2024).
- **Financial constraints**: Many FPOs struggle to obtain working capital and credit. The lack of consistent financing is a major factor affecting their performance (Kumar et al., 2023).
- **Limited diversification and initial struggle**: New FPOs or those engaged only in input supply often face lower effectiveness and sustainability issues (Anand et al., 2023).

- **Infrastructure limitations**: Fragmented land, poor storage, and transport challenges reduce the potential for large-scale operations and value addition (Patel et al., 2025).
- **Governance and management issues**: Weak leadership, lack of transparency, and insufficient professional skills can hinder growth.
- **Dependence on grants**: Many FPOs rely heavily on government funding for formation, raising concerns about long-term viability.

Addressing these challenges is crucial for ensuring that FPOs deliver sustained benefits to farmers.

Government Scheme: "Formation & Promotion of 10,000 FPOs"

The Government of India launched this scheme to strengthen farmer collectives by providing:

- **Financial support**: Up to ₹18 lakh per FPO for formation and management, including equity grants to members and credit guarantee support.
- **Capacity building**: Training, hand-holding, and professional guidance to help FPOs operate efficiently.
- **Membership requirements**: Minimum of 300 farmers in plain areas and 100 in hilly/NE regions.
- **Cluster approach**: Promotion of "One District-One Product" (ODOP) for focused production and marketing.

This scheme addresses key factors identified by research, such as capital, membership, diversification, and professional management.

Integrating Research Insights with Policy:

The scheme aligns with findings from recent studies:

- FPOs with higher membership and capital perform better (Kumar et al., 2023).
- Professional support during early years enhances long-term effectiveness (Anand et al., 2023).
- Cluster-based approaches encourage product specialization and market alignment.

While the scheme addresses formation and capacity challenges, ongoing support for marketing, infrastructure, and governance remains critical.

Recommendations:

To strengthen FPOs further, the following steps are recommended:

i. Develop market infrastructure and linkages.
ii. Build professional management and leadership capacity.
iii. Encourage value addition and diversification of activities.
iv. Ensure access to long-term finance beyond grants.
v. Promote inclusion of women, youth, and marginal farmers.
vi. Tailor support for challenging regions and crops.
vii. Monitor and evaluate FPO performance regularly.
viii. Foster cooperative clusters to enhance efficiency and competitiveness.

These measures can improve sustainability and ensure that FPOs continue to benefit small farmers.

Conclusion:

FPOs have the potential to transform Indian agriculture by empowering small and marginal farmers. Their success depends on strong governance, diversified activities, financial stability, and effective market linkages. Government initiatives like the Formation & Promotion of 10,000 FPOs scheme provide a strong foundation, but long-term sustainability requires continuous support, capacity building, and policy alignment. By adopting best practices and addressing challenges, FPOs can help small farmers increase incomes, reduce risks, and participate actively in the agricultural economy.

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Poverty in India: Trends, Government Interventions and Emerging Challenges

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Abstract

Poverty in India remains one of the most persistent socio-economic challenges despite decades of policy interventions. This article examines the concept and types of poverty, with a special focus on poverty trends in India and disparities between rural and urban areas. It reviews major government initiatives for poverty alleviation and employment generation from early programmes such as IRDP and Jawahar Rozgar Yojana to recent flagship schemes including Ayushman Bharat, PMAY-G, Ujjwala, PMJDY and Jal Jeevan Mission. The analysis highlights the strengths and limitations of these schemes, issues of leakages, administrative inefficiencies, inadequate resource allocation, and the limited participation of local institutions. The paper also discusses the impact of the COVID-19 pandemic, which reversed years of poverty reduction and pushed millions back into extreme poverty. The findings underscore the need for more inclusive, transparent, and community-driven strategies to sustainably uplift vulnerable populations.

What is Poverty

Poverty is a condition wherein an individual lacks the financial resources & essential conditions for meeting the minimum standard of living. It refers to the condition wherein the economic condition of a person is so low that even the most basic needs are not met.

Introduction

Poverty is a curse for humanity; it is a condition in which people do not have the basic comforts of life, such as food, clothes, shelter, etc. The United Nations defines poverty as the denial of options and opportunities. a violation of human dignity. It means a lack of basic skills to participate effectively in a society (Sen, 1999; NITI Aayog, 2021).

Different types of poverty

1. **Absolute poverty:** When a person does not obtain the minimum income necessary to sustain life, they are said to be living in absolute poverty. This form of poverty is assessed based on minimum subsistence and nutritional requirements essential for survival (Bullamore, 1974; Planning Commission, 2014).
2. **Relative poverty:** Relative poverty refers to a condition in which a section of the population is economically disadvantaged in comparison to a more affluent section of society. It highlights inequality in income distribution and access to resources rather than absolute deprivation (Sen, 1999).

Poverty in India

According to the Rangarajan Committee Report, individuals earning ₹32 per day in rural areas and ₹47 per day in urban areas are considered to be living below the poverty line. Earlier, the Tendulkar Committee had fixed the poverty line at ₹27 per day for rural areas and ₹33 per day for urban areas. Following the revised methodology of the Rangarajan Committee, the estimated number of people living below the poverty line increased by nearly 100 million, reflecting stricter poverty thresholds and broader consumption norms (Planning Commission, 2014). The identification of Below Poverty Line (BPL) households is carried out by State governments, and these households are the primary beneficiaries of government-aided poverty alleviation programmes (Government of India, 2019).

Rural and Urban Disparity

A significant disparity exists between rural and urban areas, as urban regions offer relatively more employment opportunities due to the concentration of manufacturing, service-sector activities, and informal employment. In contrast, rural populations largely depend on agriculture, which is often characterized by low productivity, dependence on rainfall, and income instability. These structural challenges in rural areas lead to large-scale migration to urban centers in search of better employment and livelihood opportunities (Government of India, 2019; World Bank, 2022).

Governmental Initiatives for Poverty Alleviation & Employment Generation in India

To foster economic growth and social inclusion, the Government of India has undertaken several initiatives since independence to alleviate poverty and generate employment. These programmes aim to enhance income security, provide basic services, and improve livelihood opportunities for vulnerable populations (Planning Commission, 2014).

Initiatives for Poverty Alleviation

- Integrated Rural Development Programme (IRDP)
- Jawahar Rozgar Yojana/Jawahar Gram Samridhi Yojana
- Rural Housing – Indira Awaas Yojana
- Food for Work Programme
- National Old Age Pension Scheme (NOAPS)
- Annapurna Scheme
- Sampoorna Gramin Rozgar Yojana (SGRY)
- Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) 2005
- National Rural Livelihood Mission: Aajeevika (2011)
- National Urban Livelihood Mission
- Pradhan Mantri Kaushal Vikas Yojana
- Pradhan Mantri Jan Dhan Yojana

Government Initiatives for Employment Generation in India

The initiatives undertaken by the government of India since independence for employment generation are:

- Nehru Rozgar Yojana
- National Food for Work Programme
- Training of Rural Youth for Self-employment
- National Rural Employment Programme
- Rural Landless Employment Guarantee Programme
- Jawahar Rozgar Yojana
- Rural Employment Generation Programme

- Prime Minister's Rozgar Yojana for Educated Unemployed Youth
- Swarna Jayanti Shahari Rozgar Yojana
- Swarnjayanti Gram Swarozgar Yojana
- Sampoorna Grameen Rozgar Yojana
- National Rural Employment Guarantee Scheme
- Employment Assurance Scheme
- Deen Dayal Upadhyaya Grameen Kaushalya Yojana
- Deendayal Antyodaya Yojana - National Urban Livelihoods Mission (DAY-NULM)
- Pradhan Mantri Kaushal Vikas Yojana (PMKVY)

Governmental schemes in recent years

At recent Since the NDA government came to power, the Government has launched many pro-poor schemes in the past 7 years for the upliftment of the poor. Those are-

1. Ayushman Bharat: World's largest free healthcare scheme. Ayushman Bharat is a flagship scheme of the Government of India, which was launched to achieve the vision of Universal Health Coverage (UHC). This initiative has been designed to meet Sustainable Development Goals (SDGs) and its commitment, which is to "leave no one behind." It provides a cover of up to Rs 5 lakhs per family per year for secondary and tertiary care hospitalization. Over 10.74 crore poor and vulnerable families (about 53 crore beneficiaries) are eligible for these benefits. The scheme provides cashless and paperless access to services for the beneficiaries at the point of service.

2. Pradhan Mantri Awaas Yojana Gramin - Pradhan Mantri Awas Yojana Gramin was launched to address the housing gaps existing in the rural areas. The houses built under the PMAYG scheme are low-cost and disaster-resilient. The Government also provides financial assistance to those who are homeless or living in kaccha houses. So far, 1.26 crore houses have already been built across the country under the scheme.

3. Ujjwala scheme and Saubhagya scheme - The Ujjwala scheme aims to benefit 5 crore families, especially the women living below the poverty line. By providing free gas connections and electricity connections under the Saubhagya scheme, to crores of poor, their dependence on wood has greatly reduced. Apart from reducing pollution, it has also helped a lot in

improving health and strengthening environmental protection. Under Ujjwala, cash assistance of Rs. 1,600 is given to each beneficiary to get a deposit-free new connection. Till now, 80 million poor families have benefited from availing free cooking gas connections.

4. Swachh Bharat Abhiyan: Swachh Bharat Abhiyan or Clean India Mission is a country-wide campaign initiated by the Government of India in 2014 to eliminate open defecation and improve solid waste management. The problem of open defecation and contamination of drinking and bathing water in India prompted the government to take measures to deal with the problem and improve the health conditions of the poor people. Since October 2014, over 9.5 crore toilets have been built all over the country and 564,658 villages have been declared Open Defecation Free (ODF).

6. Pradhan Mantri Jan Dhan Yojana: Pradhan Mantri Jan Dhan Yojana was launched in 2014 to ensure comprehensive financial inclusion of all households in the country by providing universal access to banking facilities with at least one basic bank account to every household for financial literacy, access to credit, insurance, and pension facility. Under this, a person without a savings account can open an account without the requirement of any minimum balance. 41.94 crore accounts have been opened under Pradhan Mantri Jan Dhan Yojana.

7. Jal Jeevan Mission: To improve the lives of people, Jal Jeevan Mission has been implemented with speed so that every household has the provision of an assured tap water supply by 2024. In this period, in the whole country, about 4.25 Crore households have been provided tap water connections, thus increasing coverage by 22 per cent to presently 7.50 Crore, i.e. 39 per cent of the total rural households in the country. This has also created new employment opportunities in villages, boosting the rural economy.

Conclusion

Poverty in India is a multidimensional issue encompassing economic deprivation along with limited access to health, education, sanitation, and social opportunities. Although the government has implemented numerous welfare programmes, their effectiveness varies due to structural challenges such as administrative inefficiencies, targeting errors, and limited community participation. While schemes such as MGNREGA, Ayushman Bharat, PMJDY,

and PMAY-G have yielded notable improvements, these gains remain fragile, particularly in the face of economic shocks, natural disasters, and pandemics. The COVID-19 crisis highlighted the vulnerability of poor households and reversed years of poverty reduction (World Bank, 2022). Therefore, future poverty alleviation strategies must emphasize stronger implementation mechanisms, real-time monitoring, local institutional engagement, and beneficiary capacity-building to ensure inclusive and sustainable development.

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