



Application and Gaps in Advanced Packaging Technology in the Indian Food Industry

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ABSTRACT

This review critically examines the current applications of advanced packaging technologies in the Indian food industry and identifies existing gaps that hinder their widespread adoption. The analysis focused on applications, technological innovations, adoption barriers, and policy implications. Significant advancements have been made in active, intelligent, biodegradable, and modified atmosphere packaging. However, cost constraints, infrastructural limitations, regulatory challenges, and fragmented supply chains impede large-scale adoption in India. Bridging these gaps could improve food safety, extend shelf-life, reduce food loss and waste, and enhance the global competitiveness of Indian food products. This paper consolidates fragmented studies on advanced food packaging in India and provides a comprehensive analysis of technological adoption and the barriers impeding its diffusion.

Keywords: Biodegradable, Food, Packaging, Radio-frequency identification, Supply chain

INTRODUCTION

India's food industry is the fifth largest globally, with significant contributions from processed foods, fruits, vegetables, dairy, and meat sectors (FAO, 2021). However, post-harvest losses, spoilage, and contamination continue to challenge food safety and quality, reducing profitability for producers and limiting export potential (Bhalla and Singh, 2020). Advanced packaging technologies—encompassing active, intelligent, biodegradable, and modified atmosphere packaging—have emerged as critical tools to preserve food quality, extend shelf life, and maintain safety standards (Jana, 2024; Palanisamy, 2025). These technologies are particularly relevant in India due to the fragmented supply chain, high perishability of produce, and increasing consumer demand for convenience and sustainability (Karnwal, 2025).

Despite global advancements, adoption in India is limited by infrastructure gaps, high initial costs, lack of awareness, and regulatory barriers. This paper aims to synthesize existing research on advanced packaging applications in India, highlight gaps in adoption, and propose strategies for improvement. The objectives of this study were to identify key advanced packaging technologies applied in India. Review empirical studies on their adoption, effectiveness and

impact. Identify gaps and challenges in implementation and Provide recommendations for policymakers and industry stakeholders

Advanced Packaging Technologies

a) Active Packaging

Active packaging incorporates substances into packaging materials to interact with food or the environment, controlling oxygen, moisture, or microbial growth. Oxygen scavengers, ethylene absorbers, and antimicrobial films have been successfully applied to extend shelf life in dairy, meat, and fresh produce (Jana, 2024; Zhang *et al.*, 2023). Tomato and mango packaging with ethylene absorbers to delay ripening (Rao *et al.*, 2020) and dairy packaging with antimicrobial coatings to reduce spoilage (IIT Delhi, 2023).

b) Intelligent/Sensor-Based Packaging

Intelligent packaging monitors food condition in real time using sensors, indicators, Radio-frequency identification (RFID) tags, or QR codes. Applications in India include temperature monitoring during cold chain transport of perishable fruits and real-time freshness indicators for ready-to-eat meals (Palanisamy, 2025; Sharma *et al.*, 2022).

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Table 1: Comparison of active, intelligent, and biodegradable packaging applications in India.

Feature	Active Packaging	Intelligent Packaging	Biodegradable Packaging
Shelf Life Extension	Yes	No	Yes
Real-Time Monitoring	No	Yes	No
Environmental Impact	Moderate	Moderate	Low
Cost	High	High	High
Consumer Awareness	Moderate	Low	Low
Infrastructure Needs	Moderate	High	Low

c) Biodegradable and Sustainable Packaging

Environmental concerns and plastic waste have driven research into biodegradable packaging, including starch-based films, cellulose composites, and fungal mycelium packaging (Karnwal, 2025; IIT Madras, 2025). These materials reduce environmental impact but face challenges in strength, moisture resistance, and scalability.

d) Modified Atmosphere and Controlled Atmosphere Packaging

Modified atmosphere (MAP) and controlled atmosphere (CAP) involve altering the composition of gases surrounding the food to slow microbial growth and oxidation. Widely used in high-value horticultural exports, MAP helps extend shelf life of bananas, grapes, and pomegranates (FAO, 2021).

Applications of Advanced Packaging Technologies in the Indian Food Industry**a) Fresh Produce**

The Indian fresh produce sector, encompassing fruits, vegetables, and minimally processed commodities, benefits substantially from the integration of active and intelligent packaging systems. These technologies help mitigate post-harvest losses that typically range between 25–40% due to inadequate handling, temperature fluctuations, and ethylene accumulation (FAO, 2021; Singh *et al*, 2023). Active packaging materials incorporating ethylene scavengers, moisture regulators, and antimicrobial agents significantly reduce spoilage during storage and transit. For instance, ethylene-absorbing sachets and nano-clay composite films used for mangoes and tomatoes have demonstrated up to 25–30 per cent reduction in physiological deterioration (Rao *et al*,

2020; Kumar and Sahu, 2022). Intelligent packaging systems—such as time–temperature indicators (TTIs) and freshness sensors—are increasingly used in export consignments of grapes, bananas, and pomegranates to monitor real-time quality and ensure cold chain integrity (Palanisamy, 2025; APEDA, 2023). These innovations not only improve shelf life but also enhance consumer confidence in both domestic and international markets.

b) Dairy and Meat Product

Advanced packaging technologies play a pivotal role in maintaining the safety, freshness, and sensory quality of perishable dairy and meat products. The use of antimicrobial films incorporating silver nanoparticles, chitosan, or essential oil extracts has been shown to suppress microbial growth in milk, paneer, and cheese (IIT Delhi, 2023; NIFTEM, 2023). Modified Atmosphere Packaging (MAP) and vacuum sealing are increasingly employed for paneer, butter, and ready-to-cook meat to extend shelf life while minimizing oxidation and spoilage (Gupta *et al*, 2021). Intelligent temperature and gas sensors, coupled with QR-based traceability tags, help processors ensure compliance with FSSAI hygiene and safety regulations (FSSAI, 2023; Sharma *et al*, 2022). For meat and poultry products, oxygen scavengers and CO₂-regulated MAP systems effectively delay rancidity and discoloration, thereby improving marketability in urban retail chains and export consignments (Chaudhary and Yadav, 2020).

c) Processed and Packaged Food

Processed food segments—including snack items, ready-to-eat (RTE) meals, bakery goods, and frozen products—have emerged as major beneficiaries of smart and active packaging integration (Bharadwaj

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Table 2: Studies on Modified Atmosphere Packaging (MAP) and Controlled Atmosphere Packaging (CAP) in Indian horticultural exports.

Crop	Packaging Technology	Study / Author (Year)	Objective / Key Findings	Country of Export
Mango	MAP	Rao <i>et al</i> , 2020	Ethylene-absorbing MAP reduced post-harvest losses by ~15%; maintained firmness and color.	UAE, Saudi Arabia
Grapes	MAP	Palanisamy, 2025	MAP with low O ₂ and elevated CO ₂ extended shelf life from 7 to 21 days.	Netherlands, UK
Pomegranate	CAP	Sharma <i>et al</i> , 2022	CAP slowed respiration rate and microbial growth; extended storage up to 30 days.	USA, Europe
Banana	MAP + CAP	FAO, 2021	Combination of MAP and CAP reduced spoilage and transport losses during long-haul exports.	Middle East, Europe
Papaya	MAP	Singh <i>et al</i> , 2019	MAP maintained quality parameters (color, firmness) for 14 days; reduced decay incidence.	Thailand, Malaysia
Avocado	CAP	Mehta and Gupta, 2021	Controlled atmosphere storage delayed ripening; maintained export quality for 21 days.	USA, Middle East
Strawberries	MAP	Reddy <i>et al</i> , 2020	MAP slowed microbial growth; improved shelf life from 4 to 10 days during air transport.	UAE, Singapore
Tomato	MAP	Kumar and Patil, 2019	MAP extended shelf life from 6 to 14 days; preserved color and vitamin C content.	Bangladesh, Sri Lanka

and Ghosh, 2021). MAP systems with optimized oxygen–carbon dioxide ratios are widely adopted in chips, namkeen, and extruded products to prevent lipid oxidation and moisture gain. Intelligent labels—such as freshness indicators, RFID tags, and blockchain-enabled QR codes—are increasingly used in packaged meals and online food delivery platforms to enhance transparency and consumer trust (Sharma *et al*, 2022; Kaur *et al*, 2023). Biodegradable films made from starch, polylactic acid (PLA), or protein-based materials are gaining traction as sustainable alternatives to multilayer plastics, aligning with India's 2022 Plastic Waste Management (PWM) Rules (MoEFCC, 2022). In frozen and convenience food packaging, temperature-sensitive inks and smart labels

allow distributors to monitor product exposure during storage and transit, minimizing returns and ensuring safety.

d) Export-Oriented Packaging

The success of India's agri-food exports—particularly mangoes, grapes, litchi, and pomegranates—depends heavily on the adoption of advanced packaging and integrated cold-chain systems (FAO, 2021; Palanisamy, 2025). Export consignments increasingly utilize MAP, vacuum-sealed punnets, and breathable films to maintain product firmness and visual appeal during long-haul shipments to Europe,

the Middle East, and East Asia. Intelligent packaging equipped with RFID and TTIs facilitates real-time tracking of temperature, humidity, and shock exposure, thereby reducing spoilage and rejection rates at destination ports (APEDA, 2023; EFSA, 2021). Recent trials using nano-enabled antimicrobial coatings and gas-permeable films for Indian mangoes exported to the UK demonstrated up to 40% reduction in fungal decay and extended shelf life by 6–8 days (Karnwal, 2025; Singh and Choudhary, 2021). These innovations have strengthened India's competitiveness in high-value global markets while aligning with sustainability and traceability standards demanded by importing nations.

- MAP: Modified Atmosphere Packaging – alters gas composition (O₂, CO₂, N₂) around the product.
- CAP: Controlled Atmosphere Packaging – maintains specific environmental conditions (temperature, humidity, gas composition) to extend shelf life.
- These studies indicate that MAP and CAP significantly reduce post-harvest losses, improve fruit quality, and make Indian horticultural exports competitive in international markets.

Gaps and Challenges

A) High Costs

The transition toward advanced packaging technologies in the Indian food industry is constrained by the high costs associated with innovative materials, equipment, and technical expertise. Active and intelligent packaging—incorporating antimicrobial agents, oxygen scavengers, biosensors, and nanomaterials—demands substantial investment compared to conventional systems (Karnwal, 2025; Nandini *et al*, 2023; Mahalik and Nambiar, 2010). SMEs, which constitute nearly 75% of India's food processing sector, often lack access to affordable credit and venture funding (FICCI, 2022). Moreover, the absence of large-scale domestic production of biodegradable and smart materials escalates dependency on imports, further inflating costs (Bharadwaj and Ghosh, 2021). Consequently, high capital intensity and low immediate returns discourage adoption among smaller processors and cooperatives.

B) Infrastructure Limitations

India's food logistics infrastructure remains a major bottleneck in realizing the potential of advanced packaging. Limited availability of integrated cold chain systems, refrigerated vehicles, and temperature-controlled warehousing undermines the effectiveness of technologies designed to enhance product shelf life (FAO, 2021; APEDA, 2023). Approximately 40% of post-harvest food losses in India occur due to inadequate cold storage and transport infrastructure (NITI Aayog, 2022). Advanced packaging systems, such as modified-atmosphere or vacuum packaging, depend on consistent environmental control—something difficult to maintain in regions with poor power supply or limited connectivity (Shukla *et al*, 2020). The infrastructural divide between large organized processors and fragmented smallholders widens the gap in technology adoption and food quality assurance.

C) Regulatory Barriers

The regulatory landscape for food packaging technologies in India remains fragmented and ambiguous. While the FSSAI and BIS provide general packaging and labeling guidelines, there are limited standardized protocols for testing and approving biodegradable, compostable, and intelligent materials (MoFPI, 2022; FSSAI, 2023). Regulatory delays in certifying new materials or sensors often discourage innovation. Furthermore, lack of clarity in defining sustainability metrics and end-of-life management complicates compliance (Chaudhary and Yadav, 2020). In contrast, regions like the EU and Japan have well-established frameworks for smart and bio-based packaging (EFSA, 2021; Yoshida *et al*, 2020). The absence of similar harmonized standards in India restricts export competitiveness and consumer confidence in new packaging technologies.

D) Supply Chain Fragmentation

The Indian food supply chain is highly fragmented, involving millions of small-scale producers, traders, and informal processors (Rao *et al*, 2020; Singh and Choudhary, 2021). Such fragmentation disrupts traceability, uniformity, and quality control—key enablers for advanced packaging deployment. Smart packaging systems that rely on sensors, data loggers, and blockchain-based traceability require integrated and digitized value chains (Pandey *et al*, 2022). However, smallholders often operate outside organized systems, limiting the adoption of such technologies. Additionally,

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inconsistent handling practices, poor sanitation, and lack of trained personnel further reduce the effectiveness of packaging innovations (NIFTEM, 2023). Without supply chain integration and capacity building, scaling up advanced packaging remains challenging.

E) Consumer Awareness and Perception

Consumer awareness about the benefits of advanced packaging—such as food safety, freshness indicators, and environmental sustainability—remains relatively low in India (Sharma *et al.*, 2022; Kaur *et al.*, 2023). Most purchasing decisions in the mass market are price-sensitive, leading to preference for low-cost, conventional packaging (Ravindran and Sen, 2020). Although urban consumers are gradually shifting toward eco-friendly and premium packaged foods, rural and semi-urban markets still prioritize affordability over innovation (Sinha and Deshmukh, 2021). Limited educational outreach, weak labeling transparency, and lack of trust in novel packaging technologies further restrict consumer acceptance. Consequently, low demand perpetuates low investment by manufacturers, creating a self-reinforcing cycle of under-adoption.

RECOMMENDATIONS

Government Incentives:

The Government of India can play a crucial role in accelerating the adoption of advanced packaging technologies by providing targeted subsidies, low-interest loans, and tax incentives to small and medium-sized enterprises (SMEs). Financial support mechanisms under schemes such as the *Pradhan Mantri Kisan Sampada Yojana (PMKSY)* or the *Production Linked Incentive (PLI)* can be extended to include investments in intelligent, active, and biodegradable packaging systems.

Infrastructure Development:

Enhancing physical infrastructure—including cold storage, refrigerated logistics, and digitalized transport networks—is essential to unlock the full potential of advanced packaging technologies. Strategic investments in integrated cold-chain systems and smart logistics hubs would reduce post-harvest

losses and improve product quality, particularly for perishable commodities.

Standardization and Certification:

Developing clear regulatory guidelines and standardized certification systems for biodegradable, compostable, and intelligent packaging materials would facilitate faster approval and market entry. Collaborative efforts among FSSAI, BIS, and MoFPI are needed to harmonize testing protocols and labeling norms, improving consumer trust and export competitiveness.

R&D and Collaboration:

Strengthening R and D through public–private partnerships and industry–academia collaborations can drive innovation and scalability of indigenous packaging solutions. Establishing dedicated research centers and technology transfer platforms at institutions such as NIFTEM and IITs would help develop cost-effective, locally sourced materials and smart packaging technologies.

Consumer Education:

Comprehensive awareness campaigns highlighting the benefits of advanced packaging—such as improved food safety, sustainability, and reduced waste - can stimulate consumer demand. Educational outreach, eco-labeling initiatives, and sustainability branding would enhance market acceptance and encourage producers to adopt environmentally responsible packaging practices.

CONCLUSION

Advanced packaging technologies are critical to improving food safety, reducing post-harvest loss, and enhancing sustainability in the Indian food industry. While adoption has increased in exports, dairy, and processed foods, gaps remain due to costs, infrastructure, regulation, and supply chain fragmentation. Addressing these challenges requires a coordinated approach involving government, industry, academia, and consumers. Enhanced adoption of advanced packaging can strengthen India's competitiveness in domestic and global food markets.

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