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Innovation-led value chain management in mango and banana

Among fruit crops, mango and bananas are the most important crops hovering 50% share in fruits areasubstantially dominated by mango. Fruit crops production witnessed significant increase from 28.6 million metric tonne (MMT) in 1991–92 to 118.76 MMT in 2024-25. Subtropical production, however, faces distinct constraints: variable climates, short and uneven fruiting periods, cultivar-specific postharvest sensitivity, and fragmented, smallholder-based value chains that depress farm-gate prices and heighten losses. Persistent gaps include limited pre- and postharvest technologies suited to subtropical cultivars, weak cold-chain and controlled-atmosphere capacity, inadequate extension and aggregation services, inconsistent grading standards, low uptake of processing, and poor market information and finance access. The production and processing for premium markets faced stringent competition from the imports. These challenges arise from biological factors, infrastructure deficits, seasonal gluts, and limited product diversification. ICAR CISH developed innovation led solutions in value chain management of mango, banana and honey with four interoperable pillars: (1) improved on-farm interventions— canopy management, bagging of fruits, IPM based biointensive pest disease management system; (2) cost-effective postharvest options—low-cost precooling, better packaging, modular cold-chains, and basic ethylene and decay control; (3) value addition—community processing, standardized grading, aggregation models, and quality/ origin branding; and (4) enabling systems—capacity building, cooperatives, inclusive finance, and digital market information. An implementation roadmap emphasizes scalable pilots, public–private partnerships, and gender-responsive approaches to reduce losses and raise incomes.

Keywords: Cold-chain logistics, Good Agricultural Practices, Postharvest loss reduction, Sea-freight export protocols, Value chain management

MANGO *(Mangifera indica L.)* is one of the most commercially important fruits in tropical and subtropical regions, playing a vital role in cultural traditions, dietary intake, and rural livelihoods. Subtropical belts–particularly those in northern India, Pakistan, Egypt, China, and parts of Mexico–contribute significantly to global mango production but face distinct agro-climatic and socio-economic challenges. High climatic variability, irregular temperature fluctuations, frost events, erratic flowering, and alternate bearing make subtropical mango production systems fundamentally different from tropical ones. Although production volumes are substantial, farm-gate prices often remain low due to fragmented supply chains, inadequate postharvest infrastructure, limited cold-chain coverage, and insufficient processing capacity. Postharvest losses typically range between 20–35%, driven by physiological disorders, mechanical injury, pathogen infection, and improper temperature and humidity management. Value-chain development has therefore become a central strategy for improving efficiency and farmer profitability. A well-functioning mango value chain integrates production, harvesting, grading, storage, transportation, processing, marketing, and consumer engagement through coordinated technical, institutional, and financial interventions. In many subtropical regions, however, such integration remains incomplete, with persistent gaps in technology adoption, traceability, quality standardization, and market linkages. This manuscript synthesizes available scientific evidence and field-level experiences to identify these gaps and proposes practical solutions to enhance value-chain efficiency, profitability, and resilience.

India is home to more than 1,000 mango cultivars, yet only a few are commercially exported. Major export varieties include Alphonso, Totapuri, Kesar, Bombay Green, Rajapuri, Banganapalli, Dasheri, and Chausa, grown primarily in specific production clusters. Uttar Pradesh is one of the leading mango-producing states, with 2.79 lakh ha under cultivation and an annual production of 46.62 lakh tonnes. Despite being the second-largest producer, the state's export share was only 0.086% of total production in 2021–22. More broadly, India's global

mango exports remain disproportionately low relative to its production, largely due to challenges in meeting international food safety, phytosanitary, and quality standards. To address these constraints, ICAR–Central Institute for Subtropical Horticulture (CISH), Lucknow, has developed innovations in Good Agricultural Practices (GAP) standards specific to mango. Innovations include, bagging of fruits, application of FASAL PRABHAT a micronutrient mixture designed for fruit crops, mechanical harvester, post harvest desapping and washing protocol. Adoption of GAP reduces the risk of non-compliance with national and international regulations–including those of the International Plant Protection Convention (IPPC)–related to permissible pesticide use, maximum residue limits (MRLs), and contamination risks (chemical, microbial, and physical). Implementation of GAP also strengthens traceability, quality assurance, and export readiness across the mango value chain. Banana is another major fruit crop in India, with an annual production of 30.15 million tonnes across 0.87 million hectares, making the country the world's largest banana producer. However, the banana export value chain faces distinct logistical and technological challenges. Most exports currently are restricted to middle east markets through sea due to lack of protocol for distant markets. Developing a viable sea-freight value chain is essential for competitive export growth, but this requires scientifically validated postharvest protocols that maintain fruit quality for 40–45 days–the typical transit time for long-distance sea routes. Achieving these demands improvements in preharvest practices, cultivar selection, controlled-atmosphere packaging, ethylene management, postharvest fungicidal or bio-safe treatments, and robust cold-chain infrastructure. Strengthening both mango and banana value chains–from production to export–will require integrated interventions in GAP adoption, postharvest handling, supply-chain modernization, market alignment, and adherence to global quality and safety standards.

Production Dynamics and Value Chain Mapping

Cultivation of subtropical fruits like mango and banana is largely influenced by climatic conditions. The flowering in mango cultivars as well as banana is highly sensitive to temperature variations, and off-season rains may largely impact on fruit quality and disease incidence. The subtropical mango value chain encompasses farmers, aggregators, traders, packhouses, processors, wholesalers, and retailers. Each node influences the physical, economic, and informational flow of mangoes. The concentrated harvest season creates supply gluts, reducing prices by up to 40% in peak weeks. Without cold-chain facilities, farmers are forced to sell immediately at low prices.

Development of sea route protocol

The sea route protocol plays a vital role in the export of mango and banana from India, as it provides a systematic approach for handling and shipping large volumes of highly perishable fruits during long distance transportation. Unlike air freight, which is faster but expensive and makes it difficult to export large volumes of fruits, while air cargo can be used to transport fruits to short-haul destinations such as Dubai, Singapore, Nepal, Bangladesh, etc., fruits shipped via the sea route take 15 to 30 days to reach destinations such as Europe, Japan or the Middle East. This long transit time necessitates the adoption of strict scientific measures to maintain the quality of the fruits and reduce post-harvest lossessteps involving the pre harvest to final reach of product to consumers. The sea route protocol provides for pre-harvest practices at field level to harvesting pre cooling of fruits immediately after harvest, use of reefer containers, controlled atmosphere (CA) packaging, and strict temperature and humidity management throughout the sailing journey of the produce and post withdrawal inspection for quality and disease incidence. In addition, quarantine treatments such as hot water treatment, vapour heat treatment or irradiation are mandatory to eliminate fruit flies and stone weevil pests. The protocol also emphasizes on traceability, ensuring that each consignment can be linked to the orchard and packhouse, thereby increasing confidence among international buyers.

Export of mangoes by sea provides a cost-effective alternative to air freight, enabling bulk shipments at lower costs and thus increasing the competitiveness of Indian mangoes in global markets. By complying with the sanitary and phytosanitary (SPS) requirements of the importing countries, the sea route protocol reduces the risk of consignment rejection and ensures smooth market access. It also helps in maintaining the natural taste, aroma, and nutritional quality of the fruits during long-term storage. Overall, the sea route protocol not only makes mango exports more economical but also strengthens India's reputation as a reliable supplier of safe and high-quality fruits.

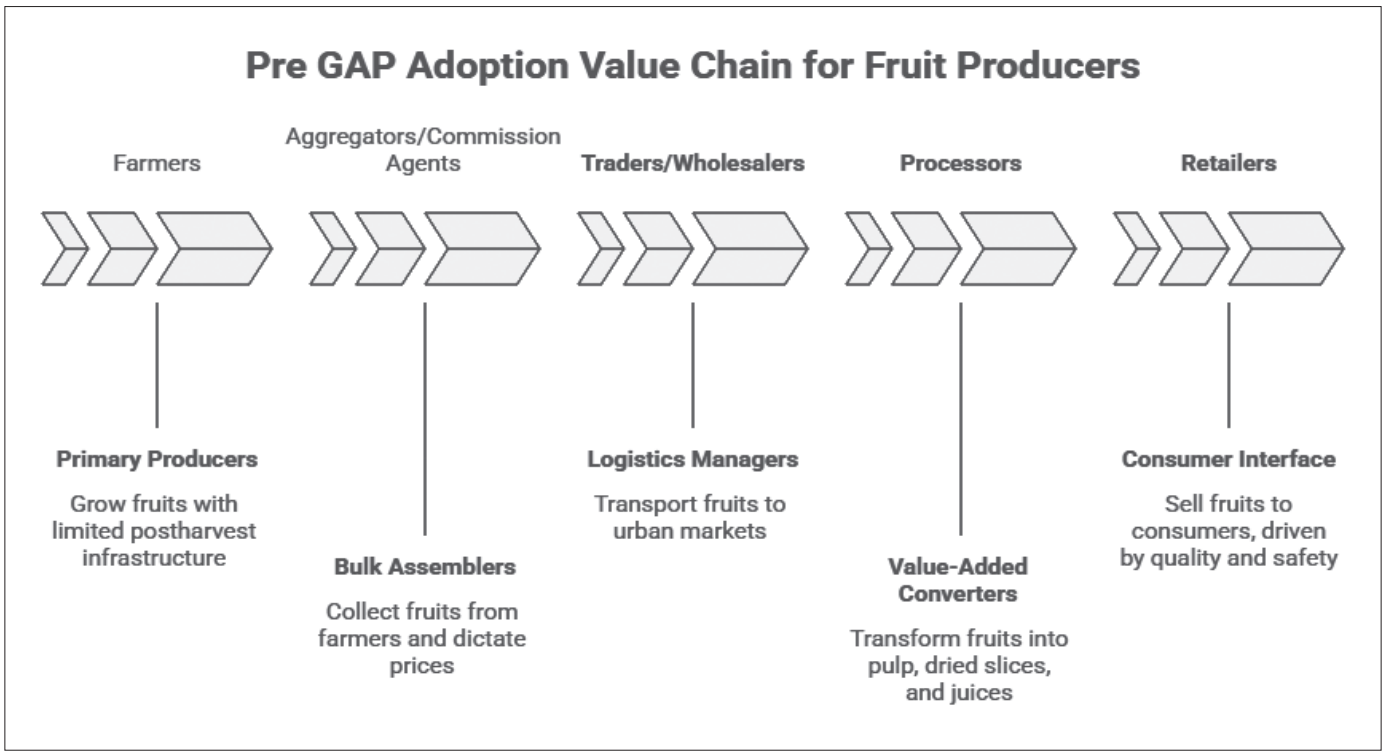
Creation of export cluster

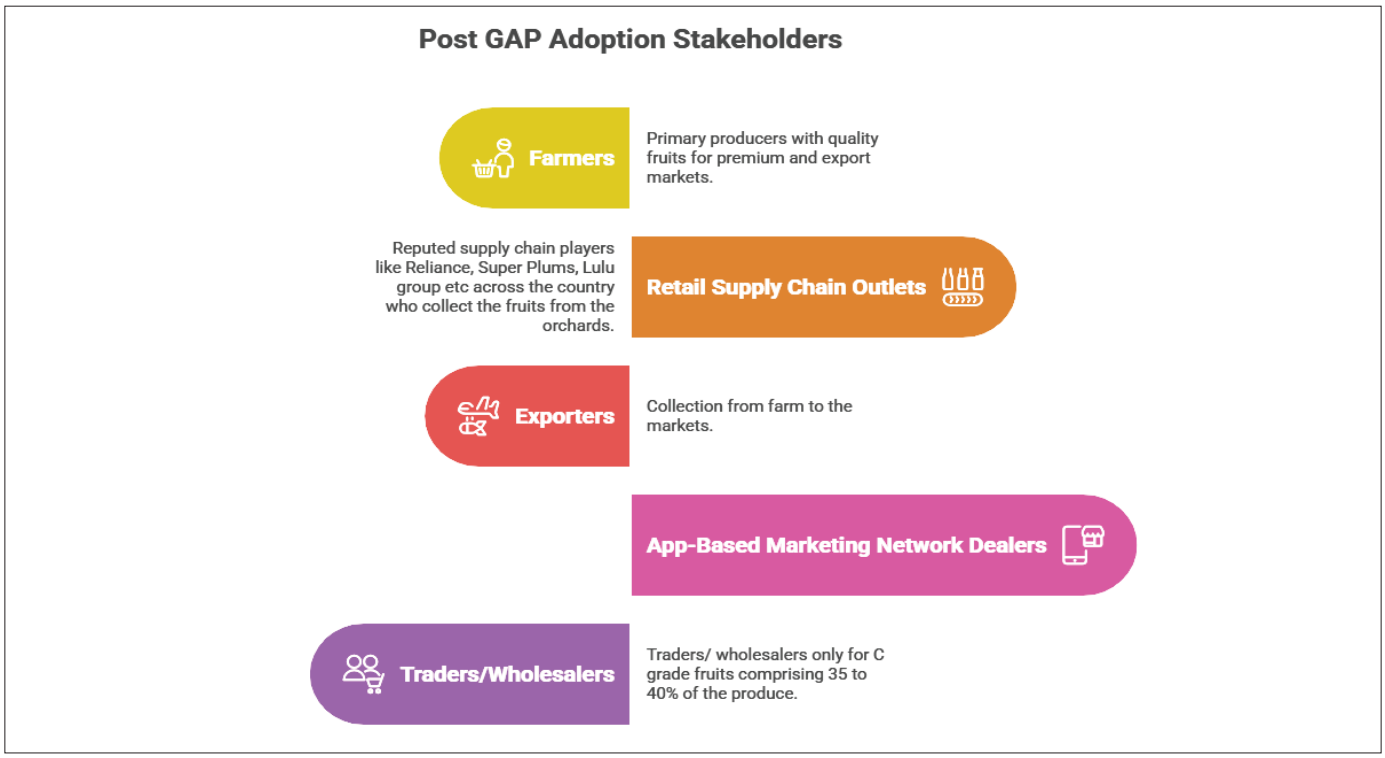
Mango and banana are two of the most important tropical fruits of India, contributing significantly to both domestic consumption and export earnings. North India, particularly the Lucknow–Malihabad belt for mango and the eastern Uttar Pradesh–North Bihar region for banana, has immense production potential but faces constraints in international trade due to fragmented supply chains, inadequate postharvest infrastructure, and limited access to export-compliant facilities. The ICAR CISH initiative of establishment of GAP adopted export clusters offers a strategic approach to address these challenges by integrating production, postharvest handling, and market access within a single framework. Such clusters would enable the development of packhouses, pre-cooling and cold storage units, reefer logistics, and protocol-linked facilities such as irradiation and vapor heat treatment, which are essential for accessing high-value markets including the USA, Japan, South Korea, and the European Union. Adoption of Good Agricultural Practices (GAP), residue management protocols, and sea-route export technologies would further enhance competitiveness and sustainability. Government initiatives through APEDA, MoFPI, PMFME, and Operation Greens provide avenues for financial and technical support, encouraging collective participation of farmers, exporters, and research institutions. By fostering a scientifically managed and

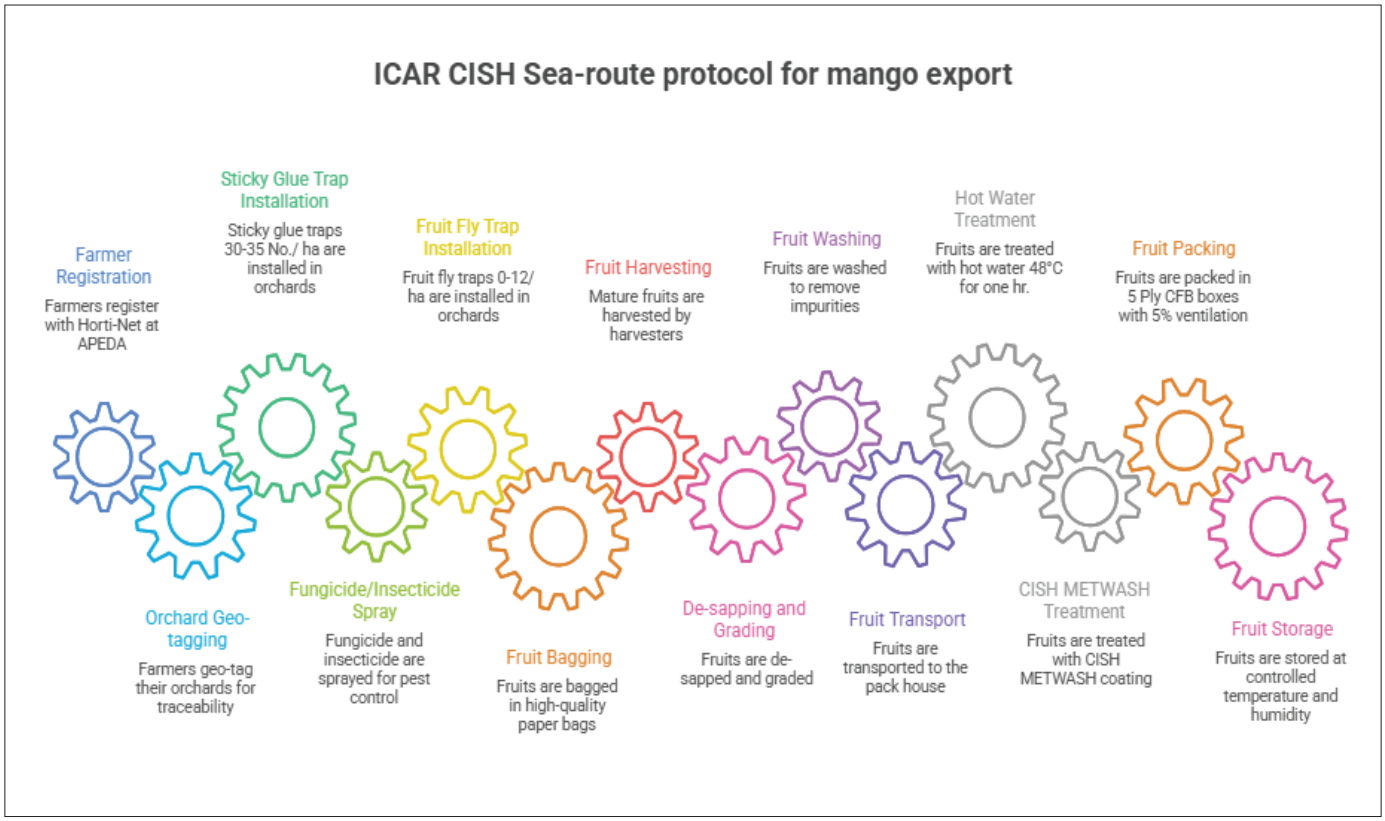
infrastructure-supported export cluster, North India can emerge as a reliable hub for global mango and banana trade, ensuring improved farmer income, reduced wastage, and consistent supply of high-quality fruits to international markets.

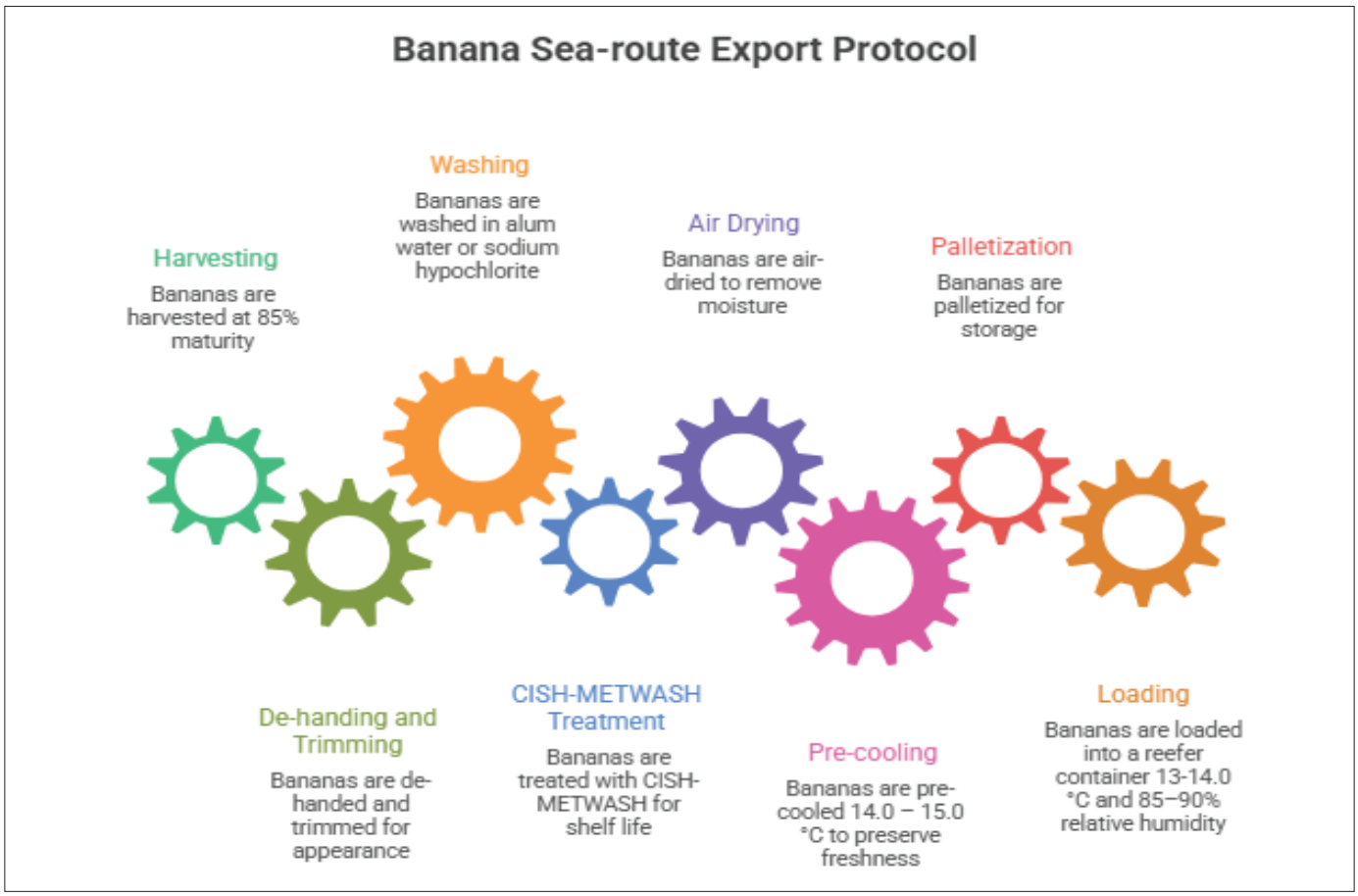
Adoption of GAP for residue free fruit production

The adoption of Good Agricultural Practices (GAP) is central to the sustainable production of residue-free mango (*Mangiferaindica L.*) and banana (*Musa* spp.), which are priority fruits in India's export basket. Residue-free production has become increasingly important due to the









stringent maximum residue limit (MRL) requirements of importing countries, particularly the European Union, Japan, and the United States. GAP provides a systematic framework covering all aspects of production, including soil and water management, judicious nutrient application, integrated pest and disease management, and safe harvest practices, to ensure both quality and safety of fruits. In mango, GAP emphasizes the use of biological control agents, pheromone traps, and need-based spraying with pre-harvest intervals, thereby reducing pesticide residues and mitigating fruit fly incidence. In banana, GAP focuses on integrated nutrient management, sanitation of fields, biological alternatives for

Sigatoka and crown rot control, and regulated irrigation, ensuring healthy bunch development with minimal chemical inputs. Proper training in record keeping, traceability, and compliance with Global G.A.P. and GRASP certification standards further enhances export readiness. Adoption of GAP not only ensures residue-free fruits but also extends shelf life, reduces postharvest losses, and improves market acceptability. Moreover, consumer awareness of food safety and sustainability is driving global demand for GAP-certified produce. Systematic implementation of GAP in mango and banana orchards coupled with regular monitoring and residue testing, is vital to strengthen export potential, achieve compliance with international standards, and enhance farmers' profitability through access to premium markets.

CONCLUSION

Mango and banana value chains face multiple challenges, including inconsistent production, high post-harvest losses, and weak market linkages, which limit profitability and global competitiveness. These challenges arise from inadequate orchard management, improper harvesting practices, insufficient post-harvest handling, and limited access to modern cold-chain infrastructure. However, science-based and economically feasible solutions exist across all segments of the value chain. Incremental improvements in canopy management, timely and careful harvesting, efficient postharvest treatments, proper packaging, and value addition can significantly enhance fruit quality, reduce losses, and increase farmer incomes. Strengthening institutional frameworks and promoting Farmer Producer Organizations (FPOs) can improve coordination, market access, and resource sharing. Investments in low-cost cold-chain technologies, including pre-cooling, refrigerated storage, and controlled transport, are critical for maintaining quality during export. Policymakers must focus on integrated interventions, gender-inclusive approaches, and research on storage physiology and ripening to ensure the resilience, sustainability, and global competitiveness of subtropical mango and banana systems.

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