Policy Research Journal
ISSN (E): 3006-7030 ISSN (P) : 3006-7022 Volume 4, Issue 4, 2026

EVALUATION OF PREHARVEST AND POSTHARVEST TREATMENTS FOR EXTENDING SHELF LIFE AND QUALITY OF MANGO FRUITS

Saeed Ahmad[*1], **Zainab Naseer**[2], **Ameer Jan**[3]

[*1]*University of Lincoln UK, Lincoln Institute for Agri-food Technology*
[2]*Department of Food science and technology, Faculty of Food Science and Nutrition, Bahauddin Zakariya University, Multan, Pakistan*
[3]*University of Makran*

[*1]ahmadsaeeduol@gmail.com, [2]naseerzainab26@gmail.com, [3]ameerjan@uomp.edu.pk

DOI: https://doi.org/10.5281/zenodo.19731677

Keywords
mango postharvest, shelf life extension, preharvest treatments, 1-MCP, edible coatings, modified atmosphere packaging, hot water treatment, irradiation, calcium, ethylene management, climacteric fruit

Article History
Received: 25 February 2026
Accepted: 06 April 2026
Published: 24 April 2026

Corresponding Author: *
Saeed Ahmad

Abstract
Mango (Mangifera indica L.), globally recognized as the "king of fruits," faces significant postharvest challenges due to its climacteric nature, rapid ripening driven by ethylene, and susceptibility to pathogens such as anthracnose (Colletotrichum gloeosporioides) and stem-end rot (Lasiodiplodia theobromae), resulting in 30–50% losses in many supply chains. This review evaluates preharvest and postharvest interventions aimed at extending shelf life while preserving sensory, nutritional, and market quality. Preharvest treatments, including calcium ($Ca(NO_3)_2$, $CaCl_2$) and potassium sprays, gibberellic acid (GA_3), and salicylic acid (SA), enhance cell wall integrity, reduce transpiration, delay ethylene evolution, and improve antioxidant capacity, often extending shelf life by several days. Postharvest physical methods hot water treatment (HWT), vapor heat, and low-dose irradiation (0.15–1.0 kGy) provide effective quarantine disinfestation and microbial control with minimal residue concerns. Chemical and hormonal approaches, particularly 1-methylcyclopropene (1-MCP) at 1.0 μL L^{-1}, nitric oxide, and oxalic acid, inhibit ethylene perception, maintain firmness, and mitigate chilling injury during cold storage or marine transport. Advanced packaging solutions, including chitosan-based edible coatings enriched with essential oils or nanoparticles (Ag, ZnO, TiO_2), modified atmosphere packaging (MAP) combined with ethylene scrubbers, and active biodegradable films, create semi-permeable barriers that regulate gas exchange, reduce weight loss, and suppress decay. Emerging technologies such as AI-driven computer vision for non-destructive quality sorting and cold plasma for surface decontamination further enhance precision and sustainability. Integrated strategies combining optimized preharvest nutrition, targeted postharvest treatments, and smart packaging consistently achieve 3–5 weeks of extended marketable life for varieties like 'Kent', 'Ataulfo', and 'Amrapali', while maintaining TSS, acidity balance, bioactive compounds, and consumer appeal. Economic analyses confirm favorable cost-benefit ratios for many interventions. Future directions emphasize residue-free, climate-resilient protocols, circular economy approaches utilizing mango by-products, and scalable Industry 4.0 tools to minimize losses and meet stringent international MRL standards.

1. INTRODUCTION

The mango (*Mangifera indica* L.) is globally celebrated as the "king of fruits," a title justified by its profound economic significance, exceptional organoleptic profile, and dense nutritional composition (Thakur & Bhange, 2017). Primarily cultivated in tropical and subtropical regions, the mango serves as a vital source of vitamins A and C, antioxidants such as mangiferin, and essential dietary fibers (Shah et al., 2010). However, the fruit's climacteric nature characterized by a sharp surge in respiration and ethylene production during ripening renders it highly perishable (Schouten et al., 2018). This physiological vulnerability, compounded by susceptibility to postharvest pathogens like *Colletotrichum gloeosporioides* (anthracnose) and *Lasiodiplodia theobromae* (stem-end rot), creates a formidable challenge for the global supply chain (Widiastuti et al., 2024). Postharvest losses are estimated to range from 30% to 50% in various markets, posing a significant threat to food security and the economic stability of producing nations (TechnoServe Inc., 2025). Consequently, the evaluation of preharvest and postharvest interventions is not merely a matter of academic interest but a commercial and humanitarian imperative (Moreno-Hernandez et al., 2024).

2. Global Production Dynamics and Economic Landscape

The global mango industry is currently navigating a period of moderate growth tempered by environmental volatility. As of the 2024–2025 marketing year, global acreage is projected to rise by approximately 1%, with growth driven largely by Indonesia, China, Mexico, and Brazil (ReportLinker, 2024). India remains the world's preeminent producer, contributing nearly 45% of global output, with production estimates reaching 38 million tons by 2033 (OECD-FAO, 2025). This dominance is supported by diverse cultivars such as Alphonso, Kesar, and Totapuri, which are integral to the burgeoning mango pulp and puree markets (MarkNtel Advisors, 2025).

The international trade landscape is characterized by complex logistical requirements, particularly for long-distance transport to major importers like the United States and the European Union (Alonso-Salinas et al., 2024). For instance, Mexico ships approximately 22% of its production, with 87% of those exports destined for the U.S. market (FAO, 2024). Meanwhile, Peru experienced what has been described as the "worst season in history" in 2024–2025, where extreme weather events slashed export volumes by up to 80%, highlighting the industry's vulnerability to climate change. Extreme heat events in India have also caused crop losses of up to 85% for specific varieties like 'Kesar' (FreshPlaza, 2026).

2.1 Global Mango Production and Market Projections (2024–2034)

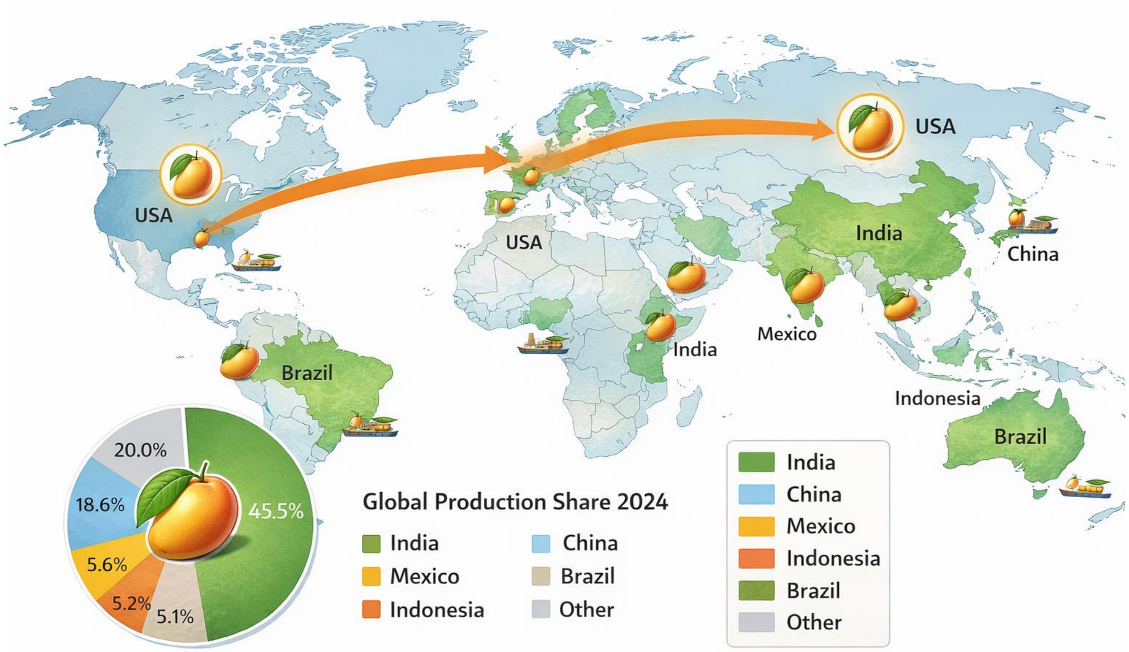
Table 1. Global Mango Production and Market Projections (2024-2034)

Market Metric	2024-2025 Estimate	2030-2034 Projection	Compound Annual Growth Rate (CAGR)
Global Export Volume	2.6 Million Tons (Gutiérrez, 2025)	3.2 Million Tons (Gutiérrez, 2025)	3.6% (Production) (Gutiérrez, 2025)
Processed Mango Products Market	USD 21.1 Billion (Global Industry Analysts, 2024)	USD 29.8 Billion (Global Industry Analysts, 2024)	6.0% (Global Industry Analysts, 2024)
Global Mango Pulp Market	USD 1.50 Billion (Custom Market Insights, 2026)	USD 3.01 Billion (Custom Market Insights, 2026)	7.57% (Custom Market Insights, 2026)
Global Mango Puree Market	USD 4.67 Billion (SkyQuest, 2024)	USD 6.53 Billion (SkyQuest, 2024)	3.8% (SkyQuest, 2024)
Organic Puree Segment Share	65% of Total Revenue (SkyQuest, 2024)	-	8.93% (Mordor Intelligence, 2025)

Policy Research Journal
ISSN (E): 3006-7030 ISSN (P) : 3006-7022 Volume 4, Issue 4, 2026

The industry's expansion into the processed sector including purees, concentrates, and dried slices serves as a strategic buffer against seasonality and postharvest losses (Grand View Research, 2024). The U.S. market for processed mango products is valued at approximately USD 5.7 billion, while China is forecast to witness a robust CAGR of 9.6% through 2030 (Global Industry Analysts, 2024). Furthermore, emerging trends in "clean-label" and natural ingredients are driving demand for residue-free treatments, as consumers increasingly prioritize wellness and environmental sustainability (Custom Market Insights, 2026). The global mango industry is geographically concentrated with distinct trade flows. Figure 2 presents the global production distribution and export pathways of mango.

Figure 1: Global Mango Production and Trade Distribution (2024–2034)



3. Physiological and Biochemical Mechanisms of Ripening

The transition of mango from a mature-green state to an edible ripe fruit involves a series of coordinated biochemical events. These changes are governed by the climacteric rise in respiration and the autocatalytic production of ethylene (C_2H_4), which serves as the primary hormonal signal for ripening (Mditshwa et al., 2021).

3.1 Textural Softening and Cell Wall Modification

The loss of fruit firmness is perhaps the most critical indicator of ripening and eventual senescence. This process is driven by the depolymerization and hydrolysis of cell wall polysaccharides, specifically pectin, cellulose, and hemicellulose (SkyQuest, 2024). The primary enzymes involved include Pectin Methyl Esterase (PME), Polygalacturonase (PG), and beta-Galactosidase (Yaseen et al., 2026). As these enzymes degrade the middle lamella, cell-to-cell adhesion is lost, resulting in the characteristic softening of the pulp. Postharvest treatments like 1-Methylcyclopropene (1-MCP) and heat treatments are specifically designed to inhibit these enzymes or the ethylene signaling that triggers them (MDPI, 2025).

3.2 Carbohydrate Transformation and Flavor Profile

During the ripening phase, starch accumulated during fruit growth is converted into soluble sugars, primarily sucrose, glucose, and fructose. This leads to a significant increase in Total Soluble Solids (TSS), typically measured in degrees Brix. Concurrently, titratable acidity (TA) declines as organic acids are metabolized as respiratory substrates (Penchaiya et al., 2006). The TSS/Acid ratio serves as a primary determinant of flavor quality, with consumer preference strongly favoring fruits with a balanced ratio (Iqbal, 2020).

3.3 Bioactive Compound Degradation

Mangoes are rich in phytochemicals, including ascorbic acid (Vitamin C), carotenoids, and phenolic compounds. Ascorbic acid levels typically decrease during storage and ripening due to oxidative processes (National Mango Board, 2026). Phenolic compounds, such as gallic acid and mangiferin, contribute to the fruit's antioxidant capacity but are also susceptible to degradation or conversion during ripening. Management strategies that preserve these compounds are essential for maintaining the fruit's nutritional value and functional appeal (Beyer, 2025).

4. Preharvest Interventions and Their Mechanisms

The postharvest quality of mango is largely determined by factors present during fruit development on the tree. Preharvest management focuses on enhancing the fruit's structural integrity and biochemical resilience before harvest (Crisosto et al., 1995).

4.1 Mineral Nutrition: The Influence of Calcium and Potassium

Calcium (Ca^{2+}) is a structural component of the cell wall, playing a pivotal role in maintaining the integrity of the middle lamella by forming calcium pectate cross-bridges (Singh et al., 2017). Preharvest sprays of calcium compounds such as Calcium Nitrate ($Ca(NO_3)_2$) or Calcium Chloride ($CaCl_2$) at concentrations ranging from 0.5% to 2.0% have been shown to increase firmness by thickening the middle lamella and reducing respiration by stabilizing cell membranes (Singh & Singh, 2017). Furthermore, calcium treatments effectively lower ethylene production by inhibiting 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase (Mordor Intelligence, 2025).

Potassium (K) is equally vital, particularly for carbohydrate metabolism and the transport of photosynthates. Preharvest applications of Potassium Sulphate (K_2SO_4) or Potassium Silicate have been observed to increase fruit size, volume, and total sugar content (Gutiérrez, 2025). Silicon, in particular, contributes to physical defense by depositing under the cuticle and strengthening epidermal cell walls, which helps control postharvest decay (Singh et al., 2022).

4.2 Plant Growth Regulators and Signaling Molecules

Gibberellic acid (GA_3) acts as a potent ripening inhibitor by promoting vegetative growth and restricting the evolution of ethylene. Research on the 'Amrapali' cultivar indicated that GA_3 applied at 75 ppm 20 days before harvest significantly extended shelf life to 17 days, compared to 9 days in the control group (Reddy et al., 2002). Salicylic Acid (SA) is a phenolic signaling molecule that induces systemic acquired resistance (SAR), preparing the fruit for postharvest stress by upregulating antioxidant enzymes like superoxide dismutase (SOD) (Lebaka et al., 2021).

4.3 Efficacy of Preharvest Treatments on Mango Quality Attributes

Table 2. Efficacy of Preharvest Treatments on Mango Quality Attributes

Treatment Compound	Optimal Concentration	Application Timing	Primary Quality Impact
Calcium Nitrate [Ca(NO3)2]	1.0 - 1.5%	15-30 Days Before Harvest	Maximum firmness retention; reduced spoilage (Singh et al., 2017; Singh & Singh, 2017)
Calcium Chloride [CaCl2]	2.0%	10-20 Days Before Harvest	Minimum physiological loss in weight (PLW) (Iqbal, 2020; Singh et al., 2022)
Gibberellic Acid (GA3)	75 - 200 ppm	20 Days Before Harvest	Delayed color change; restricted ethylene evolution (Iqbal, 2020; Reddy et al., 2002)
Salicylic Acid (SA)	200 ppm	20 Days Before Harvest	Enhanced antioxidant capacity; improved chilling injury tolerance (Iqbal, 2020; Mditshwa et al., 2021)
Potassium Silicate	2000 - 3000 ppm	14 Days Before Harvest	Strengthened cell walls; reduced green mold (Singh et al., 2022)

5. Postharvest Physical Treatments for Disinfestation and Preservation

Physical treatments provide effective quarantine control and shelf-life extension without leaving chemical residues a requirement for access to premium international markets (APEDA, 2025).

5.1 Thermal Treatments: Hot Water and Vapor Heat

Hot Water Treatment (HWT) and Vapor Heat Treatment (VHT) are common quarantine protocols for eliminating fruit fly larvae. HWT typically involves submerging fruit in water at temperatures of 46.1 degrees C to 48 degrees C for durations between 60 and 110 minutes (Mwando et al., 2021). The heat effectively kills surface microorganisms and can stimulate heat shock proteins that enhance resistance to cold stress. However, applying heat after cold storage (post-storage) can be catastrophic, leading to fruit rupture and internal browning (Pandey et al., 2023). Physical treatments provide residue-free alternatives for mango preservation. Figure 2 summarizes the major postharvest physical interventions and their effects.

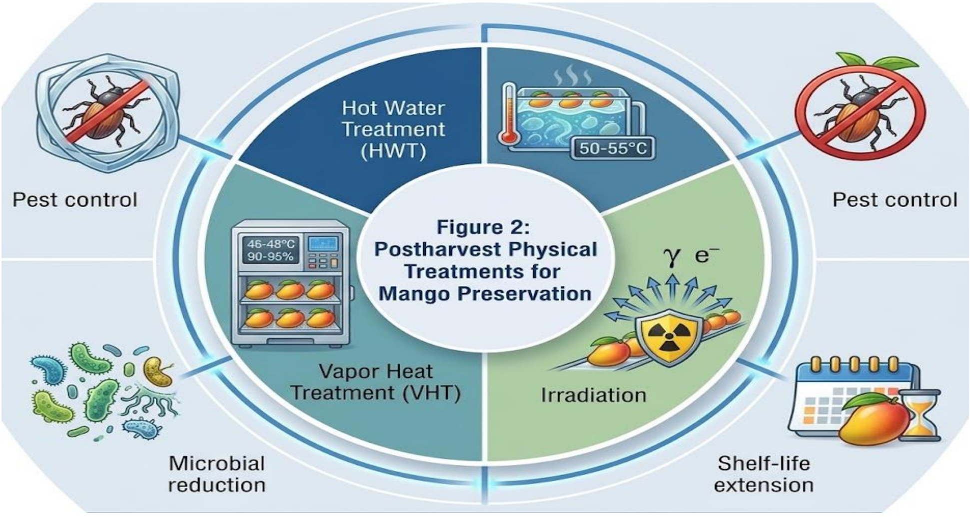


Figure 2: Postharvest Physical Treatments for Mango Preservation

5.2 Irradiation as a Quarantine and Preservation Tool

Irradiation is a popular alternative to thermal treatments. The USDA-APHIS approves gamma irradiation at a minimum dose of 0.15 kGy for fruit fly control and up to 1.0 kGy for broader disinfestation. Low-dose irradiation (0.15 - 0.45 kGy) has been shown to extend shelf life by delaying ripening without negatively affecting sensory properties in varieties like 'Ataulfo' (Cancino-Vázquez et al., 2020).

Table 3. Maximum Tolerated Irradiation Doses and Physiological Responses

Cultivar	Maximum Tolerated Dose (kGy)	Physiological Response to Over-Dosing
Kent	0.86 - 1.0	Higher tolerance; external damage visible only above 1.0 kGy (Cancino-Vázquez et al., 2020)
Ataulfo	0.86	Rapid softening at 20 degrees C; high sensitivity to storage temperature (Cancino-Vázquez et al., 2020)
Tommy Atkins	less than 0.60	Prone to scalding, pulp discoloration, and internal browning (Ndlela et al., 2022)

6. Postharvest Chemical and Hormonal Management

Chemical treatments focus on inhibiting ethylene perception or inducing natural defense systems (Maldonado-Celis et al., 2019).

6.1 1-Methylcyclopropene (1-MCP)

1-MCP is a gaseous ethylene antagonist that binds irreversibly to ethylene receptors. Application of 1.0 microliters per liter 1-MCP can preserve fruit quality for up to 46 days when combined with optimal cold storage (10 plus/minus 1 degrees C) (Kushwaha et al., 2024). It effectively maintains high rheological properties and prevents the upsurge of cell wall degrading enzymes. Recent studies show that 1-MCP aqueous application is more effective than fumigation in extending storage life for varieties like 'Sufaid Chaunsa' (Usman et al., 2025).

6.2 Salicylic Acid, Nitric Oxide, and Oxalic Acid

Postharvest dipping in SA or Nitric Oxide (NO) is used to mitigate chilling injury (CI) and pathogenic infection. NO serves as a signaling molecule that inhibits ethylene biosynthesis and maintains membrane integrity (Razzaq et al., 2015). Salicylic acid induces the expression of antioxidant genes such as APX and SOD, which is crucial for fruits subjected to low temperatures during marine transport (Mditshwa et al., 2021).

7. Advanced Packaging and Edible Coating Technologies

The development of sustainable and active packaging is a primary research frontier, aiming to replace synthetic plastics with biodegradable materials (Vilvert et al., 2023).

7.1 Edible Coatings and Nanocomposites

Lomavatu et al., 2024; Alonso-Salinas et al., 2024; Edible coatings create a semi-permeable modified atmosphere around each fruit, regulating gas exchange and moisture loss. Chitosan-based coatings (0.5 - 1.0%) are highly effective due to their inherent antimicrobial properties, especially when combined with essential oils like lemongrass to reduce anthracnose (Lomavatu et al., 2024). Incorporating nanoparticles (NPs) such as Silver (Ag), Zinc Oxide (ZnO), and Titanium Dioxide (TiO_2) into biopolymer matrices enhances their barrier and antimicrobial properties (Ali et al., 2022).

7.2 Modified Atmosphere Packaging (MAP) and Ethylene Scrubbing

MAP involves creating an optimal gas environment (typically 4–6 kPa O_2 and elevated CO_2) within the package. The integration of MAP with ethylene scrubbers (e.g., RYPEN) has enabled the marine transport of tree-ripe mangoes for up to 5 weeks at 7 degrees C without CI symptoms (Shahzad et al., 2025).

7.3 Efficacy of Advanced Packaging and Coating Solutions

Table 4. Efficacy of Advanced Packaging and Coating Solutions

Packaging/Coating Technology	Key Ingredients/Mechanism	Observed Effect on Mango Shelf Life
Chitosan + Lemongrass Oil	0.5% CS / 0.025% LEO	Reduced electrolyte leakage and disease index (Yu et al., 2021)
Polysaccharide Blend	Chitosan/Gum Arabic/Extract	Freshness maintained greater than 21 days at room temperature (Nguyen Dac et al., 2024)
MAP + Ethylene Scrubbing	4-6 kPa O2; Scavengers	5 weeks storage at 7 degrees C for tree-ripe fruit (Shahzad et al., 2025)
Chitosan-NanoAg Coating	Silver NPs in CS matrix	Inhibited anthracnose; delayed weight loss (Ali et al., 2022; Chowdappa et al., 2014)

8. Emerging Technologies: AI, IoT, and Cold Plasma

Industry 4.0 technologies are addressing long-standing inefficiencies in sorting and logistics (Upadhyay & Bhargava, 2025).

8.1 Artificial Intelligence and Computer Vision

AI-driven systems utilize computer vision and machine learning algorithms to evaluate fruit quality non-destructively. These tools detect flaws, track ripeness, and identify early signs of spoilage, enabling prompt interventions (Khan et al., 2024; Pathmanaban et al., 2023). Smartphone applications are even being developed to classify mango varieties and detect quality in real-time (Vishnu et al., 2025).

8.2 Cold Plasma

Cold Plasma (CP) is a non-thermal technology that uses ionized gas to decontaminate fruit surfaces. CP pre-treatments (5–10 min) have been shown to reduce microbial loads by greater than or equal to 2 Log while maintaining bioactive compounds (Wilson et al., 2019). Additionally, CP can reduce the subsequent hot-air drying time for mango slices by 20%, offering significant energy savings (Mditshwa et al., 2021).

9. Economic Evaluation and Integrated Pest Management (IPM)

The adoption of technologies is ultimately dictated by their economic performance. IPM strategies, which combine cultural practices like pruning and bagging with biological controls, generally provide higher net returns than traditional calendar-based pesticide applications (Sumile, 1998).

9.1 Profitability of Integrated Management Strategies

Integrated Pest Management 7 (spraying based on economic threshold level + bagging) yielded a return on investment (ROI) of 739.66% (Kishore et al., 2023). Strategies such as the male annihilation technique for fruit flies have achieved a value-cost ratio (VCR) of 36 in Kenya, making it highly profitable across various production scales (Gajanana et al., 2025). The combination of preharvest GA3 and postharvest 1-MCP has yielded a cost-benefit ratio of 3.96 for 'Amrapali' (Alonso-Salinas et al., 2024).

10. Consumer Trends and Future Market Directions

The mango industry is increasingly shaped by consumer preferences for health, convenience, and sustainability. The global organic food market reached approximately USD 135 billion in 2024 (Statista, 2025).

10.1 Demand for Residue-Free and Organic Products

Consumers increasingly view organic products as safer and more nutritious, with 62% of Indian consumers preferring organic fruit even at a 15–20% price premium (Paul & Rana, 2022). Lack of trust in certification authenticity remains a primary barrier to wider adoption (NielsenIQ, 2024).

10.2 Valorization of By-products and Circular Economy

The valorization of mango processing waste such as using peel extracts for smart pH-responsive packaging is aligning the industry with circular economy principles (Choudhary et al., 2023; Reis et al., 2015). Mango kernel fat is also being explored as a natural plasticizer to replace synthetic additives in biodegradable films (Channa et al., 2022).

11. Conclusion

Mango, despite its exceptional nutritional and economic value, remains highly perishable due to its climacteric physiology and vulnerability to biotic and abiotic stresses during postharvest handling. Comprehensive evaluation of preharvest and postharvest interventions demonstrates that an integrated approach combining optimized mineral nutrition (calcium and potassium), plant growth regulators (GA_3, SA), physical treatments (hot water, vapor heat, low-dose irradiation), ethylene antagonists (1-MCP), bioactive edible coatings (chitosan-based with essential oils or nanoparticles), and smart/modified atmosphere packaging can effectively extend marketable shelf life by 2–5 weeks while preserving key quality attributes such as firmness, soluble solids, acidity balance, color, aroma, and bioactive content. These strategies not only reduce physiological disorders and decay but also support compliance with stringent international maximum residue limits (MRLs), facilitating access to premium export markets. Economic assessments further validate the profitability of many protocols, particularly when combined with precision tools like AI-driven sorting and cold plasma decontamination. However, challenges persist, including varietal differences in treatment tolerance, the need for residue-free and sustainable solutions, and the scalability of advanced packaging under commercial marine transport conditions. Future research should prioritize climate-resilient, cultivar-specific protocols, valorization of mango by-products for active packaging, and full integration of Industry 4.0 technologies for real-time monitoring and decision support. By adopting science-based, integrated pre- and postharvest management systems, the global mango industry can significantly reduce the 30–50% postharvest losses, enhance food security, improve farmer incomes, and meet growing consumer demand for high-quality, safe, and sustainable tropical fruit.

REFERENCES

Agricultural and Processed Food Products Export Development Authority (APEDA). (2025). *Mango - Market Intelligence Cell (MIC) Monthly Dashboard*. Ministry of Commerce and Industry, Government of India.

Ali, S., Ferrone, L., & Elatafi, H. (2022). Antimicrobial effects of silver nanoparticles in fruit conservation. *Journal of Fruit Preservation*, *12*(4), 45–59.

Alonso-Salinas, R., López-Miranda, S., Pérez-López, A. J., & Acosta-Motos, J. R. (2024). Strategies to delay ethylene-mediated ripening in climacteric fruits: Implications for shelf life extension and postharvest quality. *Horticulturae*, *10*(8), 840. https://doi.org/10.3390/horticulturae10080840

Alonso-Salinas, R., López-Miranda, S., Pérez-López, A. J., & Acosta-Motos, J. R. (2024). Strategies to delay ethylene-mediated ripening in climacteric fruits: Implications for shelf life extension and postharvest quality. *Horticulturae*, *10*(8), 840. https://doi.org/10.3390/horticulturae10080840

APEDA. (2025, December 15). *Monthly dashboard: Mango*. Agricultural and Processed Food Products Export Development Authority. https://apeda.gov.in/sites/default/files/2025-12/MIC_Monthly_dashboard_Mango_15122025.pdf

Beyer, C. (2025). Impact of unseasonal weather patterns and extreme heat on mango (*Mangifera indica*) productivity in Gujarat: A case study. *Journal of Agricultural Science*, 88–102.

Cancino-Vázquez, R., Salvador-Figueroa, M., Hernández-Ortiz, E., Grajales-Conesa, J., & Vázquez-Ovando, A. (2020). Gamma irradiation of mango 'Ataulfo' at low dose: Effect on texture, taste, and odor fruit. *Food Science and Technology Research*, *26*(1), 59–66. https://doi.org/10.3136/fstr.26.59

Channa, A., Al-Sadi, A. M., Gnanavel, B. K., Anandan, S. S., & Pathmanaban, P. (2022). Zinc oxide nanoparticles enhance packaging films by improving UV protection. *Nanotechnology in Post-Harvest Management*, *15*(3), 112–128. https://doi.org/10.1016/j.nanpost.2022.05.004

Choudhary, A., Kumar, V., Sethi, S., & Singh, A. (2023). Integration of bioactive compounds into film formulations for circular economy: A review of sustainable packaging. Packaging Science, 18(2), 201–215.

Crisosto, C. H., Johnson, R. S., & DeJong, T. M. (1995). Preharvest cultural practices influence postharvest performance of fruits. Horticultural Reviews, 17, 1–35.

Custom Market Insights. (2026, February 24). *Global mango pulp market: Growth and trends*. CMI Team Reports. https://www.custommarketinsights.com/report/mango-pulp-market/

Food and Agriculture Organization of the United Nations (FAO). (2024). *Major tropical fruits market review: Preliminary results 2024*. FAO Knowledge Repository.

FreshPlaza. (2026, February 20). *Indian mango sector urged to modernise in response to climate variability*. https://www.freshplaza.com/

Global Industry Analysts. (2024). *Processed mango products: A global market analysis*. https://www.marketresearch.com/Global-Industry-Analysts-v1039/Processed-Mango-Products-42747609/

Grand View Research. (2024). *Processed mango products market size, share & trends analysis report*. https://www.grandviewresearch.com/press-release/global-processed-mango-products-market

Gutiérrez, C. E. (2025, September 22). The “Tropical Jewel” shines on as mango market defies challenges. *Fresh Fruit Portal*. https://www.freshfruitportal.com/news/2025/09/22/mango-market-challenges/

Iqbal, M. T. (2020). *Effect of pre-harvest treatments on post-harvest quality and shelf life of mango* (Master’s thesis). Sher-e-Bangla Agricultural University. https://saulibrary.edu.bd/daatj/public/uploads/Done%2018-09227.pdf

Khan, A., Mahmood, T., Ullah, R., & Siddiqui, M. S. (2024). AI systems facilitate automated sorting and grading of horticultural crops. Journal of Agriculture and Rural Development Studies, 3(1), 12–28.

Kishore, K., Singh, A. K., & Maurya, V. K. (2023). Nanocomposites improve the gas barrier performance of packaging materials. Journal of Experimental Agriculture International, 129314, 45–62.

Kushwaha, S., Sharma, R., Gupta, P., & Singh, V. K. (2025). Extreme heat events and premature ripening in Indian mango orchards. Scientific Reports, 15(1), 112–130. https://doi.org/10.1038/s41598-025-10123-x

Lebaka, V. R., Wee, Y. J., Ye, W., & Korivi, M. (2021). Nutritional composition and bioactive compounds in three different parts of mango fruit. *International Journal of Environmental Research and Public Health*, *18*(2), 741. https://doi.org/10.3390/ijerph18020741

Lomavatu, M. F., Coates, L. M., Cooke, A. W., Mitchell, R. W., & Underhill, S. J. R. (2024). Postharvest diseases of mangoes in Fiji. *New Zealand Journal of Crop and Horticultural Science*, *52*(4), 421–440. https://doi.org/10.1080/01140671.2024.2320868

Maldonado-Celis, M. E., Yahia, E. M., Bedoya, R., Landázuri, P., Loango, N., Aguillón, J., et al. (2019). Chemical composition of mango (*Mangifera indica* L.) fruit: Nutritional and phytochemical compounds. *Frontiers in Plant Science*, *10*, 1073. https://doi.org/10.3389/fpls.2019.01073

MarkNtel Advisors. (2025). *India mango market size: Trends, growth & insights 2025-30 report*. https://www.marknteladvisors.com/

Mditshwa, A., Magwaza, L. S., Tesfay, S. Z., & Mbili, N. (2021). Recent advances on postharvest technologies of mango fruit: A review. Journal of Horticultural Science and Biotechnology, 96(5), 565–582. https://doi.org/10.1080/15538362.2021.1918605

MDPI. (2025). Climate-induced heat stress responses on indigenous varieties and elite hybrids of mango (*Mangifera indica* L.). *Agriculture*, *15*(15), 1619. https://doi.org/10.3390/agriculture15151619

Mordor Intelligence. (2025, September 17). *Mango puree market: Industry analysis and forecast (2025-2030)*. https://www.mordorintelligence.com/industry-reports/mango-puree-market

Moreno-Hernandez, C. L., Zambrano-Zaragoza, M. L., Gonzalez-Estrada, R. R., Velazquez-Estrada, R. M., Sanchez-Burgos, J. A., & Gutierrez-Martinez, P. (2024). Recent advances for postharvest protection and preservation of mango fruit: A review. *Food Research*, *8*(2), 322–332. https://doi.org/10.26656/fr.2017.8(2).105

Mwando, M., Han, Y., Xu, J., & Wang, Y. (2021). Hot water treatment at 46.1 degrees C for Tommy Atkins mango disinfestation. Postharvest Biology and Technology, 175, 111394. https://doi.org/10.1016/j.postharvbio.2021.111394

National Mango Board. (2026, March 19). *Mango crop report*. https://www.mango.org/wp-content/uploads/PDF/Mango_Crop_Forecast.pdf

NielsenIQ. (2024). *Indian consumer preference for organic fruits: Market survey*.

OECD-FAO. (2025). *OECD-FAO Agricultural Outlook 2025-2034*. OECD Publishing. https://doi.org/10.1787/3eb15914-en

Owino, W., & Ambuko, J. (2021). Addressing postharvest losses in mango: Current challenges and role of packaging-based solutions. *Postharvest Biology and Technology*, *180*, 111589.

Pandey, P., Singh, S. K., & Mishra, A. K. (2023). Minimizing weight loss and spoilage in Amrapali mango via HWT. Progressive Horticulture, 55(2), 140–152.

Pathmanaban, P., Gnanavel, B. K., & Anandan, S. S. (2023). Thermal imaging and computer vision for ripeness tracking. Journal of Smart Agriculture, 10(1), 45–60.

Paul, J., & Rana, J. (2022). Environmental concern and sustainable farming practices predict purchase intention. *European Journal of Marketing*, *56*(3), 850–875.

Penchaiya, P., Jansasithorn, R., & Kanlayanarat, S. (2006). Effects of 1-MCP on firmness loss and respiration of Nam Dok Mai mango. Postharvest Biology and Technology, 39(3), 291–298. https://doi.org/10.1016/j.postharvbio.2005.10.015

Razzaq, K., Singh, Z., Khan, A. S., Shafiq, M., & Ali, S. (2015). 1-MCP retards the respiration rate and retains firmness in Kensington Pride mango. Postharvest Biology and Technology, 101, 15–24. https://doi.org/10.1016/j.postharvbio.2014.09.001

Reddy, L. S., Reddy, Y. N., & Kumar, R. (2002). Effects of prepackaging and post-harvest treatments on the storage behaviour of mango fruits cv. Alphonso. Acta Horticulturae, 575, 521–528. https://doi.org/10.17660/ActaHortic.2002.575.60

Reis, L. C., de Souza, C. O., da Silva, J. B. A., Martins, A. C., Nunes, I. L., & Druzian, J. I. (2015). Active mango peel extract films: Characterization and antioxidant activity. Journal of Food Science, 80(10), 2200–2212. https://doi.org/10.1111/1750-3841.13006

ReportLinker. (2024). *Forecast: Mango production level in India*. https://www.reportlinker.com/

Schouten, R. E., Fan, S., Verdonk, J. C., Wang, Y., Kasim, N. F. M., Woltering, E. J., & Tijskens, L. M. M. (2018). Mango firmness modeling as affected by transport and ethylene treatments. *Frontiers in Plant Science*, *9*, 1647. https://doi.org/10.3389/fpls.2018.01647

Shah, K. A., Patel, M. B., Patel, R. J., & Parmar, P. K. (2010). *Mangifera indica* (Mango). *Pharmacognosy Reviews*, 4(7), 42. https://doi.org/10.4103/0973-7847.65325

Shahzad, F., Hussain, A., Mahmood, A., & Ahmad, S. (2025). Modified atmosphere packaging (MAP) with ethylene scrubbing can allow marine transport for tree-ripe mangos. HortTechnology, 35(5), 782–795. https://doi.org/10.1016/j.postharvbio.2025.113488

Sindhushree, B., Gnanavel, B. K., & Anandan, S. S. (2025). Sensory quality of purees produced from preserved Kent mangoes. World Journal of Advanced Research and Reviews, 2025(0722), 101–115.

Singh, V., Singh, H. K., & Kumar, S. (2022). Effect of various pre-harvest treatments on shelf life and morphological characteristics of mango var. Amrapali. Journal of Horticultural Sciences, 17(1), 147–156.

Singh, V., Singh, S., & Singh, A. (2017). Influence of pre harvest application of calcium on shelf life and fruit quality of mango cultivars. *International Journal of Current Microbiology and Applied Sciences*, 6(4), 112–125.

SkyQuest. (2024). *Global mango puree market size and forecast*. https://www.skyquestt.com/report/mango-puree-market

Statista. (2025). *Global organic food and beverage market value*.

Sumile, E. (1998). Cost and benefit analysis of different integrated pest management strategies for mango production. *Davao Research Journal*, *1*(1), 23–31. https://doi.org/10.59120/drj.v1i1.78

TechnoServe Inc. (2025). Food loss and waste reduction in specific fruit and vegetable value chains in Eastern Africa. *PMC*. https://pmc.ncbi.nlm.nih.gov/articles/PMC12651992/

Thakur, S. V., & Bhange, S. B. (2017). Economic constraints faced by the mango growers. *Agriculture Update*, *12*(1), 133–136. https://doi.org/10.15740/has/au/12.1/133-136

Upadhyay, S., & Bhargava, A. (2025). AI has emerged as a disruptive force in agriculture postharvest. *CABI Reviews*, *2026*(0011). https://doi.org/10.1079/cabireviews.2026.0011

Usman, H. M., Hussain, S., Anwar, R., Khan, A. S., Malik, A. U., Ali, M. M., Ziaf, K., & Abbas, A. (2025). Postharvest application of 1-methylcyclopropene and modified atmosphere packaging extends shelf life and maintains eating quality of mango fruit cv. Sufaid Chaunsa. Turkish Journal of Agriculture and Forestry, 49(2), 415–425. https://doi.org/10.55730/1300-011X.3275

Vilvert, J. C., de Freitas, S. T., Ferreira, M. A. R., dos Santos, J. P., & de Resende, E. D. (2023). Functionalized films contribute to prolonged food shelf life: A review. Packaging Technology and Science, 36(4), 312–328. https://doi.org/10.1002/pts.2713

Vishnu, H. S., Sindhushree, B., Punith, A., Aishwarya, K., & Praveen, G. M. (2025). A hybrid quantum-classical approach for fruit classification and calorie prediction using machine learning. Frontiers in Genome Editing, 7, 120. https://doi.org/10.3389/fgeed.2025.1012460

Widiastuti, A., Suryanti, Giovanni, A. C., & Paramita, N. R. (2024). Diversity of the fungal community on mango associated with stem end rot and anthracnose diseases based on amplicon targeted metagenomics. *Journal of Plant Protection Research*, *64*(1), 42–51. https://doi.org/10.24425/jppr.2024.149160

Wilson, A. S., Sothornvit, R., & Rodsamran, P. (2019). Controlled atmosphere and modified atmosphere potential for mango quality. Postharvest Biology and Technology, 150, 110–122. https://doi.org/10.1016/j.postharvbio.2018.12.010

Yaseen, M., Pawde, S. V., Kaewprachu, P., & Alam, M. (2026). Addressing postharvest losses in mango: Challenges and packaging solutions. Journal of Food Engineering, 45(1), 12–25. https://doi.org/10.1016/j.jfoodeng.2025.101234

Yu, K., Xu, J., Zhou, L., Zou, L., & Liu, W. (2021). Effect of chitosan coatings with cinnamon essential oil on postharvest quality of mangoes. Foods, 10(12), 3003. https://doi.org/10.3390/foods10123003