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Causes and strategies for mitigating postharvest losses within the mango supply chain

Mawela Aluthgedara Ralala Madhushika Pushpamali Jayathilaka[1], Jayalathpurage Sasanka Jayalath[2], Wickrema Arachchige Harindra Champa[3,*] and Thushanthi Perera[1]

1, Department of Nutrition & Dietetics, Faculty of Livestock, Fisheries & Nutrition, Wayamba University of Sri Lanka, Makandura, Gonawila, 6017, Sri Lanka
2, Department of Aquaculture & Fisheries, Faculty of Livestock, Fisheries & Nutrition, Wayamba University of Sri Lanka, Makandura, Gonawila, 60170, Sri Lanka
3, Department of Food Science & Technology, Faculty of Livestock, Fisheries & Nutrition, Wayamba University of Sri Lanka, Makandura, Gonawila, 60170, Sri Lanka

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***Corresponding author:**
Department of Food Science & Technology, Faculty of Livestock, Fisheries & Nutrition, Wayamba University of Sri Lanka, Makandura, Gonawila, 60170, Sri Lanka.

Email: harindra.bsu@wyb.ac.lk

A B S T R A C T

Purpose: Mango (*Mangifera indica* L.) is a globally choicest fruit crop facing substantial pre- and post-harvest challenges, resulting in significant postharvest losses worldwide. These losses impact food security, economic growth, and the sustainability of the mango supply chain. This systematic review explores existing literature on causes and mitigation strategies of postharvest losses of mango supply chain providing a comprehensive overview of the sector. **Findings**: Mango faces significant postharvest losses due to damage caused by faulty handling practices, diseases and pest infestations. Key challenges include inadequate packaging, poor storage, and inefficient transport facilities alongside insufficient knowledge dissemination mechanisms, disorganized marketing systems, and limited government interventions leading to exacerbate losses. Providing improved mango varieties, investing in infrastructure, strengthening stakeholder collaboration, enhancing knowledge dissemination and establishing mango-based value-added industries are critical for the sustainability of the sector. Adopting standardized harvest maturity indices, consumer friendly methods for pest and disease prevention, and applying edible coatings to maintain fruit quality play a pivotal role for supply of quality mangoes to fresh and processed markets. The findings emphasize immediate necessity for collaboration between government, non-government, and private sector companies to make available funds for research and startups in mango sector. **Limitations:** This review is limited by the availability of region-specific data and variations in postharvest loss assessment methodologies. **Directions for future research:** Future research should focus on the development of non-destructive techniques to determine correct harvest maturity stage of mango precisely, advanced technologies to monitor and manage the losses, such as digital tracking systems, smart packaging solutions, and eco-friendly preservation techniques.

Keywords:
Food loss, Food security, Fruits, *Mangifera indica*, Marketing systems

INTRODUCTION

Mango (*Mangifera indica* L.), which is known as "king of fruits", is one of the most cherished and economically significant fruit crops due to its delectable flavor, vibrant color, and nutritional richness. Mango is the second most cultivated fruit crop in the world. It is also one of the most popular and widely consumed fruits in Sri Lanka. It is grown on a commercial scale in more than 90 countries worldwide. India is the main global producer of mango with 26.3 million Metric Tonnes (MT), followed by Indonesia (4.1 MT), China (3.8 million MT), Pakistan (2.8 million MT), Mexico (2.5 million MT) and Brazil (2.1 million MT) are the other major producers in the world (Anon, 2025).

Mango is grown in 29,229 ha of area with a production of 529.5 million fruits in Sri Lanka. However, the biggest challenge to the mango sector is the poor quality of the fruit, which causes significant post-harvest losses. It has been reported that in Sri Lanka postharvest losses of mango occurring during the supply chain range from 25% to 45% (Herath et al., 2021).

Pre-harvest losses occur due to various factors, including the adverse effects of diseases, pests, and unpredictable climatic conditions, all of which hinder optimal mango production. (González-Fernández & Hormaza, 2020). Such losses occur even before the fruits reach maturity, leading to reduced yields and economic setbacks for farmers.

Post-harvest losses refer to losses (product not acceptable/ usable) and waste (usable product thrown away) that occur after food crops were harvested. They occur along the entire value chain, from farm handling and packaging to processing, distribution, and transport to wholesale and retail marketing. (Kitinoja et al., 2018). These losses not only diminish the overall availability of mangoes but also undermine the sustainability of agricultural practices and exacerbate food insecurity. (Kasso & Bekele, 2018). Minimizing postharvest losses is imperative to secure food for a nation as losses reduce the amount of available food (Kitinoja & Kader, 2015). According to Amaakaven et al. (2024) postharvest losses of mangoes have been shown to affect the socio-economic wellbeing of mango growers, by limiting their ability to access basic needs such as health care services, nutritious food, quality housing, education and clothing at Ushongo Local Government Area of Benue State in Nigeria. Minimizing postharvest losses is more sustainable and environmentally sounds than increasing production areas to compensate these losses. The increased attention afforded to postharvest in recent years has come through the awareness that faulty handling practices after harvest can cause large losses of produce and wastage of farming inputs (seeds/planting materials, fertilizer, agrochemicals) and natural resources (land, water, energy). Informed opinion now suggests that increased emphasis should be placed on conservation after harvest rather than striving to further boost crop production as this would appear to offer a better return for the resources spent on food production.

Implementing value-addition technologies would reduce postharvest losses further, giving growers high returns for their crops. Mangoes can be processed into various products. For instance, unripe mangoes can be processed into pickles, preserves, desserts, chutneys, and dehydrated mango powder, whereas ripe mangoes can be processed into dried or osmotically dehydrated mango chips, wine, juice, concentrate, jam, jelly, syrup, and canned mango (Owino & Ambuko, 2021). The introduction of processing methods that can maintain nutritional value, rheological properties, and other sensory qualities of fresh mangoes can help to mitigate postharvest losses (Herath et al., 2020).

In this context, the present review article aims to explore multiphase causes of post-harvest losses of mangoes and shed light on the innovative reduction strategies that have the potential to revolutionize production and distribution.

MATERIALS AND METHODS

Strategy for literature search

This review conducted a thorough search for relevant literature across five databases: Google Scholar, Science Direct, PubAg, AGRICOLA, and SEMANTIC SCHOLAR. Most of the keywords came from previously released research. In line with the primary objective of this study, the inclusion of additional keywords aimed to identify the main factors contributing to post-harvest loss & waste and potential mitigation measures. Articles were searched across electronic databases using the list of keywords ("mango", "losses ", “waste” “reduction strategies", "novel techniques ", and "eco-friendly techniques").

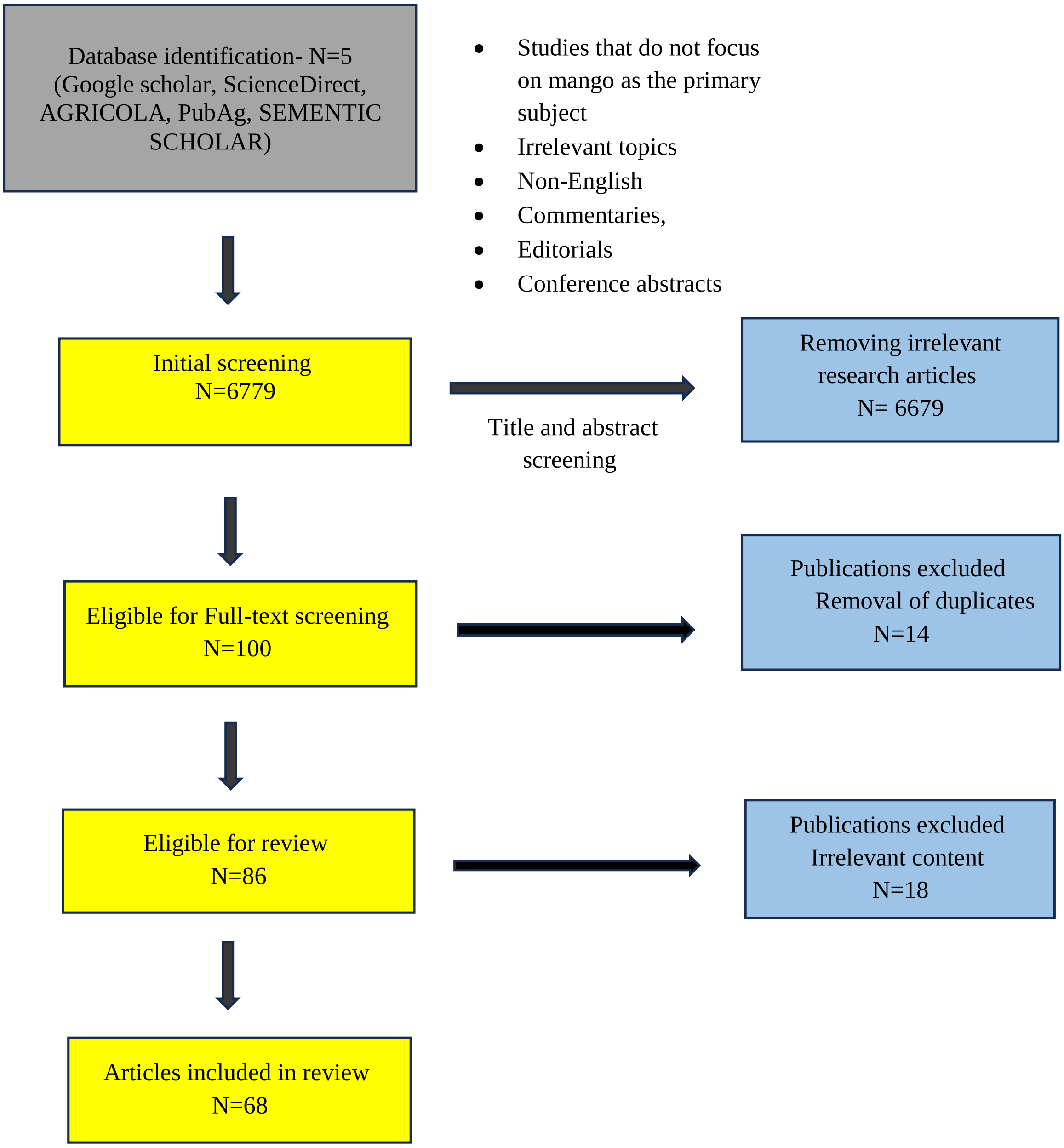

Fig. 1. PRISMA flowchart.

Criteria for inclusion/exclusion

Using a range of inclusion and exclusion criteria, relevant research papers were selected for the systematic review. Inhere; causes for mango post-harvest loss and reduction strategies-related research documents (Research articles, Case studies, Field studies, and Surveys) published from January 2019 to September 2023, published in English, were used. Only studies that specifically focused on mango as the primary subject of the post-harvest loss analysis were included.

Literature selection process

The following four stages comprised our literature selection process, which was based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis Approach) framework: (i) identifying articles to be reviewed (ii) screening the studies for review, (iii) figuring which studies are eligible, and (iv) selecting which studies to include in the systematic review.

In the initial selection stage, articles were identified using five distinct electronic databases, and then the articles were screened for selection. A total of 6779 (N=6779) articles were identified. Articles published more than 5 years ago, studies that do not focus on mango as the primary subject, studies that do not address the causes of post-harvest loss of mango and mitigation strategies, commentaries, editorials, conference abstracts, non-original research articles, newspaper articles, biographies, autobiographies, case reports and articles published in non-English were excluded. Following the application of exclusion criteria, 6679 (N=6,779) documents were removed. Subsequently, 100 (N=100) articles underwent further full-text screening. Utilizing the Mendeley reference manager to eliminate duplicate articles (N=14) and excluding irrelevant content (N=35) which is mentioned under exclusion criteria in Figure 1, a total of 51 (N=51) documents were deemed suitable for inclusion in this systematic review. Before being included in the final, the entire text of every research study that was given full inclusion was examined.

Results and Discussion

Primary causes of post-harvest loss

Mechanical

Harvesting practices, transportation methods, and packing techniques significantly contribute to mechanical damage within the mango supply chain. In a study focused on determining the optimal harvest time for 'Uba' mangoes based on textural properties in Brazil, it has been reported that the susceptibility of fruits to mechanical damage, especially during handling and transport, leads to potential compromise in structural integrity and skin firmness (Da Silva et al., 2023). The authors reported that approximately 72.5% practiced handpicking, 17.5% utilized shaking techniques, and 10% employed picking poles to harvest mangoes. The latter two practices caused considerable mechanical damage to harvested mangoes diminishing postharvest life and fruit quality because of increased respiration rates, ethylene production, water loss, and susceptibility to microbial deterioration (Grima et al., 2021). Similar results have been reported in Southern Ethiopia emphasizing that harvesting practices such as dropping fruits from tall mango varieties and use of harvesting sticks significantly contribute to mechanical damage thus postharvest losses in mangoes (Gutema & Tadesse, 2022). A survey conducted in Batticaloa district of Sri Lanka for the varieties Karthakolomban and Willard highlighted that mechanical injuries occurred during harvesting of mango often led to the abandonment of damaged mangoes in the field. Thus, they act as a potential source of inoculum for various disease infections (Thayalan et al., 2020).

A study conducted in Southern Ethiopia by Gutema and Tadesse (2022) highlighted the impact of inappropriate transportation in aggravating mango postharvest losses within the supply chain. The research revealed that approximately 30.0% of growers utilize trucks for transportation without proper ventilation facilities. Furthermore, 42.5% use animals (donkeys, mules, and horses) to transport produce to nearby village markets. The authors emphasized that these methods subject fruits to mechanical damage due to rough handling when loading, unloading, and transporting over rough roads.

Packaging practices, as highlighted by Gutema and Tadesse (2022), significantly contribute to postharvest losses. Among respondents, 47.5%, 37.5%, and 15.0% utilize sacks, baskets, and plastic crates as mango packaging containers respectively. The authors noted that densely packed fruits within these containers/packages limit gas exchange. It is also noted that there is a failure to sort them based on ripeness status. Consequently, this packaging approach expedites the ripening process, leading to shorter shelf life and increased postharvest losses.

Biological

Mango is infected by many diseases and disorders due to their perishable nature. Significant challenges in mango production in Bangladesh have been noted particularly focusing on insects and diseases (Sampa et al., 2019). Their findings revealed that 91% of surveyed farmers observed disease infection as a major constraint in mango cultivation, with only 9% considering it as a minor issue. Anthracnose and stem-end rot are the two most economically significant postharvest diseases in mango production. Disease infections of anthracnose and stem end rot are caused by *Colletotrichum gloeosporioides* and *Lasiodiplodia theobromae*, respectively. Infection of anthracnose disease occurs during the pre-harvest phase, which is called latent/quiescent infection, where the disease symptoms are visible during the post-harvest phase. The fungus responsible for anthracnose often remains dormant on green fruits, manifesting and proliferating during handling and shipping because when the fruit ripens loses its natural resistance. In contrast, fungus causing stem end rot is often referred to as direct or wound pathogen as the injuries to the pedicel or peel facilitate its invasion.

The prevalence of postharvest diseases poses significant challenges within the mango supply chain. Anthracnose emerged as the most prevalent postharvest disease, affecting approximately 50% of ripe mangoes (Girma et al., 2021). The disease symptoms are initiated as localized small, dark brown circular spots and increase rapidly in size and form dark depressed lesions in ripened fruits. The next most significant disease was bacteria spots (45%) while powdery mildew accounted for 5%.

Pathogenic diseases were identified as primary contributors to quality losses in mangoes (Thayalan et al., 2020). A study conducted by Keno and Wakgari (2022) in Eastern Ethiopia showcased a higher infestation of white scale insect in mango. Alam (2019) reported that 100% of respondents identified fruit flies as a serious pest that impairs mango production and export. White scale insects are one of the most important insect pests that affect mango causing a loss of 69% in the Western Ethiopia and they damage both leaves and fruit (Fufa & Hailu, 2024). Tarekegn and Kelem (2022) findings highlighted a 7% loss of mangoes are due to diseases and pest attacks in the study area of Gamo Zone, Southern Ethiopia.

Secondary causes of post-harvest loss

Lack of knowledge/skills and documentation

A study conducted in Maharashtra state in India noted that inappropriate post-harvest handling practices contribute to an increased post-harvest loss rate (Sawant et al., 2019). There is a crucial need to gradually reduce post-harvest loss rate to meet the demand from industry and export. Observations of this study emphasize the importance of dissemination of knowledge and appropriate technology for implementing effective post-harvest handling practices. The study found that a high level of knowledge (93%) was observed among respondents in judging the maturity indices of fruits for harvesting. The knowledge level about post-harvest handling practices, such as removal of field heat, handling in the pack house, grading, etc., was 86% among respondents.

In Thailand, mango growers were found lack in skills to identify anthracnose infection, as its symptoms cannot be visually detected during the unripe stages (Matulaprungsan et al., 2019). The study also highlighted that mango growers, despite possessing certification of good agricultural practices (GAP), have poor awareness and understanding of material traceability. For instance, 98% of the growers did not recognize the importance of material traceability, and a lagging tracking system hindered their ability to identify specific mango lots from different production areas. A small percentage of mango growers (11%) consistently documented their activities, utilizing the recorded information to calculate both income and expenses on their farms. Furthermore, Asfaw et al. (2020) focused on the management of insect pests and diseases of mangoes in Jimma Zone, Southwest Ethiopia. The study revealed that 94% of households had no information on how to manage diseases and insect pests of mangoes. This finding suggests a significant gap in knowledge regarding the management of pests and diseases in mango orchards.

A study conducted in Bangladesh highlighted that the mango growers primarily base their harvesting decisions on ripening stages of the fruit, with a few considering market demands. However, there is a lack of scientifically proven fruit maturity standards for harvesting mangoes among growers in developing countries (Yusuf Ali et al., 2020). In contrast, the growers in developed countries are provided with equipment and tools that can non-destructively detect the optimum harvest maturity of the fruit onsite. Consequently, most growers harvest fully ripe fruits, while some collect partially ripe or a mixture of ripe and unripe ones. Harvesting mangoes at an immature stage leads to issues such as shriveling of the fruit peel due to high water loss, latex burning stains on the peel resulting in poor cosmetic appearance and inferior quality. Similarly, overripe ones have a shorter postharvest life and altered biochemical parameters, contributing to both quantitative and qualitative losses.

Lack of awareness about correct harvesting and subsequent handling practices

Most farmers (60%) in Southern Ethiopia picked their fruits in the afternoon because they believed that high temperatures hastened the ripening process. Obviously, majority of fruits should be picked in the early hours of morning when there is low temperature and should be kept under shade to reduce post-harvest loss. During harvesting, the crew commonly gathers both mature and immature mangoes together, making them vulnerable to high latex contamination. The survey revealed that local collectors sometimes only sort mature mangoes, discarding the immature ones as waste. Despite available improved harvesting tools, such practices are not widely adopted by mango producers thus conventional methods like shaking trees or using picking sticks prevail in Southern Ethiopia (Grima et al., 2021).

In a study by Tarekegn and Kelem (2022), 73% of respondents identified post-harvest losses and quality decline during handling. Lack of access to updated harvesting technologies led to non-compliance with recommended equipment, exacerbating post-harvest losses. This study underscores that the highest losses occur at the harvesting stage due to the absence of improved harvesting technologies. Another study carried out on post-harvest losses of Alphonso mango in the South Konkan region of the Western Coast in India shows that the largest quantity of mangoes is lost due to damage occurred at harvesting. Involvement of many intermediaries in the system results in further wastage due to repeated handling (Kshirsagar et al., 2019). Furthermore, a study conducted in Bangladesh underscores the impact of poor harvest and handling practices, causing various blemishes on fruit skins that significantly affect the quality and consumer acceptability of the produce (Yusuf Ali et al., 2020).

A study conducted in Batticaloa district of Sri Lanka by Thayalan et al. (2020) highlighted various challenges in mango harvesting techniques. The practice of using a long pole with hooks at the end without a net often results in dropped and injured fruits. In some instances, poles with net baskets attached are employed for picking fruits, while in other cases, shaking trees to drop fruits, which are then gathered from the ground, leads to significant damage and losses. Furthermore, the authors reported that the absence of a specific recommended time for harvesting results in fruits being picked from late morning to evening, causing issues like high water loss, latex contamination and shrinkage due to higher temperatures. The existing harvesting system records approximately 10% bruise and 6% other physical damage to the fruit during this stage

Inappropriate packaging

Inadequate packaging contributes significantly to post-harvest losses. According to a study by Girma et al., (2021) in Southern Ethiopia, farmers commonly use various materials to expedite fruit ripening. The majority (70%) employed a method involving grass and newspapers to cover mangoes, exposing them to sunlight, with an additional 25% using only newspapers. A smaller percentage (5%) reported using banana leaves for this purpose. However, the study found that more than 50% of mangoes exhibited damages at ripening due to utilizing inappropriate covering materials.

Inadequate storage

According to Parihat et al. (2022), in a study carried out in Siraha, Nepal, a notable deficiency in storage mechanisms for mangoes was observed. Cold storage, a common method for keeping mangoes, was absent in most of the developing countries. Wholesalers predominantly stored mangoes in structures/rooms having poor ventilation, while half of the retailers opted for open-sky storage. Only 19% of retailers utilized refrigerators for storage. Lack of proper storage practices could contribute to challenges in mango trading, particularly during the high-price periods at the beginning and end of the season, as well as during peak times when prices are low.

A survey carried out in the Gamo Zone, Southern Ethiopia, shows that 36% of the respondents quoted issues of poor collection and storage facilities in the mango supply chain as significant factors contributing to mango loss and quality deterioration (Tarekegn & Kelem, 2022). Storage-related losses ranked as the second-highest concern in mango handling. A substantial portion of harvested mangoes frequently spoil due to the absence of refrigeration facilities at market centers. These mangoes are commonly stored in bags that hasten the ripening process. Farmers interviewed in the Ashanti Region of Ghana revealed a lack of attention to the types of bags used for mango storage (Kyei & Matsui, 2019).

According to a survey conducted in Sri Lanka, harvested mangoes are typically stored on the floor in small rooms or corridors at small-scale farms. Before storage, mangoes on the floor are commonly covered with polypropylene sacks or straws. Generally, mango storage lasts only 2 to 4 days. Findings from questionnaires indicated that up to 5% of mangoes are discarded post-storage, primarily due to stem end rot. However, the study also found that after 4 days of storage, mango losses escalated significantly, reaching approximately 40% due to diseases, impact of handling and physiological disorders (Thayalan et al., 2020).

3.2.5 Inadequate transportation facilities

Many of the developing countries including Sri Lanka use mixed transportation i.e. both fruits and vegetables are transported together in the same vehicle without considering their temperature or ethylene compatibility. Mangoes are vulnerable to damage from the weight of other fruits/cartons and are sensitive to ethylene gas emitted by other fresh commodities during transportation. In a survey conducted in Siraha, Nepal, encompassing producers, wholesalers, and retailers, diverse transportation methods for mangoes were observed. Among producers, the majority favored pickups (47%), followed by bicycles (30%), motorcycles (17%), and automobiles (7%) for transporting mangoes. Contrarily, wholesalers predominantly used trucks and pickups, with 40% opting for trucks and the remaining 60% relying on pickups, primarily due to the necessity of transporting larger quantities. Among retailers, transportation preferences varied, with 37% utilizing pickups, 28% employing bicycles, 22% using motorcycles, and 12% relying on automobiles. The study highlighted pickups as the most common transportation mode, while trucks were less frequently used. The findings underscore the necessity for enhanced transportation facilities to curtail transportation losses and uphold mango quality for consumers. Particularly, improvements in transportation methods for wholesalers dealing with larger quantities could significantly reduce losses and sustain overall mango quality in the market (Parihat et al., 2022).

A study conducted in Southern Ethiopia reported that 55% of respondents used 'Ahiya Gari' (a type of cart), while 32% utilized women's backs to transport both packaged and unpackaged mangoes. In contrast, 12% relied on men's shoulders to convey the fruits to collection sites and nearby markets. However, this mode of transport might expose the fruits to physical injury, such as abrasion damage, during transit. Generally, mangoes suffer damage due to rough handling, including throwing, excessive stacking, and vehicle overloading, potentially increasing losses across the supply chain. Approximately 67% of farmers reported issues with rough handling during loading and unloading, while 32% quoted an unsuitable road network as affecting fruit quality during transportation (Girma, 2021).

Marketing channel

Kshirsagar et al. (2019) carried out a study to investigate the effect of different distribution channels on post-harvest losses of mango variety Alphonso along the supply chain. Channel-I, involving the producer, wholesaler cum-commission agent; wholesaler, and retailer, incurred a total loss of up to 28%. Conversely, Channel II, comprising the producer, wholesaler, and retailer experienced estimated post-harvest losses of 25%. In Channel III, where producers sold fruits to village merchants for processing, the losses were recorded at 7%. Channel-IV, involving the producer selling Alphonso mangoes directly to consumers through retailers, registered post-harvest losses of 16%. This indicates that when the intervention of middlemen is high, the losses go up, emphasizing the importance of implementing well-organized short distribution channels. Introducing value addition also plays a crucial role in minimizing postharvest losses, as evidenced by the minimum losses in Channel III. Hence, optimizing distribution strategies by reducing the number of intermediaries is crucial to decreasing post-harvest losses and enhancing fruit quality.

Inadequate marketing systems

A study conducted in Durg district of Chhattisgarh, India, found that total post-harvest losses of mango at the market level were 100%, with contributions from wholesaler and retailer levels being 64% and 36%, respectively. Transportation at the wholesale level accounted for the maximum share of losses among different marketing operations, such as loading and unloading (1.02%), sorting and grading (15.54%), packaging (6.18%), and storage (4.60%), contributing 33.23% to the total losses at the market level. Sorting and grading had the second maximum contribution, representing 15.54% of the total losses at the market level (Savaria et al., 2020). Constraints that influence mango marketing can be divided into two as intrinsic and extrinsic factors. Intrinsic factors include seasonality of production and perishable nature of the fruit, while the extrinsic factors include inadequate grading and standardization, lack of storage facilities, absence of uniform pricing, inadequate market information, high transportation costs, lack of processing plants, and a high level of competition (Chiebonam et al., 2020). Lack of capital and inefficient care during harvesting and transport are the main secondary factors causing mango postharvest loss (Girma et sl., 2021).

In Siraha, Nepal 42% of mangoes produced were traded within the district and consumed locally (Parihat et al., 2022). Highest percentage of mango was supplied to Kathmandu (21%), followed by Pokhara (16%), Dharan (14%), and 7% to other districts. The study suggested a need for promoting mango exports emphasizing collaboration among producers and traders. This study highlights the lack of adequate market facilities for mango trading. Most retailers left their fruits under the open sky covered by some locally available material of tarpaulin sheet to prevent animals like cows eating the fruits at night. There was a notable absence of proper infrastructure for marketing activities in most of the developing countries.

Government regulations and legislation

Lack of awareness about the significance of postharvest losses and, therefore, the suboptimal intervention of the respective government authorities is another important aspect that contributes to high losses in mango supply chain. A study carried out by Chiebonam et al. (2020) in Benue State, Nigeria, emphasizes the need for strategic interventions by the government to mitigate postharvest losses in the mango sector. The study recommends establishment of efficient storage facilities to encourage large-scale purchases of produce and suggests provision of packing houses at both production sites and market centers to maintain quality along delivery channels.

Absence of information access for farmers from governmental organizations, extension agents, research centers, and media have been identified as another important area that deserves attention (Asfaw et al., 2020). Their findings emphasize the necessity for collaboration of government, non-governmental organizations, and various stakeholders to disseminate knowledge and technology among farmers efficiently. This collaborative approach is seen as essential for educating farmers on effective practices to manage the orchards and protect the crop from insect pests and diseases. Such awareness initiatives are anticipated to enhance the mango sector, ultimately improving the livelihoods of orchard owners and contributing to the national economy.

Gap between government policies and their inefficient implementation in horticulture sector are affecting negatively to the optimum functioning of mango supply chain. Despite the formulation of policies and laws, there is a notable lack of proper implementation. Absence of a dedicated mango production and marketing program and the government's failure to encourage farmers to engage in mango cultivation have been identified as two major constraints that affect the progress of the sector. This emphasizes the need for more effective and proactive government measures to support mango cultivation and marketing practices among farmers (Parihat et al., 2022).

Mitigation strategies

Maintenance of mango fruit quality during the supply chain is a challenge primarily found worldwide because there is a lack of readily available or adaptable post-harvest technologies. The following content of this review offers a thorough overview of the various pre- and post-harvest methods currently applied to mango fruit to mitigate the aforesaid post-harvest losses.

Adoption of harvest maturity indices and appropriate field handling practices

Picking mangoes at their ideal maturity stage helps prevent spoiling during transportation and storage and harvesting them at the correct maturity stage greatly reduces post-harvest losses. A timely harvest reduces decay, bruises, and loss of sensory attributes, maintaining fruit quality and prolonging its shelf life. According to a study conducted in Canary Island, Spain for cv. "Osteen" mango suggests the number of days from full bloom (length of the fruit's stay on the tree) is the primary information to consider when deciding the optimum harvest maturity stage for commercial use of the cv. "Osteen" (Gianguzzi et al., 2021). Moreover, various other non-destructive (degree of raising shoulders, size, shape, and color of the fruit as per the variety) and destructive (dry matter, total soluble solids, titratable acidity, fruit firmness or hardness) parameters are used to determine the correct harvest maturity stage. Research performed by Kailaku et al. (2023) indicated that mangoes cv. "Arumanis" harvested between 105 and 108 days after flowering (DAF) are suitable for nearby markets but for long-distance transportation involving both refrigerated and nonrefrigerated vehicles, harvesting between 90 and 95 DAF is advised.

In a study carried out in Adamawa State of Nigeria demonstrated that large fruits picked by a picker had superior fruit texture, color, and marketability after being stored (Ahmed, 2019). It is advised to carefully harvest mature mangoes without letting them fall to the ground to improve the fruits' sensory qualities. Reduced sap damage in cv. "Carabao" mangoes have been achieved by harvesting fruit later in the day, cutting at the abscission zone, and washing them thoroughly (Secretaria et al., 2021). Mango cv "Shelly" harvested with a short stem reported less stem end rot disease incidence because of the presence of non-pathogenic communities over pathogenic fungi in the fruit endophytic microbiome (Galsurker et al., 2020). This study evidenced that mangos with short stems are better because they have more antioxidants and antifungal activity, which preserves a healthier microbial community and lowers postharvest incidence of stem end rot.

Post-harvest strategies

Pre-storage treatments

Several nonchemical and chemical pre-treatment techniques can help lower mango post-harvest losses. A few efficient techniques are heat treatment and chemical treatments of different kinds. These methods aid in preserving fruit quality during storage and transportation, lowering spoilage, and increasing shelf life.

Physical treatments

Heat treatment

Heat treatment is an effective method for reducing post-harvest losses of mango and is a non-chemical post-harvest treatment. Mango fruit's reaction to heat treatment is highly dependent on several variables, such as cultivar, temperature, and exposure duration (Mwando et al., 2021). Mangos are often treated with the following heat treatments: (i) Hot water treatment (HWT) and (ii) Vapor heat treatment (VHT) (Ntsoane et al., 2019). HWT and VHT are two of the more popular and less expensive heat treatments.

Management of postharvest disease has made extensive use of HWT. Application of HWT is straightforward and uncomplicated. The general idea is to immerse mango fruits in hot water at 48 to 55 °C for 4 to 60 minutes, depending on the cultivar and the types of disease infections (Le et al., 2022). With this technology, fungal pathogens and insects are controlled in the harvested mango by immersing the commodities in mild hot water (between 50 and 55 °C) for a specified period (Patel et al., 2023).

According to Mwando (2021), the most heat-tolerant stage of fruit fly - *Bactrocera dorsalis* in mango cv. "Tommy Atkins" died completely when treated with hot water at 46 °C for 72 minutes. HWT at 46 °C for 86 min resulted in complete mortality of the most heat-tolerant stage of *B. dorsalis* in cv. "Tommy Atkins," and there was no compromise on the fruit quality (Ocitti et al., 2021). Mangoes with HWT showed a longer shelf life and better quality because they exhibited lower physiological weight loss (PWL) and spoilage loss) (Pandey et al., 2023). After 15 days, mango fruit treated with HW at 55 °C for 1 and 3 minutes showed no distinct change in weight loss, firmness, TA, or TSS and the peel color remained green (Oladele & Fatukasi, 2020). Biochemical (TA, TSS, total carotenoids, β-carotene content, total phenolics, total antioxidant activity, vitamin A, crude protein, total carbohydrates, total sugars, crude fat, aromatic volatiles) and biophysical (moisture content, dry matter, firmness, electrolytic leakage, and weight) quality attributes of mango fruits were not adversely affected by HWT (46 °C for 68, 75, and 84 min). The fruit quality remained unchanged by HWT duration of up to 84 minutes, although 68 minutes was the ideal (Ndlela et al., 2022). The other heat treatment technique used in the post-harvest management of mangos is VHT. Use of VHT (52 °C - 3 min, 55 °C for 3 min) retained the peel color of mango (Oladele & Fatukasi, 2020). Table 1 presents a list of published research articles on the HWT and VHT for mangoes.

Irradiation

Irradiation is a technique used to keep fruits and vegetables fresher longer by killing pests and decay-causing microorganisms. The quality and nutritional value of the produce are preserved, but food safety guidelines and regulations must be followed. In addition to delayed ripening and senescence, irradiation also reduces the number of microorganisms and insects in mangoes. Mango cv. "Sensation" treated with gamma rays at the dose of 300 Gy stored for longer periods by using irradiation it has effectively reduced infestations (Din et al., 2021).

Chemical treatments

Edible coating

Edible coating can be considered a chemical treatment used to preserve fresh produce quality and post-harvest life. These coatings are made of synthetic or natural materials that are applied to the surface of the fruit as a thin film that suppresses microbial growth retard the rate of respiration and water loss. When the waxy cuticle of fresh fruit is compromised during handling, the application of coatings could restore it and serve as a natural barrier in places where the produce's cuticle has been removed. Edible coatings or films provide several advantages, including maintaining antioxidant activity, extending shelf life, lowering mass loss and respiration rate, and keeping treated fruits firm and colorful (Bambalele et al., 2021). These coatings are often made from natural materials like carbohydrates, proteins, and lipids. On fresh fruits, several edible coatings, such as those based on carbohydrate polymers like chitosan, cellulose, carboxymethyl cellulose (CMC), plant-derived compounds like aloe vera gel, gum Arabic, mineral oils, and proteins, lipids & plant or animal-based waxes have been applied to maintain the post-harvest quality (Champa & Weerasooriya, 2025).

Table 1. Effect of heat treatments on post-harvest quality of mango.

Treatment	Mango cultivar	Key findings	Study region	Reference
HWT (52 ºC for 10 min, 50 ºC for 20 min, 48 ºC for 20 min,)	Alphanso, Totapuri, Kesar, Sonpari and Langar	Control of post-harvest diseases and fruit flies	India	Patel et al. (2023)
HWT (46 ºC, 72 min)	Tommy Atkins	*B. dorsalis* in the cv. Tommy Atkins was completely killed, with no obvious signs of heat damage or premature skin color development.	Sub-Saharan Africa (SSA),	Mwando et al. (2021)
HWT (46 ºC, 86 min)	Tommy Atkins	Complete mortality of the most heat-tolerant stage of *B. dorsalis* in cv. Tommy Atkins, fruit quality was not compromised.	Uganda	Ocitti et al. (2021)
HWT (55 ºC, 10 min)	Amrapali	Effective in maintaining fruit quality and extended shelf life.	Nepal	Pandey et al. (2023)
HWT (46 ºC, 68, 75, and 84 min)	Apple mango	Maintain physical and biochemical properties of the fruit	Kenya	Ndlela et al. (2021)
HWT (55 ºC for 1 min and 3 min) VHT (52 ºC for 3 min, 55 ºC for 3 min)	Not mentioned	Preserve peel greenness, extend shelf life	Nigeria	Oladele & Fatukasi (2020)

HWT: hot water treatment; VHT: vapour heat treatment.

Biopolymer-based coatings

The antimicrobial properties of chitosan are demonstrated by its positively charged amino groups interacting with the negatively charged cell walls of microorganisms. The application of chitosan coating exhibits considerable promise in prolonging the shelf life and safeguarding the quality of mango cv. "Gopal Vogh" stored after harvest. Chitosan coating reduced total bacterial count and total mold count in mango fruit during storage, effectively preventing decay, limiting weight loss, and lowering postharvest diseases. Additionally, chitosan treatments provided advantages by preserving sugar, protein content, and other quality characteristics like vitamin C and TA of mango in storage (Parvin et al., 2023). Similar research carried out by Kumar et al. (2021) revealed that there was a beneficial effect of edible coating on the postharvest shelf life of mangoes in storage. The chitosan–pullulan composite edible coating demonstrated a significant retention of postharvest properties, including physiological loss in weight (PLW), color, TSS, and acidity in the sample. The functional properties (phenolic, flavonoid, and antioxidant activity) of coated mangoes during storage could improve by adding pomegranate peel extract to the edible coating (Kumar et al., 2021). A study by Shah and Hashmi (2020) has shown that a combination of chitosan and aloe vera gel effectively reduced the rate of post-harvest decay while maintaining fruit quality characteristics, including firmness, TA, TSS, weight loss, and peel color of mango. Shah and Hashmi (2020) indicated that thyme oil in chitosan coating proved to be the most effective method against to control anthracnose caused by *Colletotrichum gloeosporioides* in infected "White Chaunsa" mango. Furthermore, the combination of chitosan and thyme oil effectively decreased naturally occurring decay and increased internal resistance against the disease. Chitosan-Aloe vera gel along with 2% beeswax treatment decreased weight loss, delayed firmness loss, minimized pH change, preserved TSS content, and preserved total phenolic and antioxidant activity of mango (Amin et al., 2021). A study by Rukunuzzaman et al. (2025) revealed that fruits coated with chitosan (CTS), aloe vera gel (AVG), and a combination of CTS+AVG degraded at a lesser rate compared to the control group throughout storage. Fruits treated with AVG alone the decay incidence began at 8 days of storage, while fruits coated by CTS alone or combination of CTS+AVG the decay incidence began at 12 days. At the end of 16 days of storage, fruits coated by CTS+AVG, CTS alone, AVG alone exhibited mean decay incidence of 5.12%, 6.12% 7.65% respectively as opposed to 11.72% for the control (Rukunuzzaman et al., 2025). Use of chitosan, gum Arabic, and aloe vera gel treatments as postharvest coatings showed higher efficacy for controlling post-harvest deterioration of mango cv. "Alphonse" stored at 13 °C, prolonging their shelf life to four weeks (Abd EI-Gawad et al., 2019). A significant increase in firmness, TSS, TA, total sugars, and vitamin C was observed with 2% chitosan and 50% aloe vera gel. Mangoes coated with 10% gum Arabic reported a minimum fruit weight loss and disorder percentage. Moreover, a study by Mustari et al. (2025) observed that changes in fruit firmness occurred at a faster rate in control, whereas the rates were slower in the fruits treated with chitosan oligosaccharides (COS). Fruit firmness was maximum (9.26 N) in COS 50 mg/L treated fruits and minimum (7.7 N) in the control which was statistically similar with COS 100 mg/L treated fruits. Another study was carried out for cv. "Nam Dok Mai" mango by Phuangto et al. (2019) indicated that the films formulated with CMC exhibited a significantly higher water solubility and water vapor transmission rate. It was discovered that CMC was noticeably more successful than the other coating types at preserving the fresh weight of the fruit throughout storage. On the 14th day of storage, the fruit treated with CMC showed less color change and higher soluble solids content than the fruit coated with chitosan. These findings show that a coating based on CMC might be used to prolong the fruit's commercialization period.

Plant extracts and phenolic compounds have the potential to impose antifungal effects when combined with chitosan (Silva et el., 2021). Incidence and severity of mango anthracnose caused by *Colletotrichum tropicale* were greatly reduced when pyrocatechol acid, trans-cinnamic acid, citric acid, and resorcinol added to chitosan solutions. Chitosan/nano TiO_2 composite coating could preserve the nutritional composition of mango and significantly improved the fruit quality by forming a favourable microenvironment during storage (Xing et al., 2020). It showed increased fruit firmness, lower levels of TSS content, and malondialdehyde (MDA – a stress marker). In addition, it showed higher levels of total phenol and flavonoid content. According to Daisy et al. (2020) mangoes with gum Arabic coating ripened more slowly and extend their shelf life up to 15 days compared to untreated control fruit. The gas and water vapor barrier qualities of gum Arabic coating allowed mangoes to be stored longer without compromising fruit quality. Table 2 presents a comprehensive summary of published research articles on effect of edible coatings on quality attributes of mango during post-harvest phase.

Table 2. Effect of edible coatings on quality attributes of mango during post-harvest phase.

Coating material	Mango cultivar	Key finding	Study region	References
Chitosan	Gopal Vogh	Reducing weight loss, lowering total mold and bacterial counts, extending shelf life	India	Parvin et al. (2023)
Chitosan, and pullulan with pomegranate peel extract	Safeda	Reducing weight loss	India	Kumar et al. (2021)
Chitosan, aloe vera	White Chaunsa	Extended shelf life	Pakistan	Shah & Hashmi (2020)
Chitosan and aloe vera, beeswax	Not mentioned	Reducing weight loss & disease incidence delaying firmness loss	Pakistan	Amin et al. (2021)
chitosan, gum Arabic and aloe vera gel	Alphonso	Reducing weight loss, decreasing fruit disorders	Egypt	Abd EI-Gawad et al. (2019)
Carboxymethyl cellulose	Not mentioned	Reducing weight loss, extended shelf life	Germany	Phuangto et al. (2019)
Chitosan, phenolic compounds (pyrocatechol acid, transcinamic acid, citric acid, and resorcinol)	Palmer	Reducing the incidence and severity of anthracnose	Brazil	Silva et al. (2021)
Gum Arabic	Apple mango	Extended shelf life	Kenya	Daisy et al. (2020)

Essential oils incorporated edible coatings

Growers have been using various fungicides, growth regulators, and waxing materials after harvest to increase the shelf life of fruits. While all these methods can be effective in reducing post-harvest losses, efforts to develop alternative control measures have increased due to increased resistance of fungi and pests, environmental impact, health concerns, regulatory restrictions, and cost. Therefore, plant-based extracts have become more well-known and attracted higher attention recently as they showed potential to reduce post-harvest loss through the expression of antimicrobial properties (Yadav et al., 2023).

Cardamom oil in warm water effectively reduced the severity of SER under in vivo conditions. Essential oils (EOs) such as basil, cardamom, and citronella significantly reduced the growth of *Lasiodiplodia sp*. under in-vitro conditions (Kulasinghe et al., 2019). These findings have been achieved without impacting on sensory properties or physicochemical quality parameters of mango. A composite film of chitosan–polylactic acid containing 1.2% EO extracted from *Melaleuca alternifolia* leaves effectively stopped the growth of fungus that causes post-harvest mango diseases (Gunny et al., 2023) along with improved fruit quality.

These films demonstrated active packaging functions creating and maintaining a favourable microenvironment for the fruit. Research by Huang et al. (2021) showed that EO of *Artemisia scoparia, A. lavandulafolia*, and *A. annua* had an antifungal effect against *C. gloeosporioides* in mangoes. Results of the ultra-depth microscope and scanning electron microscopy evidenced that *C. gloeosporioides* mycelium treated with *Artemisia sp.* EO was severely deformed, broken and leaked its contents to form an empty tube. When *A. scoparia* EO was inoculated in vivo and tested for paroxysm under natural conditions, it exhibited strong inhibitory effect on the pathogenic organism. These findings suggest that *A. scoparia* EO could be used against *C. gloeosporioides* and other post-harvest fungal diseases.

Mandal and Mualchin (2021) reported that mangoes dipped in citronella oil (*Cymbopogon nardus*) maintained low weight loss, high fruit firmness, ascorbic acid content, total phenol content, and the least amount of fruit decay in 12 days after storage. The treated mangoes showed delayed pulp color development, reduced rates of β-carotene, and total sugar accumulation, indicating delayed ripening and thereby extending the shelf life by 7 days compared to the control (water-dipped fruits) stored at ambient conditions (T:20 ±3 °C; RH:70 ±5%). Therefore, citronella oil can be applied to preserve fruit quality and increase the shelf life of mangoes under ambient conditions. Nyangena et al. (2021) indicated that when *Ocimum gratissimum* EO and *Morchella esculeta* coating were combined, mangoes could be stored for up to 18 days at room temperature (25±2 °C) and 27 days at low temperature (4±2 °C) respectively. This treatment could represent a useful farm-based post-harvest method for extending the shelf life of mango while preserving its physicochemical characteristics.

Hexanal-based coatings

Hexanal is a naturally occurring compound well known for its ability to inhibit phospholipase-D activity retard ethylene production leading to delay in ripening of fruit and senescence (Jincy et al., 2017, Champa et al., 2019). Shelf life of mangoes extended when hexanal is applied as a dip after harvest, preserving the fruit's physical characteristics as it ripens (Mutinda, 2022). Fruit treated with hexanal formulation (enhanced freshness formulation -EFF) maintained reduced rates of respiration and ethylene production, as well as a higher firmness and a slower rate of color change. Throughout the storage period, the rate of weight loss in treated fruit was minimal. Applying a 3% EFF post-harvest dip to mangoes significantly increased their shelf life. Preethi et al., (2021) revealed that the storage life of mangoes increased from 5 days to 20 days by application of hexanal formulation (2% EFF) as a pre-harvest foliar spray followed by cold storage dip treatment (T: 13 °C, RH: 90 ±3%). Application of hexanal treatment twice reduced the action of tissue softening enzymes and preserved the integral membrane stability, maintaining the fruit's firmness and other post-harvest qualities related to taste and pulp color. Kaur et al., (2020) reported that mango fruit respiration rate, pectin methyl esterase activity, and decay incidence were markedly decreased by hexanal formulation at 1600µM and treated fruit showed improvements in firmness, TSS, acidity, and acceptable palatability after being stored for 28 days (T: 12± 2°C, RH: 85%-90%).

Storage strategies to mitigate postharvest loss

Mango postharvest treatments include a variety of storage techniques to preserve quality and minimize losses. Controlled atmosphere packaging, modified atmosphere packaging, and cold storage are a few efficient post-harvest storage techniques.

Modified atmospheric packaging

Protecting against mechanical damage, prevention of microbial contamination, minimizing weight loss, reducing respiration rate, and delaying ripening are the primary purposes of packaging of fresh produce. Mango fruit quality has been preserved using methods like modified atmosphere packaging (MAP). It has been demonstrated that MAP works well when combined with other treatments like coatings and HWT (Bambalele et al., 2021). MAP which involves sealing the product in polymeric film packages to change the amount of respiratory gas of in-package headspace. It alters the atmosphere to have low oxygen and high carbon dioxide levels, which reduces the commodity's respiration and ethylene production (Kodituwakku et al., 2020). It has been shown that mango postharvest pathogens are effectively controlled by EO treatments when combined with passive MAP. The said treatment considerably decreased the stem end rot severity of mango without negatively affecting the peel color and certain physicochemical characteristics like firmness and TSS (Kodituwakku et al., 2020). In a study by Perumal et al., (2021), they have compared MAP + EO vapor-treated fruit with MAP alone and non-packed fruits. The results revealed that MAP +EO vapor-treated fruit retained overall fruit quality compared to MAP alone and non-packed fruits, suggesting that MAP+EO vapour treatment could be utilized as a novel technique to preserve the postharvest quality of fresh mango fruit.

CONCLUSION

Mango is a highly economically significant fruit having attractive flavor and functional properties deserving of year-round demand. Mango encounters high postharvest losses along the supply chain due to various primary and secondary factors, which we strived to identify, classify, and summarize in this review for the benefit of policymakers, government authorities, researchers, growers, and other stakeholders engaged in the mango fresh fruit trade. The key primary factor is the lack of genetic purity of existing varieties in Sri Lanka to produce fruits of uniform size and shape for efficient packaging in export cartons alongside tolerant to the impact of mechanical damage during harvesting and subsequent handling operations. Moreover, having varieties that show resistance to two key postharvest diseases, *i.e.*, anthracnose and stem end rot, is imperative. The other major challenge is overcoming fruit fly infestation, which imposes a huge barrier to exports.

The secondary cause is a lack of knowledge and skills and poor awareness of available technology about correct harvest maturity, harvesting methods and subsequent handling practices, highlighting the fact that growers have not received enough exposure to the extension services. A huge gap was identified in the availability of suitable packaging and packing containers/cartons along the supply chain especially for the high-end markets. Unavailability of appropriate storage structures and lack of awareness about pre-storage treatments for preserving fruit quality after harvest are another constraint in the sector. Inadequacy of suitable vehicles for transportation of fresh produce, poor condition of the roads in remote areas where most of the mango orchards are located could be listed as the other barriers faced by many mango growers in developing countries like Sri Lanka. Obviously, disorganized marketing channels, along with inadequate market information, contribute to a significant volume of post-harvest losses of mango. Lack of awareness of the socioeconomic significance of postharvest losses and, therefore, the suboptimal intervention of respective government authorities is another important aspect that contributes to high loss and waste in the mango supply chain.

Therefore, in the long run, developing suitable high-quality varieties targeting efficient packaging, enhanced shelf life with better cosmetic quality and making available the said planting materials for the growers to upgrade their orchards is one of the strategies for the sustainability of the mango-fresh fruit industry. The findings emphasize the immediate necessity for collaboration between government, non-government, and other private sector companies for developing high quality packing cartons to succeed in competitive export markets. Investing in developing appropriate storage structures and transportation facilities alongside executing organized marketing channels would make remarkable impact on development of the mango fresh fruit trade. Moreover, establishing mango-based value-added industries at three levels namely cottage, medium and large scale is mandatory for the sustainability of the business. Finally, knowledge, information, and technology developed in research centers, universities, and other government agencies should reach the growers on time. In this context, the researchers, public extension services, and media should work in close collaboration with the growers and other stakeholders of the supply chain.

Conflict of interest

The authors declare that they have no conflict of interest.

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