The Journal of Agricultural Sciences - Sri Lanka
Vol. 20, No 1, January 2025. Pp 1-16
https://doi.org/10.4038/jas.v20i1.10342

Towards Sustainable Postharvest Management of Mangoes in Sri Lanka; Evaluating Current Practices, Latest Research, and Future Interventions

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Received: 17th June 2023 / Accepted: 21st November 2024

ABSTRACT

Purpose: *This research aims to examine the sustainable postharvest management of mangoes in Sri Lanka, identifying the gap between current practices and recommended practices, and exploring future perspectives through recent discoveries in the field of mango postharvest management in the country.*

Research Method: *A Literature review was employed to gather information and insights.*

Findings: *The study reveals a significant disparity between the recommended postharvest handling practices and the methods currently practiced in Sri Lanka. The identified gaps encompass inadequate preharvest strategies, inappropriate harvesting practices, insufficient disease prevention measures in field operations, limited use of treatments at packhouses, questionable ripening protocols, and problematic transportation practices. Although many innovative research studies have been conducted in Sri Lanka to control postharvest losses, many of them were halted at the primary level, without follow-up, application of findings on a commercial scale, or implementation of recommendations.*

Research Limitations: *The main focus is only on the mango value chain in Sri Lanka and there is limited published information on mango postharvest management in Sri Lanka.*

Value: *This research highlights the value of addressing postharvest losses in mangoes, providing insights into the gap between recommended and practiced methods in Sri Lanka. It serves as a case study for countries facing similar challenges, promoting the dissemination of knowledge and fostering sustainable mango value chains globally.*

Keywords: *Postharvest losses, Recommended practices, Value chain, Innovation, Postharvest handling.*

INTRODUCTION

The United Nations' Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production), have set a target to end hunger, achieve food security, promote sustainable agriculture, and reduce food waste by 2030. To accomplish these goals, it is vital to identify challenges in the value chain and implement innovative solutions to minimize postharvest losses in developing countries, particularly in the perishables fruits like mangoes. Mangoes are a significant agricultural commodity, widely produced in countries such as India, China, Indonesia, Bangladesh, Brazil, Egypt, and Sri Lanka (FAO, 2021). Mango (*Mangifera indica* L.) is a popular tropical fruit consumed globally. With its origins in Southeast Asia, India is the largest mango producer, contributing 44% of the world's annual mango supply, which amounts to approximately 24 million tons (FAO, 2021). There are over 1000 varieties of mango traded worldwide. In Sri Lanka, mangoes hold cultural and religious significance; thus, mango trees can be found in home gardens and small-scale cultivations across different regions. Large-scale cultivation is mainly conducted in the dry zone.

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The major mango-cultivating districts in Sri Lanka are Kurunegala, Hambanthota, Gampaha, Rathnapura, Matale, Monaragala, Puttalam, and Matara (Pricewaterhousecoopers-Sri Lanka[pwc], 2017). The total extent of mango cultivation in Sri Lanka is approximately 30000 hectares, with an annual production of 186663 tonnes (FAO, 2021). The Department of Agriculture has listed *'Karthakolomban,' 'Willard/Villard,' 'TJC/TomJC,' 'Velleikolomban,' 'Malwana,' 'Dampara,' 'Giraamba,'* and *'Horanahiru'* as recommended cultivars (DOA, 2023). Additionally, cultivars such as *'Betti,' 'Kohu,' 'Amrapalavi,'* and *'Polamba'* are also commonly found in Sri Lanka. (Peiris, 2016). Mangoes are mainly harvested in two seasons: from May to July and October to January (Pricewaterhousecoopers-Sri Lanka[pwc], 2017). However, Sri Lanka's mango production, export, and value addition are at an elementary level.

The main mango value chains in Sri Lanka are traditional, modern, and export-oriented (Rathnayake and Silva, 2022). Traditional value chains are the most prevalent and they cater to local markets. Export-oriented channels mostly start from large-scale commercial cultivations where the fruits are high-quality, certified, value-added, and premium-priced, while modern value chains cater to high-end local markets and are placed between traditional and export-oriented channels (Rathnayake and Silva, 2022).

The export potential of Sri Lankan mangoes is not yet tapped with only 665.5 tonnes (1.82 million USD) exported in 2021, representing a mere 0.025% in quantity and 0.05% in value compared to global trade (FAO, 2021). Although Sri Lanka's current mango exports represent 1.3% of the total fruit exports (FAO, 2021), there is much room for growth in the industry, with the primary mango importing markets being the USA, the Netherlands, Germany, the UK, Canada, and Asian markets such as China, Vietnam, the UAE, and Hong Kong. (FAO, 2021). Among the mango varieties grown in Sri Lanka, the *Tom EJC* (TJC) mango has excellent export potential because of its large size, juicy flesh, fibreless texture, and attractive color (Pricewaterhousecoopers-Sri Lanka[pwc], 2017). Several large-scale farming enterprises have initiated large TJC orchards in the dry zone for fresh fruit and value-added mango product exports.

However, mango postharvest loss in Sri Lanka is a significant challenge, with estimated total losses at the grower, wholesaler, and retailer levels as 30-35% (Mahendranathan, 2018). To address this issue, it is crucial to reduce postharvest losses both qualitatively and quantitatively, thereby improving the sustainability of traditional mango value chains. While global standards exist for postharvest handling of mangoes, publications on such practices and their evaluation in developing countries like Sri Lanka are relatively scarce. Furthermore, despite extensive research on this topic, implementation of such innovations remains limited. Therefore, this study aims to address these issues by identifying current postharvest handling practices in Sri Lanka, comparing them to globally established standards, and highlighting the gaps. This study will also explore innovative solutions proposed by recent research on postharvest loss prevention and offer insights into future perspectives for sustainable mango postharvest management in Sri Lanka. Finally, this study will serve as a case study for countries facing similar postharvest loss challenges, thereby contributing to broader knowledge dissemination and promoting sustainable mango value chains globally.

POSTHARVEST LOSS PREVENTION STRATEGIES IN SRI LANKA

Fig. 01 depicts a comparison of the postharvest loss reduction strategies currently implemented by traditional medium/small scale producers in Sri Lanka along the value chain (right) with the recommended global-level practices proposed by experts (Left) (Yahia, 1999; Esguerra *et al.*, 2018; Brecht *et al.*, 2020). Most export-oriented/ large-scale mango producers also closely adhere to these protocols.

Preharvest Practices

Genetic variations, environmental conditions, and agricultural and cultural practices significantly influence the postharvest quality of produce (Yahia *et al.*, 2019). Although this review primarily focuses on postharvest handling, key preharvest measures for mango, such as cultivar selection, quality planting materials, plant nutrition, pesticide use, orchard hygiene, and fruit bagging, play a crucial role in determining quality and postharvest life (Anusuya *et al.*, 2016; Islam *et al.*, 2019; Kaur *et al.*, 2020; Samwel *et al.*, 2020; Alkolaly *et al.*, 2022). The utilization of naturally occurring compounds like Hexanal and allium-based natural fungicides derived from garlic has demonstrated effectiveness in controlling pest and disease infestations (Kaur *et al.*, 2020; Alkolaly *et al.*, 2022). Despite the potential benefits of these practices, it is noted that Sri Lankan farmers, in general, do not adhere to such methods, resulting in poor quality within the supply chain. In contrast, export-oriented orchards that adhere to preharvest procedures to meet quarantine protocols have been observed to maintain higher quality standards (Vidanapathirana *et al.*, 2018).

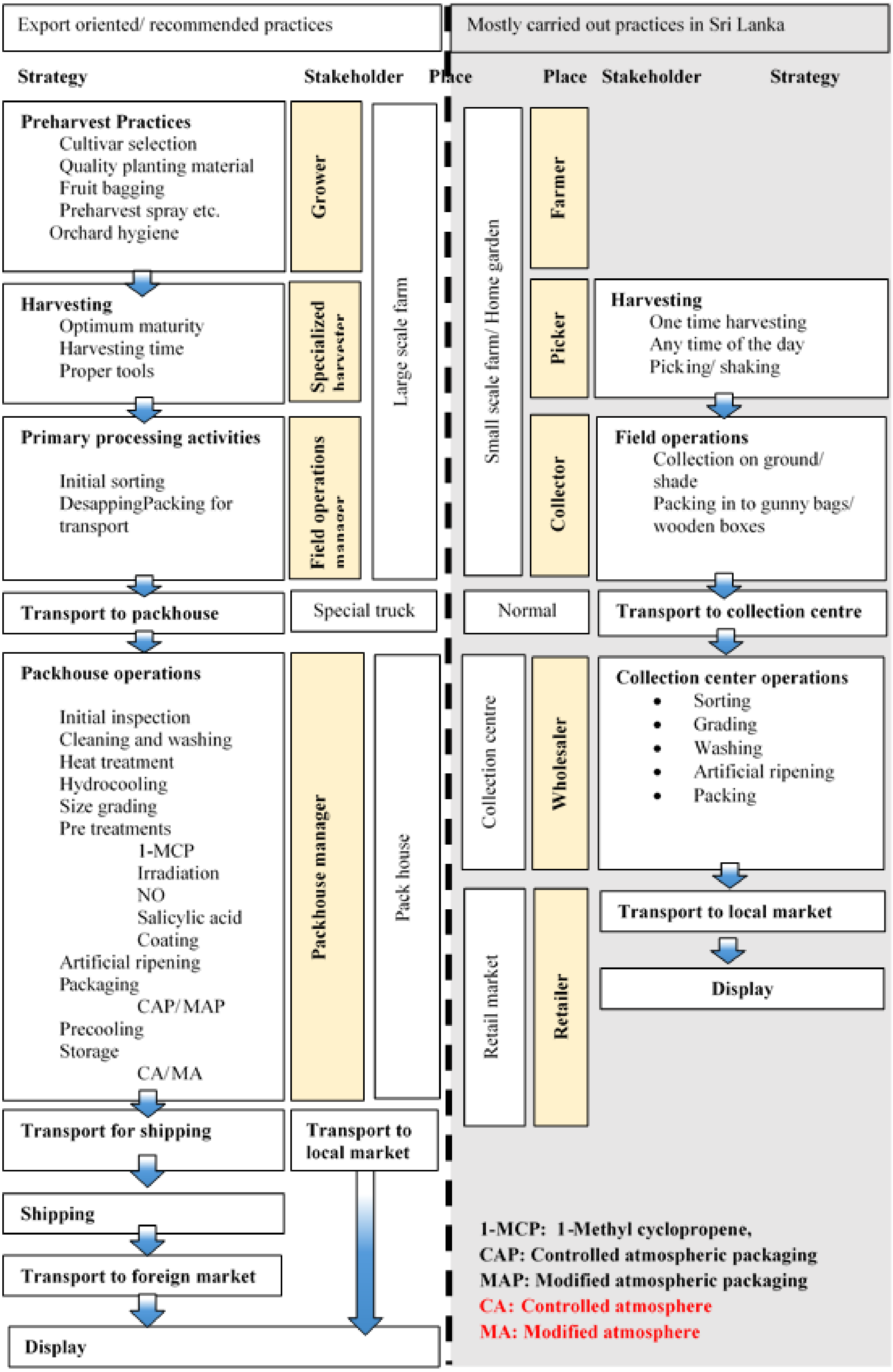

Figure 1: Recommended strategies for mango postharvest loss reduction compared to the currently carried out practices in Sri Lanka.

Harvesting

Harvesting stage, time, and tools are the most critical determinants of mango postharvest quality in the value chain. When mangoes are harvested after the optimum maturity, ripening, and physiological development can lead to excessive softening and fruit damage during transport and shortened shelf life. When harvested before, flavor, color and aroma development is hindered and prone to chilling injury during cold chains (Amarakoon, *et al.*, 1999a; Brecht *et al.*, 2020). The recommended practice for harvesting mangoes is to harvest at full maturity and multiple times for each tree (Yahia, 1999). Optimum maturity indices may differ according to mango variety. Non-destructive methods such as whitish blooms (powdery coating resulting from changes in peel wax composition), prominent lenticels, latex squirt, size, shape (fullness of the shoulders at the stem end), skin color (dark green turning into light green), and destructive indices such as total soluble solids and flesh color (light yellow color) are prominent indices (Esguerra *et al.*, 2018; Brecht *et al.*, 2020). As per harvesting time, the coolest parts of the day are recommended to minimize field heat, respiration, and fruit deterioration (Yahia, 1999) while some manuals instruct harvesting from 9.00 am to 3.00 pm to minimize latex squirt (Esguerra *et al.*, 2018).

As harvesting tools, picking poles with attached nets and sharp blades should be used by specialized harvesters (Brecht *et al.*, 2020). When bigger mangoes are harvested using a picker, they can retain better sensory attributes (Ahmed, 2019). Handpicking can be performed for properly pruned short-height trees with the aid of ladders. However, picking tools and personnel should avoid contamination by soil-borne pathogens (Brecht *et al.*, 2020). After picking, fruits should be inserted in clean plastic containers away from the sun (Esguerra *et al.*, 2018).

However, in the Sri Lankan conventional method of harvesting, mango collectors rent the whole tree, and all fruits are harvested by a picker without considering the maturity indices. Thus, immature fruits are also harvested. Mango pickers use picking poles with only a hook or they shake the trees and pick fallen mangoes. This can cause serious damage at the time of harvesting, or along the supply chain due to the development of physiological disorders and diseases (Thayalan *et al.*, 2020). Sri Lankan mangoes face 16.5% postharvest losses due to bruising and mechanical damage that occurred during harvesting at the farm. (Thayalan *et al.*, 2020). However, intensive care in mango harvesting is performed only in export-oriented farms or modern value chains. There, the fruits are selectively harvested either by hand or using a long pole with a net. As per harvesting time, a study conducted in Batticaloa District found that mangoes are harvested at any time of the day without much consideration of shrinkage and evaporation caused by higher temperatures (Thayalan *et al.*, 2020). This is also common in the conventional channels in other districts.

Primary Processing Activities in the Field

The primary processing activities in the field are initial sorting, de-sapping, and packing for transport. Fieldworkers carry out these tasks under the supervision of a field operations manager (Fig.01). In Sri Lanka, the collector mostly performs field operations such as collecting, sorting, and packing.

Initial sorting: Harvested fruits should be kept on a clean tarpaulin in the shade to avoid contact with soil (Esguerra *et al.*, 2018; Brecht *et al.*, 2020). In Sri Lanka, conventional channels are not efficient in sorting and grading compared to modern export-oriented channels (Rajapaksha *et al.*, 2021). Mangoes are sorted manually in the field to remove damaged and rotten fruits, followed by grading according to size, color, or maturity. In modern value chains mangoes are sorted after de-sapping and then packed in plastic crates (Herath *et al.*, 2021; Rajapaksha *et al.*, 2021).

Desapping: Latex burning on peels during harvesting, accumulation in the field, or transport can be accelerated by heat treatment. Therefore, it is advised to place fruit stem-down on decapping racks to ensure that the skin is not in contact with latex and ground (Brecht *et al.*, 2020). Destemmed fruits can also be dipped in 1% alum solution so that the latex is coagulated. In addition, long stems can be trimmed in the pack house after 12-24 hours, so that latex will no longer drip (Brecht *et al.*, 2020). However, in Sri Lanka, postharvest latex damage is a common challenge for smallholder farmers, with nearly 54% not following any desapping practices (Thayalan *et al.*, 2020). Instead, 34% of dry mango latex was in the sun and 12% washed and dried the mangoes (Mahendranathan, 2018). Nonetheless, improved supply chains in Sri Lanka conduct desapping by placing mangoes stem-end down on racks for approximately 15-20 minutes (Herath *et al.*, 2021). Even though washing is recommended just after harvest, such facilities are not available in the fields; thus, they are mostly used in pack houses.

Packing for transport: The fruits should be packed in plastic crates after drying (Esguerra *et al.*, 2018). In the conventional system in Sri Lanka, fruits are packed in gunny bags and wooden crates without proper packaging and overloaded to reduce transportation costs (Vidanapathirana *et al.*, 2018; Thayalan *et al.*, 2020). The NIPHM (National Institute of Postharvest Management) introduced the use of plastic crates for fresh produce transport and caused many controversies owing to some practical drawbacks.

Transport to pack house: Ideally, packing houses should be located near the field, and if long distances are necessary, care should be taken to abate adverse effects by minimizing waiting times for loading and unloading and transporting during cooler hours. The use of a vehicle with a top cover to protect the mangoes from direct sunlight and with proper ventilation is recommended (Brecht *et al.*, 2020). However, (Thayalan *et al.*, 2020) observed that the vehicles used for mango transport in Batticaloa are not specialized for fruit transport and proper sanitization is not performed before loading. Transport in unspecialized vehicles ultimately leads to overloading, tight packaging, and poor ventilation over long distances, causing major postharvest losses (Vidanapathirana *et al.*, 2018). However, improved transport systems are being used in modern value chains with plastic crates and refrigerated trucks.

Packhouse Operations

Packhouse operations are conducted by workers under the supervision of a manager. However, in Sri Lanka, mangoes from multiple areas are taken to a collection center, where the wholesaler handles grading, washing, sorting, and packing operations.

Initial inspection: Before unloading fruits at a packing house, it is crucial to conduct an initial inspection of a representative sample for fruit fly infestation, maturity, and damage (Brecht *et al.*, 2020). For export-oriented fruits, quarantine regulations agreed upon by the exporter and importer are strictly followed to prevent the exportation of infested fruits (Yahia, 1999). In Sri Lanka, the National Plant Quarantine Service (NPQS) oversees mango export procedures and has introduced a phytosanitary protocol involving 1. establishment of commercial mango orchards; 2. registration of export-oriented mango orchards; 3. Field certification for export, 4. Packhouse inspection procedure, 5.Vapor heat treatment (VHT), 6. Exit point inspection and exportation (Wickramarachchi, 2020).

Cleaning and Washing: To remove dirt and latex, mangoes are gently transferred to the sanitized water tanks, where they are promptly washed within a 30-second timeframe (Brecht*et al.*, 2020).

This rapid washing is essential to prevent potential pathogenic infiltration. Following this initial washing phase, the mangoes are directed to a sizing line equipped with a rolling or conveyor belt system. Here, additional measures such as spraying and brushing are employed to thoroughly eliminate any remaining soil and debris. This comprehensive cleaning and washing process not only enhances the visual appeal of the mangoes but also plays a pivotal role in minimizing the risk of contamination and ensuring the overall quality and safety of the fruit for consumers.

Heat treatment: Heat treatments eliminate microorganisms, insect eggs, and larval stages that are prevalent on mango skin in alternative to the discontinued ethylene bromide and ethylene dibromide fumigants (Yahia, 1999; Brecht *et al.*, 2020). Three heat treatments can be distinguished: hot air treatment (HAT), hot water treatment (HWT), and vapor heat treatment (VHT).

HWT is typically conducted in tanks or conveyor belts, as discussed by (Le, *et al.*, 2022) and (Ntsoane *et al.*, 2019) in their respective reviews of HWT's impact on mango quality. The treatment temperature and duration can vary according to the size, variety, and maturity of the fruits. For example, the USDA recommends 46.1°C to control fruit flies (Brecht *et al.*, 2020), while the FAO recommends 55°C for 5-10 minutes (Yahia, 1999).

HWT treatment should be performed for mangoes free of latex damage, mechanical damage, bruises, and over-mature stages within 36 h of harvesting, during the green stage, and the water temperature, even distribution, dipping time, cleanliness should be closely monitored, to avoid exacerbated damage on fruit quality (Yahia, 1999; Esguerra *et al.*, 2018; Brecht *et al.*, 2020).

VHT is used as a quarantine treatment for fruit fly control during export. Phytosanitary requirements differ according to the country of import; VHT of 46°C surface and 46.5 seed temperature for 10 min is applied when mangoes are imported to Japan from Australia and 43.3°C for 6 h is applied when exported from the Philippines to the USA. There was no evidence in the literature about commercial applications of heat treatments for mangoes in Sri Lanka. However, VHT is performed before exportation.

Hydrocooling: After HWT, mangoes are cooled for 10 min in clean water (<21.1°C) and dried using forced air cooling to ensure rapid cooling (Yahia, 1999; Brecht *et al.*, 2020). The rapid decrease in flesh temperature can mitigate hot water injury from HWT. Hydrocooling can also be carried out immediately after arrival at the packhouse as a precooling treatment to reduce the field heat (Yahia, 2019). Hydrocooling too is not reported to be practiced in Sri Lanka.

Size grading: In packhouses, damaged and imperfect mangoes are removed before waxing and packaging (Brecht *et al.*, 2020). Manual sorting by trained professionals and electronic grading methods are used mostly (Yahia, 1999)., but automated systems are advancing. Conveyor belts with cameras and image-processing devices can sort mangoes based on various characteristics (Yimyam *et al.*, 2005; Sa'ad *et al.*, 2015; Mon and ZarAung, 2020). However, the irregular shape of mangoes makes automated grading challenging, with accuracy ranging from 90-97% (Khoje and Bodhe, 2013). Comparatively in Sri Lanka, mostly manual grading is done by untrained personnel.

Postharvest treatments; Postharvest treatments such as 1-Methylcyclopropene (1-MCP) treatment, irradiation, NO, Salicylic acid, and various coatings are performed at the packhouse before packing. Ethylene is a gaseous plant hormone that regulates the ripening process naturally and its exogenous application is long been used to induce ripening. However, ripening before or during transport is unfavorable for the mango quality. Therefore, 1-MCP is used commercially to control ripening during extended transport durations by maintaining quality characteristics (Ntsoane *et al.*, 2019). Bambalele and the team (2021) reviewed how 1-MCP can delay mango softening and ripening by inhibiting gene accumulation and enzyme activities relevant to cell wall modification.

Irradiation using gamma rays from 0.15-0.3 kGy doses is used to delay ripening and also to irradicate insects. However, it is essential to select an irradiation frequency that is enough to control a specific insect and not too high to damage the fruit (Yahia, 1999). Irradiation by UV-C was reviewed by (Le *et al.*, 2022) extensively.

NO gas treatment has proven to be involved in physiological and biochemical processes as a signal molecule. It has proven effects on inhibiting ethylene synthesis, reducing respiration, minimizing weight loss and, softening and control of postharvest diseases (Hu *et al.*, 2014). Various coatings consisting of carnauba wax, chitosan, shellac, Arabic gum, carboxymethyl cellulose, and other natural substances can form a gas and moisture barrier and it extends the postharvest life of mangoes by reducing the moisture loss, ethylene synthesis and ripening while maintaining the flavor and firmness quality (Ntsoane *et al.*, 2019). Waxing reduces moisture loss and enhances the gloss when applied according to the instructions (Brecht *et al.*, 2020). Wax is usually applied on dry fruit as a thin layer using roller brushes or hand. HWT removes natural waxes present on the mangoes and waxing can substitute the role of natural waxes. However, waxing can also lead to anaerobic fermentation (Yahia, 1999). Despite the numerous pre-treatments recommended to reduce postharvest quality deterioration of mangoes, such practices are rarely implemented at the commercial level in Sri Lanka.

Artificial ripening: When mangoes are harvested at the mature green stage, they should be ripened at the receivers' end (Wholesaler/retailer). There, the main physiological changes desired are, a change of skin color, flesh color, softening, increased TSS and aroma (Brecht *et al.*, 2020). Distribution centers are equipped with ripening chambers where there are ethylene generators or ethylene cylinders that provide 100ppm concentration ethylene for 24 hours with continuous gas and temperature monitoring. Once the ethylene treatment is over, the mango will ripen at ambient temperature (Brecht *et al.*, 2020).

However, developing countries like Sri Lanka are unable to accommodate such sophisticated systems and ripening using calcium carbide has long been practiced. Since now the carbide is banned in Sri Lanka, ethephon is used. According to manufacturer recommendations, a sealable room is used as the ripening chamber and it is then stacked with mango fruits.

Packaging: Packaging is essential in reducing postharvest loss during transport and handling. For local transport, plastic crates or cushioned wooden and bamboo crates are recommended. However, over-packing, dropping, sitting on them, and chemical contamination, should be avoided (Esguerra *et al.*, 2018). It is advisable to pack the fruits as soon after hydrocooling or to keep the mangoes in a cold room at 10-15°C until packing. Mangoes with higher flesh temperatures can be kept at 10°C (below the standard 12°C) temporarily at the packinghouse before shipping to slow down the fruit's metabolism (Brecht *et al.*, 2020). In the absence of a cold room, mangoes can be kept at ambient temperature with 8 inches of space between the stacks and proper ventilation (Brecht *et al.*, 2020). Mangoes should be packed in strong corrugated cardboard boxes with ventilation holes to facilitate the airflow. They should be tightly packed preferably in a single layer to avoid bruising, crushing, vibration and impact. And proper labeling to provide product identity, amount, source, treatments, contact information, etc. (Brecht *et al.*, 2020). However, in Sri Lanka, such advanced packing is used only for export markets or high-value local markets. Conventional market channels use poly sack bags to tightly pack the mangoes. Sleeping on polysacks and rough handling is observed. Improper ventilation in polysack bags, exposing fruits to sun and rain, uneven road conditions, and extended durations cause the damages to accumulate (Vidanapathirana *et al.*, 2018).

Precooling and storage: Precooling is done before shipping or storage of the mangoes to slow down fruit metabolism, moisture loss and disease infection. Mangoes are precooled and stored at 12°C temperature around 85-95% humidity which can extend the shelf life to about 15 days (Brecht *et al.*, 2020). It is crucial to avoid lowering the temperature below 12°C to prevent chilling injury, which may vary depending on the mango variety; additionally, ensuring proper air circulation through the pallets is essential to maintain uniform relative humidity and prevent condensation (sweating) within the corrugated boxes. (Brecht *et al.*, 2020).

In the Sri Lankan context, warm temperatures and high humidity are the main challenges to overcome to prevent rapid deterioration. However, there are not enough storage facilities available in wholesale markets, thus surplus is always wasted (Rajapaksha *et al.*, 2021). In the Batticaloa district, mangoes are stored for 2-4 days at ambient temperature (30°C) on the floor covered with straw. Although the handlers assume the losses to be as low as 5% after storage, the actual study showed the losses go up as high as 40% mainly due to stem end rot (SER) and, latex burning and other damages (Thayalan *et al.*, 2020).

Control atmosphere (CA)/Modified atmosphere (MA) packaging and storage: CA and MA packaging and storage could preserve the fruits for longer durations. CA in low O_2 levels can reduce respiration, ethylene production, softening and quality alterations with the risk of decay, anaerobic metabolism, flavor and irregular physiological maturity (Ntsoane *et al.*, 2019; Le *et al.*, 2022). Modified Atmospheric Packaging (MAP) with elevated levels of CO_2 and reduced oxygen O_2 has been reported to effectively decrease the respiration rate of fruits (Le *et al.*, 2022). However, the widespread adoption of this technology in developing countries faces challenges, including limited technical expertise, financial constraints, and difficulties in sourcing appropriate gases, packaging materials, and installation infrastructure.

Shipping

Shipping is the last step for the mangoes intended for export. When loading, the container should be precooled and the dock should also be refrigerated to avoid condensation, cartons should be stowed for proper ventilation and temperature distribution (Brecht *et al.*., 2020). After the quality evaluation and temperature check, fruits are repacked and loaded (Brecht *et al.*, 2020). It is worth noting that despite Sri Lanka being involved in mango exports, specific protocols for exportation have not yet been published.

RECENT FINDINGS ON MANGO POSTHARVEST HANDLING IN SRI LANKA

To bridge the gap between recommended and current practices, implementing innovative research findings along the mango value chain is crucial. Recent studies primarily focused on 'TJC', *'Karthakolomban'*, *'Willard'*, And *'Velleikolomban'* cultivars, with limited research conducted on *'Kilinodan'*, *'Chembaddan'*, And *'Ambalavi'*.

Research on Preharvest Treatments

Preharvest spraying of different solutions was tested as a means of improving mango quality. Hexanal formulations can alter the phospholipase D enzyme responsible for membrane deterioration and extend the tree life (duration fruits remain attached to the tree) of 'TJC' mango by 4 weeks while lowering disease incidence (Hewajulige *et al.*., 2017; Subramanian *et al.*, 2018). Preharvest spraying of KCl, K2SO4 or CaCl2 together with Teepol® could extend the shelf life of mangoes by controlling SER and anthracnose diseases with or without enhancing internal qualities (Krishnapillai *et al.*, 1996; Wijesinghe *et al.*, 2011; Nisansala *et al.*, 2016).

Research on Harvesting

Harvesting indices for local mangoes could differ depending on the cultivar. Shoulder fullness is an effective index for *'Karthakolomban'*, *'Willard'*, and *'Velleikolomban'* while peel color change for *'Willard'* and float test for *'Willard'* and *'Karthakolomban'* (Amarakoon, *et al.*, 1999a). Days after the full bloom stage is an indication of *'Kilichondan'* and *'Karthakolomban'* mango maturities. After 93 days

'Kilichondan' developed a slight yellow patch on the shoulder and *'Karthakolomban'* developed a dark yellow color after 94 days, both of which were concluded as the optimum maturity according to the sensory properties (Kapilan *et al.*, 2015; Kapilan and Anpalagan, 2015)

Limited research has been conducted on mango harvesting tools and harvesting time. Hand harvesting gives the lowest performance while an improved harvester showed the best performance and minimum postharvest losses in the *'Willard'* and *'Karthakolomban'* mangoes (Risvy and Thenaraj, 2019).

Research on Desapping

For *Karthakolomban* mangoes, dipping the stalk ends in a solution of 5% sodium chloride and 1% calcium hydroxide prevented sap burn while *Willard, Chembaddan,* and *Ambalavi* mangoes were effectively treated with a solution of 1% NaCl and 0.5% calcium chloride without affecting fruit quality (Krishnapillai and Wijeratnam, 2016). Also, when mangoes with long stems are harvested and trimmed 24 hours later, latex squirt can be avoided (Krishnapillai and Wijeratnam, 2016). Mango latex contains antifungal compounds like resorcinols, gallotanins, and chitinase, which inhibit anthracnose, Alternaria rot, and stem end rot diseases (Karunanayake *et al.*, 2014). Therefore, retaining latex is a promising strategy to enhance resistance to these diseases (Karunanayake *et al.*, 2014) while evading sap burn.

Research on Transport

Transportation of mangoes from the farm to the collection center and distribution from there is a critical stage in the postharvest handling process. Amongst limited research conducted in this discipline, (Herath *et al.*, 2021) found that improved transport with ventilated top-covered trucks with a leaf spring suspension system extended the shelf life and maintained the quality of mangoes, collectively with other improved practices. Although the initial investment is high in these systems, higher prices can be fetched from preserved quality and reduced postharvest losses.

Research on Washing, Heat Treatment and Hydrocooling

Washing and heat treatments are primarily focused on reducing infestations and improving external appearance without significant adverse effects. However, water is not recommended for washing as it increases susceptibility to SER (Amarakoon, *et al.*, 1999a). The use of BioWish™ solution has been effective in reducing infestations for *Karuthakolomban* mangoes (Gunathilake and Tiwari, 2018). Heat treatments, such as HWT, at temperatures of 50-53°C for 5 minutes, have shown a 20-30% reduction in SER and anthracnose susceptibility in *Karthakolomban, Willard,* and *Ampalavi* mango cultivars while improving visual quality through uniform ripening (Krishnapillai, 2004). For mangoes exported from Sri Lanka, the National Plant Quarantine Service requires a VHT of 47°C for 15 minutes for TJC mangoes and 47°C for 8 minutes for *Karuthakolomban* mangoes to eliminate fruit fly infestations at all stages (Wickramarachchi, 2020).

Hydrocooling at approximately 10°C could delay ripening, and storage at 12°C after hydrocooling could preserve better quality of Willard mango (Perera *et al.*, 2009).

Research on Grading and Sorting

In Sri Lanka, mango grading is predominantly done manually due to the high cost of automated machines and the small scale of operations. Researchers have been exploring low-cost mechanized grading solutions to improve efficiency and consistency at a larger scale. However, further research is required on the grading of irregularly shaped mangoes. Development of cutting-edge systems, such as the vision-based classifier system, holds great promise. One pioneering research study used surface images to identify the ripening and decaying stages of mangoes, achieving 76% accuracy in identifying the maturity stage of TJC mangoes (Hippola *et al.*, 2022).

Research on Postharvest Treatments

Among various postharvest treatments for mango, irradiation can effectively eradicate pests and diseases on the fruit surface. Gamma radiation of 100–250 Gy can effectively control fruit fly emergence in *TJC* mangoes (Madhushani *et al.*, 2018).

The application of different coating treatments for mango varieties like *Karuthakolomban* and *TJC* has been extensively studied. Beeswax and essential oils such as basil, cinnamon, and citronella have shown promising defense mechanisms against diseases such as SER and anthracnose (Kodituwakku *et al.*, 2020; Kulasinghe *et al.*, 2019; Karunarathna *et al.*, 2021; Karunarathna *et al.*, 2022). Chemicals that are Generally Recognized As Safe (GRAS), such

Table 1: Recent research carried out on postharvest loss reduction strategies and their outcomes.(KK- *Karthakolomban*,VK- *Velleikolomban*, TJC- *Tom E JC*

Postharvest Strategy	Treatment	Outcome	Variety	Reference
Preharvest Treatments	Spray “Tree Fresh" (0.2% hexanal, ethanol, tween 20) 70% formulation triple spray	Extension of tree life by 4 weeks, reduced anthracnose and SER, improved marketability	TJC	(Hewajulige *et al.*, 2017)
	Spray potassium sulphate 2%, 4%, 6% W/V	Higher L* and a* colour parameters, peel thickness, TA, and pH, reduced anthracnose incidence	TJC	(Wijesinghe *et al.*, 2011)
	Spray Potassium chloride 2 gL^{-1}, on immature fruits	Decrease SER incidence and severity, no drastic change in physiochemical properties	TJC	(Nisansala *et al.*, 2015)
	Spray Calcium Chloride 10000 ppm with 0.1% teepol	Extend storage life by 4 days	KK, VK	(Krishnapillai *et al.*, 1996)
Harvesting	Identifying harvest maturity by different indices (e.g., raising shoulders, float test, harvesting with stalk)	Optimum maturity and reduced losses	KK, VK, Willard	(Amarakoon *et al.*, 1999a)
	Harvesting tools: Improved harvester, picking poles, hand picking	Best performance by improved harvester, lowest by hand picking	Willard, KK, VK	(Risvy and Thenaraj, 2019)
Decapping	Destemming and 5% sodium chloride dip and 1% Calcium hydroxide dip	Reduce sap burn injury, no change in physiochemical properties	KK, Willard, Chembaddan, Ambalavi	(Krishnapillai and Wijeratnam, 2016)
Washing	Washing using BiOWiSH™ liquid	Improved visual quality rating	KK	(Gunathilake and Tiwari, 2018)
Hot Water Treatment	Hot water temperature 50–53°C for 5 minutes	Reduce anthracnose and SER symptoms by 20–30%, attractive color, increased market value	KK, Ampalavi, Willard	(Krishnapillai, 2004)
Vapor Heat Treatment	47°C for 15 mins	Eradicate fruit fly in mango	TJC	(Wickramarachchi, 2020)
Sorting/Grading	Vision-based classifier to identify ripening and decaying stages using surface images	76% accuracy in identifying the maturity stage	TJC	(Hippola *et al.*, 2022)
Aloe Gel Coating	Dip treatment of Aloe vera gel + Cinnamon leaf oil	Control SER when stored at 12–14°C, extend postharvest life to 10 days	KK	(Karunarathna *et al.*, 2022)
Storage	Cold storage at 10°C, 85–90% RH	Longer storage life, lower TSS, pH, TA	KK, VK, Willard	(Krishnapillai *et al.*, 1996)
MAP (Modified Atmosphere Packaging)	MAP in LDPE bags + basil/clove/cinnamon oil spray	Control SER by 93% during storage at 12–14°C for 8 days	KK	(Kodituwakku *et al.*, 2020)
Collective Measures	Optimum maturity, specialized harvester, desapping on rack, proper handling	Reduced quality loss, increased shelf life, firmness, and color	KK	(Herath *et al.*, 2021)

as sodium bicarbonate and sodium metabisulfite solutions, and fumigation with clove and cinnamon oil have also been successful in controlling anthracnose disease without altering any quality parameters (Kalupahana *et al.*, 2020). Additionally, mixing natural antimicrobial and antioxidant materials with coating agents is a promising "green" technology. Edible coatings formed from bioactive peptides produced from lacto-fermentation of palm kernel cake with *Lactobacillus plantarum* in chitosan provided an antifungal effect against anthracnose and SER, with a shelf life of 18 days at 25°C (Ranjith *et al.*, 2022a; Ranjith *et al.*, 2022b). Despite the numerous studies, further consideration is needed to investigate the practical applicability and scalability of these treatments.

The application of 1-MCP is still limited to research in Sri Lanka. Bandara *et al.* (2020) found that applying

2 ppm 1-MCP for 12 hours could delay ripening and extend the shelf life of TJC mangoes for up to 4 weeks when stored at 14°C.

Postharvest application of hexanal could delay ripening, lower disease incidence and provide higher marketability (Perera *et al.*, 2016). Application of elicitors such as Salicylic acid was reviewed by (Bambalele *et al.*, 2021); being an enzyme that interferes with the physiological activity of plants, and shown potential in reducing chilling injury and controlling anthracnose by improving disease resistance. Salicylic acid, Methyl jasmonate, and Nitric Oxide triggered phytochemical production during ripening (Vithana *et al.*, 2018). Despite recent advances, there is still a need for further research on the practical applicability and effectiveness of these pre-treatment methods in the Sri Lankan context.

Research on Artificial Ripening

Artificial ripening of mangoes is often carried out using ethylene application. Ethrel is a commercial product containing ethephon as its active ingredient. Ethrel reacts with a lime solution containing calcium hydroxide, controlled releasing ethylene gas, into the ripening chamber (Barmore, 1974). The recommended protocol involves preparing separate solutions of diluted ethephon (1 mL ethephon, ethrel 240 g L–1, in 1 L water) and hydrated lime (10 g calcium hydroxide in 1 L water) (Peiris, 2016; Herath *et al.*, 2021). Then for each cubic meter of the chamber, solutions are mixed at 110–150 mL of the ethephon solution to 185 mL of the lime solution in a plastic or clay container and placed within the chamber and sealed. After 24 hours, the chamber is opened and kept for another 48 hours to complete the ripening process (Peiris, 2016; Herath *et al.*, 2021). A study found that an ethephon concentration of 100 ppm for 12 hours was the best treatment for *Karuthakolomban* mangoes, resulting in higher acceptability and marketability (Sewwandi *et al.*, 2020). Another study found that the application of 250 ppm ethylene gas or 1.65ml Ethrel® and 0.8g NaOH for 24 hours at ambient temperature was the best for ripening mangoes within 4-5 days (Jayawickreme, 2002). However, it should be noted that the Calcium carbide and direct application of ethephon to fruits is banned in Sri Lanka.

Research on Packaging (Controlled atmospheric packaging -CAP/ Modified atmospheric packaging - MAP)

A study found that the use of plastic crates during transportation from field to packhouse, followed by final packing in 5-ply corrugated fiberboard boxes with ventilation, extended the postharvest life of mangoes by 4 days and slowed down the softening and color change (Herath *et al.*, 2021).

Another study found that packing *Karuthakolomban* mangoes in a modified atmosphere (MA) using 0.05 mm low-density polyethylene (LDPE) bags with granular charcoal as CO_2 scavengers delayed ripening for 16 days, and up to 21 days with $KMnO_4$impregnated bricks as ethylene scavengers (Illeperuma and Jayasuriya, 2002). Another study showed that packing mangoes in perforated polythene bags increased the shelf life by 4 days in Willard and 2 days in *Velleikolomban*. For *Karuthakolomban* mangoes, it was found that storage life increased with decreasing temperature (Krishnapillai *et al.*, 1996). Additionally, the inclusion of $KMnO_4$ impregnated vermiculite in the packaging extended the storage life and improved the acceptability of *Karuthakolomban* mangoes (Krishnapillai *et al.*, 1996).

Use of MAP packaging with basil, clove, cinnamon leaf and cinnamon bark essential oil sprays could reduce SER severity to 0.3 – 1.1%, compared to the 15% severity in control, during storage at 12-14°C for 8 days without any change of physical properties (Kodituwakku *et al.*, 2020).

Eco-friendly packaging is popularizing. Banana pseudo stem fruit wraps disinfected with gamma (25 kGy irradiation) can be an alternative to Styrofoam sleeves as it preserves the quality of TJC mangoes (Yoga Milani *et al.*, 2020). Incorporating hexanal into banana fibre, polymeric material, and biopolymer-based fruit wraps also preserved the firmness and marketability of TJC mangoes for up to 21 days at a temperature of 13.5°C ± 2°C in cold storage (Samarawickrama *et al.*, 2018).

Research on Precooling and Storage

Precooling or cold storage technology is essential for maintaining the quality of fresh produce, but it can be costly in developing countries, which makes it difficult for small-scale farmers to adopt (Ntsoane *et al.*, 2019). Therefore, it is necessary to research alternative methods of cooling the produce. However, no studies have been conducted on alternate systems for Sri Lankan mangoes so far. One study conducted on cold storage (10°C, 85-90% RH) and refrigerated storage (12-14°C, 70-75% RH), found that cold-stored fruits had a longer shelf life and lower TSS and acid development (Krishnapillai *et al.*, 1996). Further research is necessary to explore feasible and cost-effective methods for precooling and cold storage of Sri Lankan mangoes, especially for small-scale farmers.

Research on Shipping of Mangoes

There has been less information on the shipping of mangoes (Le *et al.*, 2022) and none on Sri Lankan mangoes. However, there should be proper research and knowledge on the damages occurred at this part of distribution process and strategies to overcome.

CONCLUSIONS

In conclusion, postharvest loss prevention strategies are crucial to ensure the quality and marketability of mangoes in Sri Lanka. These strategies can be categorized into preharvest strategies, harvesting, primary processing activities at the field, packhouse operations, post packhouse operations and transportation. However, it was found that there is a significant gap between the recommended and currently adhered postharvest handling practices in Sri Lanka. Major contributors are, inadequate use of preharvest strategies, inappropriate harvesting practices, inadequate field operations to prevent disease infections and spreading, lack of pack house operations, insufficient use of postharvest treatments to prevent loss, questionable ripening protocols, problematic transportation practices and lack of storage facilities. However, export-oriented, commercial entities specialized mostly in TJC cultivar, adhere to recommended postharvest loss prevention strategies.

Although several research studies have been conducted in Sri Lanka to decrease postharvest losses, many of them were halted at the primary level, and there is a lack of follow-up, application of findings on a commercial scale, or implementation of the recommendations. Furthermore, research on areas such as transport, handling, and storage is limited. In addition, the research on cost-effective postharvest strategies like low-cost cooling, packaging, cold storage and shipping is limited or non-existent.

RECOMMENDATIONS FOR FUTURE INTERVENTION

To effectively address postharvest loss in the Sri Lankan mango industry, it is critical to conduct research and field surveys to gain a deeper understanding of the quality loss, quantitative loss, and loss prevention strategies used by stakeholders throughout the supply chain. This information can help to identify specific areas for improvement and guide the development of targeted interventions.

Therefore, it is recommended that further research be conducted to address the gaps identified in postharvest loss prevention strategies. This will help to optimize the harvesting, sorting, handling, transportation, and storage of mangoes in Sri Lanka and ensure their quality, which will benefit both the local and export markets. Further research is needed to identify the most effective transportation methods and to develop strategies for minimizing quality loss during transport. Secondly, the identification of cost-effective postharvest treatments that can be implemented at scale is important. By identifying treatments that are both effective and affordable, stakeholders can be better equipped to prevent postharvest loss and increase profitability. Thereby, stakeholders can minimize postharvest loss and improve the quality of their mangoes. Further, there is a need for research on low-cost cooling, grading storage, and packing methods and effective quality preservation during shipping. Finally, effective knowledge dissemination is critical for ensuring that stakeholders are aware of the recommended postharvest loss prevention strategies and the newest research findings for local mango varieties. Research bodies should prioritize knowledge dissemination efforts and ensure that stakeholders have access to the latest information and resources.

DISCLOSURE STATEMENT

There are no competing interests to declare.

ACKNOWLEDGMENT

This work is supported by the Australian Center for International Agricultural Research (ACIAR) under grant CS/2020/193

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