

INVESTIGATING COLD CHAIN CHALLENGES AND SMART SOLUTIONS FOR REDUCING FRUIT AND VEGETABLE WASTAGE IN SRI LANKA

KURUWITAARACHCHI, C. N.¹, DISSANAYAKE, P.² AND CHANDANI, G.G.N.^{3*}

¹Department of Building Economics, University of Moratuwa, Sri Lanka

^{2,3} Department of Facilities Management, University of Moratuwa, Sri Lanka

*Correspondence E-mail: navodag@uom.lk

Abstract. *Post-Harvest Losses (PHL) smarting fruits and vegetables represent a critical challenge to global food security, particularly in developing nations such as Sri Lanka, where 30–40% of produce is wasted annually. Although cold chain systems are widely recognized as an effective solution for preserving the quality and safety of perishable goods through temperature and humidity control across the supply chain, limited empirical research has examined how such systems can be effectively adopted in the Sri Lankan context to reduce waste. Therefore, this study aimed to investigate inefficiencies in handling, storage, and transportation across different supply chains, with particular attention to the potential of smart and affordable cold chain technologies. A qualitative research design was employed, drawing on fifteen semi-structured expert interviews conducted with stakeholders from supermarket, export, and traditional market supply chains, as well as specialists in post-harvest management and cold chain design. Data were analysed using manual content analysis. Findings reveal that while supermarket and export supply chains demonstrate effective cold chain practices, the normal market supply chain, which serves the majority of the population, suffers severe losses due to poor packaging, rough handling, and a lack of cooling facilities. The study recommends affordable, decentralised cold chain solutions, complemented by farmer training, behavioural change initiatives, and coordinated policy support. Strengthening cold chain adoption in Sri Lanka is essential not only to reduce food wastage but also to enhance food security, improve farmer livelihoods, and build economic resilience.*

Keywords. *Cold Chain, Post-Harvest Loss, Supply Chain.*

1. Introduction

Food waste has emerged as a critical global issue, with the Food and Agriculture Organization (FAO) estimating that 1.3 billion metric tonnes of food are lost annually, representing an economic loss of nearly USD 1 trillion (Gromko & Abdurasulova, 2019). Further, fruits and vegetables are particularly vulnerable, with 25–50% lost between farm and fork, a phenomenon commonly referred to as post-harvest loss (Bancal & Ray, 2022). Such losses occur across seven stages: harvesting, handling, storage, processing, packaging, transportation, and marketing (FAO, 2019). Contributing factors include poor pre-harvest and harvesting practices, inadequate transportation systems, defective packaging, rough handling, lack of capacity and coordination among stakeholders, insufficient storage and temperature management, climate variability, microbial deterioration, short shelf life, nonconformance to standards, and overproduction (Bancal & Ray, 2022).

When it comes to Sri Lanka, a similar situation can be observed. In Sri Lanka, the National Audit Office (2018) reported that 270,000 metric tonnes of fruits and vegetables are wasted annually, resulting in an economic loss of approximately 20 billion rupees. Post-harvest damage is estimated at 30–40%, while 73% of the adult population does

not consume adequate amounts of fruits and vegetables. These figures highlight both economic inefficiencies and nutritional implications.

Cold supply chains are widely recognized as an effective strategy to preserve the quality and safety of perishable products through controlled temperature and humidity management from production to consumption (Navya Sri et al., 2022). However, conventional cold chain systems mainly focus on refrigerated storage and transport, while a smart cold chain involves the use of affordable technology-enabled solutions such as temperature monitoring systems, traceability mechanisms, improved cool room facilities, and better transport coordination to improve supply chain efficiency and minimise wastage. These smart solutions are particularly important in developing countries where full-scale advanced cold chain infrastructure may not be financially feasible.

However, temperature-controlled storage and transportation facilities remain insufficient in Sri Lanka (Rajapaksha et al., 2021). Evidence from other developing contexts indicates that inadequate storage infrastructure significantly contributes to perishable food losses (International Institute of Refrigeration, 2009). Despite this, investment in cold chain infrastructure in South Asia remains limited due to financial constraints and insufficient technical awareness (International Institute of Refrigeration, 2009). Given the declining trends in fruit and vegetable production reported by the Central Bank of Sri Lanka (2022), addressing post-harvest inefficiencies is increasingly urgent. Storage and transportation represent critical intervention points within the post-harvest period. Therefore, this study aims to investigate cold chain challenges and identify smart cold chain solutions for reducing fruit and vegetable post-harvest losses in Sri Lanka. The specific objectives are to (1) examine existing inefficiencies in handling, storage, and transportation across different supply chains, and (2) evaluate the potential of affordable smart cold chain technologies for improving post-harvest management, with particular focus on the Dambulla Dedicated Economic Centre. The findings aim to inform policy, guide implementation in other economic centres and collection points, and provide a foundation for future research.

2. Literature Review

2.1. POST-HARVEST PERIOD AND REASONS FOR FRUIT AND VEGETABLES WASTAGE

Researchers have offered multiple explanations for Post Harvest Loss (PHL), though all converge on the same meaning: the measurable quantitative and qualitative reduction of products at any point in the chain from harvest to consumption (Kikulwe et al., 2018). Navya Sri et al. (2022) describe PHL as the loss occurring between harvesting and consumption due to both qualitative and quantitative deterioration, while Tandan Chhetri et al. (2023) emphasize degradation in terms of quantity and quality across the entire journey from harvest to consumer.

The Indian Institute of Horticultural Research (2014) categorizes post-harvest losses into five stages: production/harvest, post-harvest handling and storage, processing,

distribution, and consumption. These losses represent not only reduced food availability but also wasted resources such as land, water, energy, and inputs. After harvesting, critical steps including cooling, cleaning, sorting, grading, packaging, storing, transporting, and marketing are particularly vulnerable to high losses (Tandan Chhetri et al., 2023). Table 1 illustrates estimated levels of post-harvest losses across Asia-Pacific countries, highlighting the scale of the issue. For instance, India records losses of up to 40%, Indonesia and Korea report 20–50%, while Sri Lanka experiences losses ranging from 16–41% (Rolle, 2006, as cited in Tandan Chhetri et al., 2023). These figures underscore the systemic nature of PHL across the region.

Table 1: Estimated levels of post-harvest losses in the Asia Pacific Region

Country	Estimated Level of Losses (%)
India	40
Indonesia	20-50
Iran	>35
Korea	20-50
Philippines	27-42
Sri Lanka	16-41
Thailand	17-35
Vietnam	20-25

Source: (Rolle, 2006, as cited in Tandan Chhetri et al., 2023)

2.1 COLD CHAIN USAGE IN SRI LANKA

Several reasons for post-harvest loss have been identified through the different studies. The study of Rathnayake et al. (2022) identified that improper handling, lack of knowledge among farmers, and insufficient cold storage facilities contribute significantly to the wastage of fruits and vegetables in Sri Lanka. Moreover Karunaratna et al. (2023) stated that vulnerabilities in the supply chain, leading to increased losses and underscoring the need for improved cold chain management practices.

The agricultural supply chain in Sri Lanka is characterised by traditional practices that often neglect modern logistics strategies. For instance, the rice supply chain has been noted for its inefficiencies, which can be mitigated through better collaboration and information flow among stakeholders (Weerabahu & Nanayakkara, 2014). It is same as the fruit and vegetable products also. This is crucial staple in Sri Lankan diets, and any inefficiencies can lead to food insecurity. Furthermore, the lack of empirical research on supply chain risk management in the Sri Lankan context suggests a gap in understanding how to effectively implement cold chain logistics (Sugathadasa et al., 2020). Moreover, the integration of technology into cold chain logistics is essential for enhancing visibility and efficiency. The use of smart containerization has been proposed to improve supply

chain visibility, which is particularly relevant in the context of sea freight for agricultural exports (Rathiverni & Perera, n.d.).

This technological advancement can help in tracking the conditions of perishable goods throughout their journey, thereby reducing spoilage and ensuring that products reach consumers in optimal condition. In addition to technological improvements, there is a pressing need for training and capacity building among farmers and logistics providers. Studies have shown that enhancing individual skills and performance within organizations can lead to more effective supply chain operations (Rajakaruna et al., 2017). This principle can be applied to the agricultural sector, where educating farmers about proper harvesting, handling, and storage techniques is crucial for minimizing losses (Rajapaksha et al., 2021). Finally, the economic implications of a robust cold chain cannot be overstated. The agricultural sector is a significant contributor to Sri Lanka's GDP, and improving cold chain logistics can enhance the competitiveness of Sri Lankan products in both local and international markets. If Sri Lanka can overcome the challenges in cold chain management, it can not only reduce food wastage but also improve food security and economic resilience.

Sri Lanka requires efficient and well-managed cold chain systems to reduce fruit and vegetable post-harvest losses and improve food security. Previous studies have identified several causes of wastage, including poor handling practices, inadequate transportation, insufficient storage facilities, and weak cold chain management. These issues not only reduce food availability but also create significant economic losses for farmers and the national economy. Although earlier studies have discussed post-harvest losses and general cold storage challenges, limited research has specifically examined how affordable smart cold chain solutions can be adapted to local supply chain conditions in Sri Lanka. Most existing studies focus on conventional cold storage problems rather than practical, technology-enabled interventions such as temperature monitoring, traceability systems, and improved cool room management. Therefore, this study addresses this research gap by exploring suitable smart cold chain solutions to improve supply chain efficiency and reduce fruit and vegetable wastage in Sri Lanka.

3. Research Methodology

A qualitative research approach was adopted to achieve the study objectives, as the research seeks to explore a complex socio-technical issue situated within real-world supply chain contexts. Qualitative inquiry is particularly appropriate for understanding participants' experiences, perceptions, and interpretations of social phenomena (Creswell, 2003). Given that this study investigates the adaptability of smart cold chain technologies to mitigate fruit and vegetable wastage in Sri Lanka, an in-depth exploration of stakeholder perspectives was essential. The study focused on three interrelated domains:

existing supply chain structures in Sri Lanka, the nature and causes of post-harvest losses, and the current status of cold chain and cool room infrastructure.

A total of fifteen expert interviews were carried out across three supply chain categories: supermarket supply chains, export market supply chains, and normal market supply chains. In addition, interviews were conducted with specialists in post-harvest loss management and cold chain design. The respondent profile is presented in Table 2.

Table 2: Profile of the Respondents

Interview Number	Study Field	Interview category	Expert's Identity	Code
1	Investigation of supply chains in Sri Lanka	Supermarket supply chain	Expert 01	EI-SSC1
2			Expert 02	EI-SSC2
3			Expert 03	EI-SSC3
4		Export market supply chain	Expert 01	EI-ESC1
5			Expert 02	EI-ESC2
6			Expert 03	EI-ESC3
7		Normal market supply chain	Expert 01	EI-NSC1
8			Expert 02	EI-NSC2
9			Expert 03	EI-NSC3
10	Investigation of post-harvest loss in Sri Lanka	Experts on post-harvest loss management	Expert 01	EI-PHLM1
11			Expert 02	EI-PHLM2
12			Expert 03	EI-PHLM3
13	Investigation of cold chain and cool room designing	Experts on cool room design	Expert 01	EI-CCD1
14			Expert 02	EI-CCD2
15			Expert 03	EI-CCD3
Abbreviations: EI – Expert Interview SSC – Supermarket Supply Chain ESC – Export Market Supply Chain NSC – Normal Market Supply Chain PHLM – Post Harvest Loss Management CCD – Cold Chain Design				

To enrich the practical perspective, ten farmers (coded F1–F10) and three transport drivers (coded D1–D3) were also interviewed. These participants provided ground-level insights into handling, storage, and transportation practices. Additionally, specialists in post-harvest loss management and cool room design experts shared insights on reducing wastage and improving storage conditions. The study also included an interview with a key stakeholder from the Dambulla Economic Centre to understand its role in the supply chains. These interviews helped identify critical gaps and potential improvements in the country's cold chain and logistics systems. All interviews were transcribed and analyzed using manual content analysis with thematic coding. The analysis involved identifying recurring themes related to supply chain gaps, post-harvest losses, and the potential application of smart cold chain technologies such as temperature monitoring, traceability, and improved storage management. The use of multiple stakeholder groups improved the reliability of the findings through data triangulation.

4. Findings and Analysis

4.1 REASONS FOR POST HARVESTING LOSS IN SRI LANKA

Findings from expert interviews reveal that PHL in Sri Lanka is driven by systemic weaknesses across cultivation planning, treatment practices, processing, cold chain infrastructure, transport, storage, and the limited application of food science technologies.

4.1.1 Lack of Proper Cultivation Planning

Experts emphasized the absence of demand-driven cultivation planning. As EI-PHLM1 stated, "Farmers do not have proper cultivation plans for their crops." Farmers often base decisions on previous season prices, leading to overproduction and price crashes. EI-PHLM2 noted, "Farmers always depend on last season's prices... Then overproduction may occur, and prices will rapidly reduce." Government attempts to guide crop selection through media campaigns resulted in excess supply and conflicts. Farmers prioritize profitability, as F1 explained: "There is no point in harvesting a crop type if we can't earn money from it."

4.1.2 Inadequate Crop Treatment and Environmental Challenges

Improper crop treatment significantly contributes to PHL. EI-PHLM1 highlighted, "We cannot protect the harvest if farmers do not do the crop treatment series well." However, farmers cited high fertilizer costs as a barrier. Wildlife damage, flooding, and Sri Lanka's tropical climate further aggravate losses, indicating the need for multi-stakeholder intervention and scientific mitigation strategies.

4.1.3 Processing Stage Losses

Processing was identified as the most critical loss point. EI-PHLM1 stated, "Processing is one of the main stages where more wastage happens," estimating nearly 70%

of losses occur here. Traditional use of poly sacks during transport causes mechanical damage. EI-PHLM2 mentioned, "Most of the farmers still use poly sacks; for that reason, there is wastage when transporting, loading, and unloading products." Although plastic crates can reduce damage, cost, return logistics, and reduced vehicle capacity remain challenges.

4.1.4 Insufficient Cold Chain Infrastructure

Sri Lanka's normal market supply chain lacks temperature control. EI-PHLM1 noted, "There is no temperature control supply chain (cold supply chain) in the normal market." EI-PHLM2 emphasized that a cold chain must ensure temperature control throughout the entire chain. Precooling is critical, as EI-PHLM3 stated, "Precooling is essential... otherwise, there is no significant benefit of using a cold chain."

4.1.5 Inefficient Transport and Storage

Transport and storage account for 50–60% of the total PHL (EI-PHLM1). Poor loading practices and long-distance transportation (200–400 km) exacerbate damage. Exposure to sunlight and rain due to inadequate storage facilities further reduces quality.

Experts stressed the importance of sorting, grading, maturity identification, temperature management, and pre-treatment. EI-PHLM1 stated, "We can't put all the fruit and vegetables all together." EI-PHLM3 emphasized maturity assessment and suggested ozonated water treatment to reduce pathogens. Additionally, EI-PHLM3 noted that "the ethylene sensitivity test must assure the quality of products," while EI-PHLM2 warned, "Fusarium fungi originate if there are soil particles on the products."

Overall, findings indicate that post-harvest loss in Sri Lanka is largely supply chain-related, requiring integrated planning, technological adoption, cold chain development, and coordinated government and stakeholder intervention.

4.2. SUPPLY CHAIN GAPS CONTRIBUTING TO FRUIT AND VEGETABLE WASTAGE IN SRI LANKA

Supply chains for perishable goods in Sri Lanka vary significantly in structure, management, and technology adoption. These variations strongly influence the efficiency of handling, storage, and transportation, and consequently affect the level of post-harvest loss. Understanding the operational characteristics of different supply chains provides a foundation for identifying critical inefficiencies and opportunities for improvement. This section examines three main types of supply chains in Sri Lanka, namely supermarket, normal market, and export market and highlights the key areas where inefficiencies occur.

4.2.1 Supermarket Supply Chains

Supermarkets in Sri Lanka generally have structured and partially automated supply chains, including centralized hubs, refrigerated transport, and grading procedures. Despite these organized systems, inefficiencies still exist due to operational and logistical

challenges. Forecasting product demand remains a major challenge. EI-SSC1 noted, "We are doing 140 - 150 tons of fruit and vegetable sales per day. Therefore, forecasting the products from suitable amounts is a very tough process." Incorrect forecasting directly results in wastage, with reports showing 4 to 7 per cent of products wasted daily, equating to 6 to 8 tons.

Processing methods can also damage products. EI-SSC2 stated, "Poly sack bags cause considerable damage to fruit and vegetables." While supermarkets use plastic crates, the lack of affordable, high-quality crates from farms increases the risk of damage during initial collection. Transportation inefficiencies occur during distribution. Although refrigerated vehicles are used, temperature variations still happen. EI-SSC1 highlighted, "We have a vehicle monitoring system to track all the vehicles we use in our operation," yet breakdowns or unloading periods can cause temperature disruptions. Storage is another challenge; central cool rooms are monitored only manually every four hours, leaving room for unnoticed temperature deviations. Experts emphasized that "If there is a breakdown in a refrigerated vehicle, sometimes we have to remove the contents inside it," which could lead to significant spoilage

4.2.2 Normal Market Supply Chains

The normal market supply chain in Sri Lanka represents traditional, largely uncoordinated channels of agricultural distribution, including farmers, village collectors, wholesalers, and retailers. Unlike supermarkets, these markets operate without formal forecasting or centralized management, which creates unique inefficiencies. Farmers often harvest based on weather or market trends rather than actual demand, leading to oversupply. EI-NSC1 explained, "In normal markets, the farmer often decides what and when to harvest based on weather and market trends." This unpredictability results in 15 to 20 per cent daily waste.

Post-harvest handling is inadequate. Products are packaged in poly sacks, stacked without airflow, and transported in open or poorly ventilated vehicles. EI-NSC3 said, "We package everything in sacks and offer it for sale exactly as it is." Lack of grading and sorting further accelerates spoilage as overripe or damaged items contaminate others. Storage and pre-cooling are almost non-existent. EI-NSC2 mentioned, "Leafy vegetables like spinach and coriander begin to wilt by the afternoon," reflecting the absence of temperature control. Poor road infrastructure and delayed transport exacerbate losses, while limited stakeholder knowledge on post-harvest handling compounds the problem. EI-NSC2 added, "We've never learnt how to store or pack vegetables." Overall, the absence of monitoring, traceability, and cold chain integration makes this supply chain the most vulnerable to wastage.

4.2.3 Export Market Supply Chains

Export-oriented supply chains are highly structured and comply with international quality standards, including strict pre-cooling, grading, storage, and transport protocols. While technologically advanced, they remain vulnerable to critical inefficiencies that can

have severe financial and reputational consequences. Even minor temperature deviations during transport pose risks. EI-ESC3 remarked, "Even a 2°C fluctuation during transportation can set off alarms." Pre-cooling, grading, and storage are carefully monitored, yet manual logging and limited automation increase the risk of errors. EI-ESC2 noted, "They manually log some of the readings and do not yet have a fully automated monitoring system." Coordination among small-scale farmers presents additional challenges. Many cannot meet export requirements due to limited capacity or knowledge, EI-ESC1 said, "Our clients abroad send demand schedules weeks in advance, and our collecting and processing schedule revolves around that." Finally, ethylene control and ripening management remain costly and complex, contributing to operational inefficiencies despite the advanced infrastructure.

The comparative analysis of supermarket, normal market, and export supply chains reveals that inefficiencies vary by structural maturity, technological adoption, and stakeholder coordination. However, temperature management emerges as a cross-cutting vulnerability across all three systems. This highlights the need for an integrated smart cold chain framework capable of addressing systemic inefficiencies

4.3. ROLE OF COLD CHAIN SOLUTIONS IN MINIMIZING SUPPLY CHAIN INEFFICIENCIES

Cold chain solutions play a crucial role in reducing inefficiencies in handling, storage, and transportation across Sri Lanka's fruit and vegetable supply chains. In supermarkets, while organized systems exist, forecasting remains a challenge, with EI-SSC1 noting, "We are doing 140 - 150 tons of fruit and vegetable sales per day. So forecasting the products from suitable amounts is a very tough process." Implementing cold chain practices such as pre-cooling and the use of standardized plastic crates ensures that products maintain quality from collection centres to central hubs, reducing losses caused by poor handling or inappropriate packaging. For normal markets, which currently rely on poly sack bags and open or poorly ventilated transport, introducing small-scale pre-cooling units, mobile refrigerated transport, and basic storage facilities can mitigate spoilage caused by rough handling, heat exposure, and overripe produce, addressing the 15 to 20 per cent daily waste reported by stakeholders.

Export supply chains, though advanced, remain sensitive to temperature fluctuations, with EI-ESC3 highlighting, "Even a 2°C fluctuation during transportation can set off alarms." Automated monitoring systems and strict temperature-controlled transport help prevent consignments from being rejected and ensure compliance with international standards. Across all supply chains, cold storage infrastructure, whether centralized in supermarkets or decentralized in local markets, maintains optimal temperatures, slows ripening, and protects against ethylene-related quality degradation. Experts emphasized the importance of continuous monitoring, with EI-CCD2 stating, "We have to focus on data loggers because we have to monitor temperature throughout this entire cold chain," underscoring the role of smart technologies in improving traceability and operational efficiency. By integrating pre-cooling, temperature-controlled transport, appropriate storage, and real-time monitoring, cold chains address the root causes of post-harvest losses, enhance product quality, and offer a sustainable strategy to minimize wastage across Sri Lanka's diverse supply chains.

As summarized in Table 3, each supply chain category demonstrates distinct operational inefficiencies, yet temperature management emerges as a common vulnerability across all systems. The table illustrates how targeted smart cold chain interventions, including pre-cooling, real-time monitoring, standardized packaging, and automated storage, can directly address these supply chain-specific weaknesses.

Table 3: Comparative Supply Chain Inefficiencies and Cold Chain Solutions

Supply Chain	Identified Inefficiencies	Cold Chain Solutions
Supermarket	Difficulty forecasting product demand	Pre-cooling at collection centres
	Damage during processing (e.g., use of poly sack bags)	Use of standardized plastic crates from farm to hub
	Temperature variations during transportation	Refrigerated vehicles with real-time monitoring
	Manual monitoring of storage leading to unnoticed deviations	Automated temperature monitoring in cool rooms
Normal Market	Harvesting based on weather/market trends, not demand	Community-level pre-cooling units
	Poor post-harvest handling (stacked poly sacks, rough transport)	Mobile refrigerated transport
	Lack of storage and pre-cooling	Basic cold storage facilities at local markets
	No monitoring or traceability	Training on proper grading, handling, and storage
Export Market	Sensitivity to temperature fluctuations during transportation	Strict temperature-controlled transport with real-time monitoring
	Limited automation in monitoring	Automated storage and monitoring systems
	Coordination challenges with small-scale farmers	Support for small-scale farmers to meet export standards
	Costly ethylene control and ripening management	Pre-cooling, ethylene absorbers, and multi-zone storage

5. Discussion

The findings of this study provide important insights into the systemic nature of fruit and vegetable post-harvest losses (PHL) in Sri Lanka and highlight the critical role of supply chain structure, infrastructure limitations, and behavioural practices in influencing wastage levels. Rather than being isolated issues, the results demonstrate that PHL is a cumulative outcome of inefficiencies across multiple interconnected stages of the supply chain. A key finding is that the lack of coordinated cultivation planning significantly contributes to supply-demand mismatch and price instability. Farmers' reliance on previous season price signals leads to cyclical overproduction, which aligns with classical supply chain inefficiency theories where poor demand forecasting results in surplus and wastage. This indicates that post-harvest loss in Sri Lanka begins not only after harvesting but is embedded at the production planning stage, reinforcing the need for upstream

intervention strategies such as demand-driven agriculture and market information systems. Another important insight is the role of handling and packaging practices, particularly the continued use of poly sacks in normal market supply chains. The findings show that mechanical damage during loading, unloading, and transport is a persistent issue. This is not merely a logistical limitation but also reflects behavioural and economic constraints among farmers and traders, where cost considerations override quality preservation. This finding is consistent with previous studies that highlight packaging as a critical determinant of perishable food losses in developing economies. The study also reveals that cold chain infrastructure is highly uneven across supply chains. While supermarket and export chains demonstrate partial adoption of temperature-controlled systems, the normal market supply chain remains largely unregulated and lacks basic cooling facilities. This creates a dual system where high-value supply chains benefit from advanced logistics, while the majority of domestic consumption relies on inefficient traditional systems. This structural imbalance is a key reason for persistent national-level food losses.

A particularly important contribution of this study is the identification of temperature management as a cross-cutting vulnerability across all supply chains. Even in relatively advanced export systems, small temperature fluctuations during transport were reported to cause significant quality risks. This indicates that the issue is not only infrastructure availability but also system reliability, monitoring, and real-time control—areas where smart cold chain technologies can play a critical role. The findings further highlight that post-harvest losses are not only technical but also behavioural and institutional in nature. Limited knowledge among farmers, weak coordination among stakeholders, and the absence of training in proper handling practices significantly amplify losses. This suggests that technological interventions alone will not be sufficient unless accompanied by capacity building and institutional strengthening. From a broader perspective, the study demonstrates that Sri Lanka's agricultural supply chains operate in a fragmented manner, where different supply chain types (supermarket, normal market, and export) function at different levels of efficiency. This fragmentation limits system-wide optimisation and prevents the development of integrated cold chain networks. Therefore, improving cold chain efficiency requires a holistic approach that combines infrastructure development, digital monitoring systems, and stakeholder coordination. Overall, the discussion indicates that reducing fruit and vegetable wastage in Sri Lanka requires moving beyond conventional cold storage solutions toward integrated smart cold chain systems, which combine temperature control, real-time monitoring, improved logistics coordination, and behavioural change among stakeholders. These findings contribute to a more nuanced understanding of post-harvest losses by linking operational inefficiencies with technological and institutional gaps.

6. Conclusion

This study confirms that post-harvest loss remains a critical structural challenge within Sri Lanka's fruit and vegetable sector, with an estimated 30–40% of production wasted annually, resulting in economic losses of nearly 20 billion rupees. Findings from qualitative expert interviews across supermarket, normal market, and export supply chains reveal that losses are not caused by a single factor, but by interconnected systemic inefficiencies. Key contributors include the absence of demand-driven cultivation

planning, inadequate crop treatment practices, poor handling and packaging methods, limited cold chain integration, and insufficient technical knowledge among stakeholders.

The analysis further demonstrates that although supermarket and export supply chains have partially adopted temperature-controlled systems and structured quality management practices, operational gaps such as forecasting errors, manual monitoring, and temperature fluctuations still result in measurable losses. In contrast, the normal market supply chain, which distributes the majority of produce to the population, experiences the highest wastage due to minimal cold storage facilities, reliance on traditional transport methods, lack of grading and sorting, and weak coordination mechanisms.

The findings highlight that smart cold chain solutions particularly pre-cooling, real-time temperature monitoring, standardized packaging, and decentralized cold storage at major collection hubs such as the Dambulla Economic Centre, represent a practical and scalable intervention. However, technological upgrades alone cannot eliminate post-harvest loss. Sustainable impact requires behavioural transformation among farmers, institutional coordination across ministries, targeted capacity-building programs, and context-appropriate, cost-effective cold chain models. Strengthening the integration between traditional agricultural practices and smart cold chain technologies is therefore essential to improve food security, minimize economic losses, and enhance the long-term sustainability of Sri Lanka's fruit and vegetable supply chains.

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