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R E S E A R C H   P A P E R

INVESTIGATING THE EFFECT OF THE COLD CHAIN ON THE REDUCTION OF POST-HARVEST LOSSES IN THE FRUIT AND VEGETABLE SUPPLY CHAIN IN FRESH FOOD MARKETS IN KAMPALA, UGANDA

A U T H O R S

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16.9%	91	72.9%
Average Weekly Produce Loss	Respondents | 5 Markets	Willing to Pay for Cold Storage

Study Area: Nakawa | Busega | Nakasero | Kalerwe | Nateete, Kampala, Uganda

***Keywords:** Cold chain, post-harvest losses, fruits and vegetables, food security, Kampala, Uganda*

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- Deliver evidence-based, impactful research and consultancy services that drive sustainable development across Uganda.
- Generate knowledge that informs better policy, investment and field decisions for governments, NGOs, private sector and communities.
- • Strengthen institutional capacity through rigorous monitoring, evaluation and training programmes.

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ABSTRACT

> *Post-harvest losses in Uganda's horticultural sector represent a critical challenge to food security, economic sustainability and environmental integrity. This study provides the first comprehensive, market-level empirical investigation of cold chain effectiveness across five major fresh food markets in Kampala.*

This study investigates the effects of cold chain systems on the reduction of post-harvest losses in the fruit and vegetable supply chain across five major fresh food markets in Kampala, Uganda, namely Nakawa, Busega, Nakasero, Kalerwe and Nateete. Using a mixed-methods cross-sectional design, data were collected from 91 respondents including wholesalers, vendors, retailers, transporters, policymakers and market authorities.

The study employed structured surveys, focus group discussions (FGDs), key informant interviews (KIIs), structured field observations and a controlled refrigeration experiment involving tomatoes and carrots stored at 8-10°C for over 16 days. Traders handled an average of 1,650.8 kg of produce per week, with an overall pre-sale loss of 16.9%. Wholesalers incurred significantly higher losses (8.94%) than vendors (6.3%) and transporters (1.65%), a difference confirmed statistically ($F = 3.951$, $p = 0.023$, *Tukey HSD:* $p = 0.017$).

The refrigeration experiment demonstrated that cold storage extended tomato marketable shelf-life from approximately 4 days (ambient market conditions) to 6 days, and carrots from 4 to 7 days. Despite limited current adoption, only 12% of cold storage-aware traders had used such facilities, over 72.9% expressed willingness to pay Ugx. 500-1,000 per kg per day. Awareness was significantly associated with willingness to pay ($\chi^2 = 14.886$, $p = 0.0006$). Key barriers included high capital and operational costs (90.6% of respondents), lack of technical training (100%), unreliable electricity and poor spatial accessibility.

The study concludes that cold chain systems hold transformative potential for reducing spoilage, improving trader incomes, enhancing food security and supporting Uganda's Sustainable Development Goal commitments. Coordinated multi-stakeholder interventions encompassing infrastructure investment, renewable energy integration, capacity building and supportive policy frameworks are essential to realizing this potential.

Keywords: *Cold chain, post-harvest losses, food security, fruits and vegetables, Kampala markets, refrigeration, supply chain, Uganda, smallholder farmers*

LIST OF ACRONYMS

ANOVA	Analysis of Variance
CCM	Cold Chain Management
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus Group Discussion
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IoT	Internet of Things
KCCA	Kampala Capital City Authority
KII	Key Informant Interview
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MLR	Multiple Linear Regression
NPA	National Planning Authority
PPP	Public-Private Partnership
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
TTI	Time-Temperature Indicator
UBOS	Uganda Bureau of Statistics
UNBS	Uganda National Bureau of Standards
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UGX	Ugandan Shilling
WSN	Wireless Sensor Network

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Food production will need to increase significantly to feed the expected global population of 9.7 billion by 2050 (United Nations, 2019). Meeting this challenge requires not only producing more food but also dramatically reducing what is lost or wasted at every stage of the supply chain. The lack of effective cold chain infrastructure is a leading contributor to global food loss and waste, with serious implications for food security, livelihoods, nutrition and the environment (UNEP & FAO, 2022). A food cold chain is an integrated temperature-controlled food distribution system that ensures the quality, nutritional value and safety of perishable produce from farm to consumer (FAO, 2022).

The cold chain plays a pivotal role in extending the shelf life of fruits, vegetables, dairy, meat and fish. Global cold chain infrastructure has grown rapidly in recent decades; however, this growth has been profoundly uneven (UNDP, 2021). While most developed countries now possess well-established cold chain systems, many developing economies, whose populations depend heavily on agriculture for livelihoods, remain significantly underserved.

In Uganda, agriculture contributed approximately 24% of GDP and 35% of export earnings in the financial year 2022/23, employing about 68% of the working population (MAAIF, 2024; UBOS, 2024). Despite its central importance, Uganda's agricultural sector faces persistent challenges: limited fertilizer use, and quality seeds, climate extremes, pest infestations and, critically, the near-absence of effective post-harvest management systems, especially cold storage (MAAIF, 2021). Uganda encounters formidable obstacles in establishing cold chain infrastructure, including expensive refrigerated storage facilities, inconsistent electricity supply, insufficient technical skills and a lack of investment in logistics (UBOS, 2022).

These systemic gaps translate directly into economic losses. In Kampala, food traders waste between 1.6 and 7.6 kilograms of food daily, with the highest rates recorded at Kalerwe market (Florence et al., 2024). Food waste leads to greenhouse gas emissions, land degradation and water loss, directly undermining Uganda's Sustainable Development Goal (SDG) commitments, specifically SDG 3 (Good Health and Well-being), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 15 (Life on Land) (FAO, 2021; World Bank, 2022).

> *Private sector evidence validates that preservation facilities can improve shelf life of fruits and vegetables by at least one additional week compared to normal systems that keep produce for only two days (GIZ, 2022; African Women Agribusiness Network, 2023).*

1.2 Problem Statement

Globally, an estimated 14% of all food produced for human consumption is lost, and a further 17% is wasted, costing the global economy an estimated USD 936 billion annually (FAO, 2019; UNEP, 2021). The absence of effective refrigeration directly causes the loss of approximately 526 million tons of food production, enough to feed approximately one billion people in a world where 811 million currently face hunger and three billion cannot afford a healthy diet (IIR, 2021; FAO, 2022).

In Uganda, post-harvest losses of up to 40% have been reported for fresh fruits and vegetables (FAO, 2021). Spoilage rates are estimated at 30-50% owing to inadequate refrigeration during storage and transportation (MAAIF, 2023). Yet despite this recognized crisis, empirical research specifically investigating the effectiveness of cold chain facilities in Kampala's fruit and vegetable markets is limited. Most existing literature focuses on industrial logistics or export-oriented systems, neglecting the informal market networks that dominate urban food distribution. This gap in localized, evidence-based knowledge constrains policymakers, investors and development partners from designing effective interventions.

This study directly addresses that gap by: (i) quantifying post-harvest losses at five key markets; (ii) assessing barriers to cold chain establishment; and (iii) identifying opportunities for improving cold chain systems in Kampala's fresh food markets.

1.3 Objectives

1.3.1 General Objective

To investigate the effects of cold chain on the reduction of post-harvest losses in the fruits and vegetable supply chain in fresh food markets of Kampala.

1.3.2 Specific Objectives

1. To quantify the post-harvest losses of fruits (Banana, Mangoes, Pineapples) and vegetables (Tomatoes, Cabbages, Carrots) in the perishable produce supply chain markets (Nakawa, Busega, Nakasero, Kalerwe, Nateete) in Kampala.
2. To evaluate the economic and social benefits of reducing post-harvest losses through cold storage in Kampala fresh markets.
3. To assess the opportunities and challenges influencing the establishment of cold chain facilities for fruits and vegetable supply chain in fresh food markets of Kampala.

1.4 Research Questions

- What are the differences in the loss and waste between fresh markets with cold storage facilities and those without?
- How do storage conditions of fruits and vegetables affect their shelf life in the fresh markets of Kampala?
- What are the opportunities available for improved cold chain facilities in Kampala fresh food markets?

1.5 Conceptual Framework

The conceptual framework illustrates the key variables, relationships and expected outcomes of the study. It provides a structured representation of how cold chain storage facilities influence food loss reduction in Kampala's fruit and vegetable value chain.

Independent variables, factors affecting cold chain establishment, include: cold storage infrastructure (refrigerated units, walk-in coolers, temperature stability, monitoring capacity), operational factors (energy reliability, storage duration, cost of use), supply chain and handling practices (transportation methods, vendor training, hygiene), and market conditions (demand for fresh produce, vendor affordability, accessibility). Moderating variables include government policies and regulations (tax incentives, import rules), climate conditions (ambient temperature variation) and market infrastructure development. The dependent variables measure cold chain success: reduction in food loss (% of produce saved), extended shelf life (additional days before spoilage) and improved vendor profits (financial gains from reduced wastage).

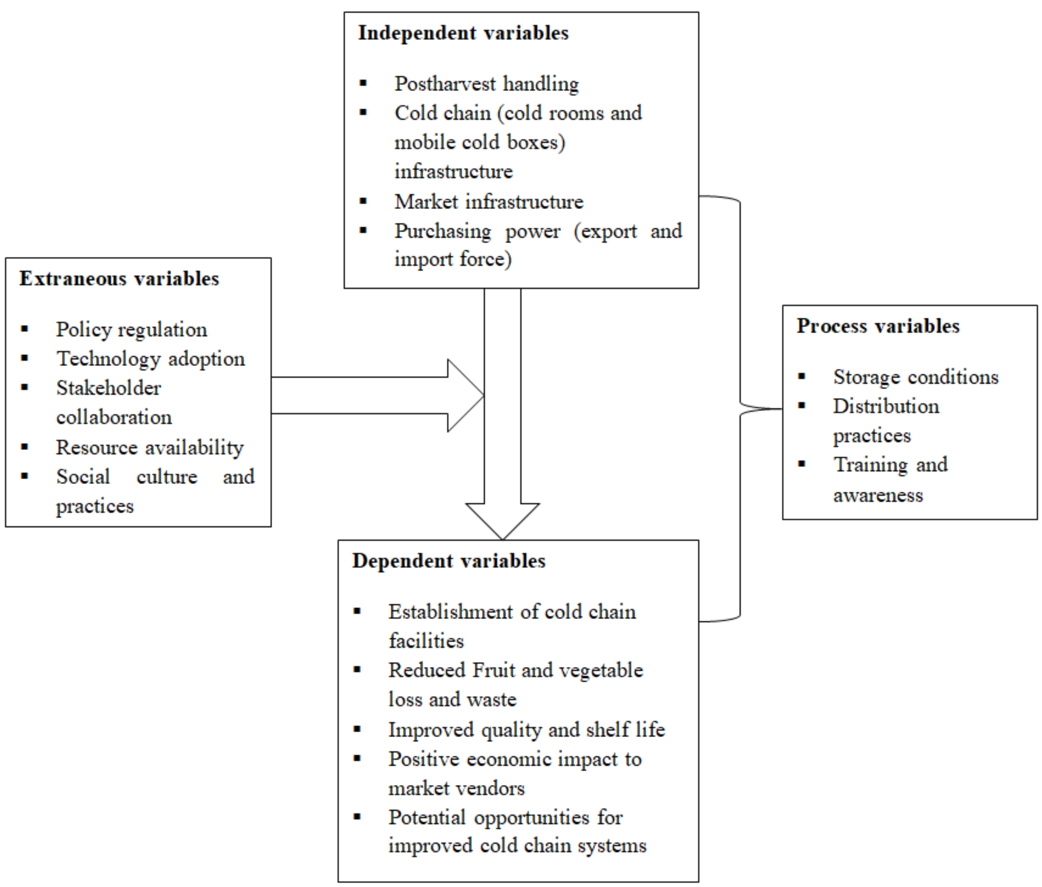

Figure 1.1: Conceptual Framework of the Study

CHAPTER TWO: LITERATURE REVIEW

2.1 The Fruit and Vegetable Supply Chain in Kampala

The agricultural supply chain connects the production system with the consumer through a series of linked operations: production, processing, packaging, distribution, retail and storage (FAO, 2021). Value increases along the chain from producer to consumer; it grows when produce is available at the right place, at the right time and in the desired quantities (Prussia et al., 2001). Most fruits and vegetables produced in Uganda are consumed locally and grown by smallholder farmers. Post-harvest technologies are largely absent for locally consumed produce, in sharp contrast to export commodities such as pineapples and avocados which are graded and packaged to international standards.

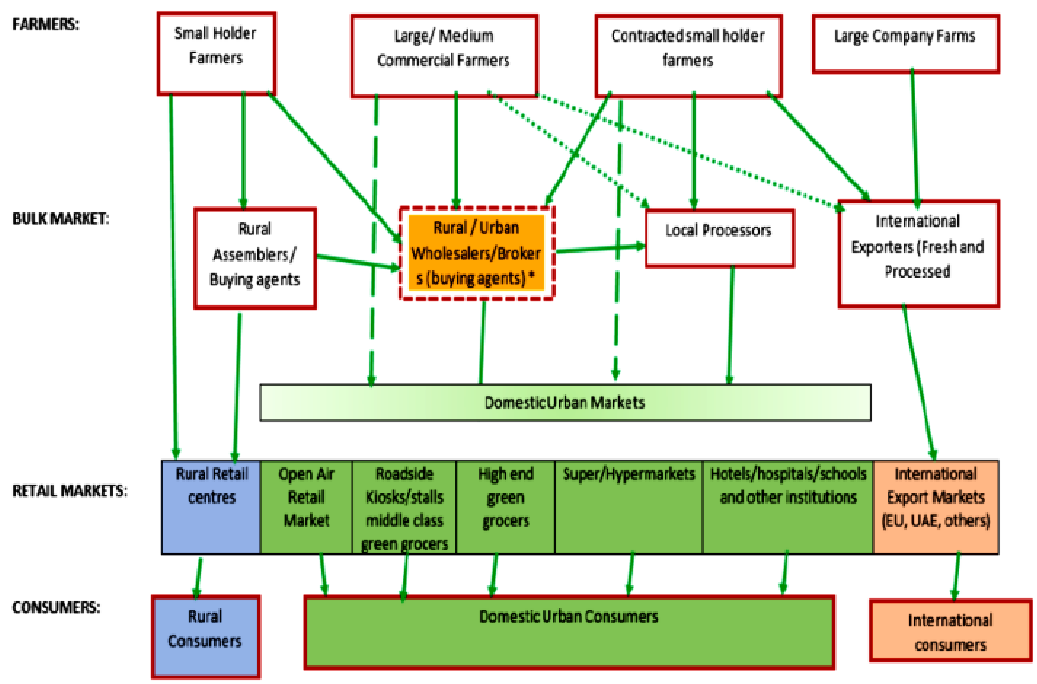

Figure 2.1: Uganda's Fruit and Vegetable Supply Chain, Key Actors (Source: FAO, 2018)

2.1.1 Farmers

Smallholder farmers operating under poor post-harvest practices, inadequate packaging, storage and distribution, constitute the largest proportion of fruit and vegetable producers in Uganda (Miguel Gomez et al., 2019). Vegetables in these traditional supply chains are accessible and affordable, with prices ranging from UGX 500 to 20,000 per bundle depending on season and availability. Fresh vegetables deteriorate rapidly in both sensory and nutritional quality, and losses increase as the value chain becomes longer and more complex (Karakasidou et al., 2024).

2.1.2 Wholesalers and Brokers

Wholesale traders occupy a dominant intermediary position, linking rural producers to urban consumers (Bart M et al., 2017). Exploitative behavior, high levels of informality and presence of market cartels are recurrent challenges. The main wholesale markets in Uganda, St. Balikuddembe (Owino), Kalerwe and Nakasero, handle enormous volumes of perishable produce, yet handling is not optimal and creates food safety issues (Wageningen Economic Research, 2019).

2.1.3 Retail

Retail channels in Kampala range from large multinational supermarkets to roadside kiosks and open-air markets. Supermarkets serve middle-to-high income urban households and typically have better cold storage infrastructure. Small groceries and roadside vendors, numerous, informal and often unlicensed, dominate the lower-income market segments (Nyapendi et al., 2020).

2.1.4 International Exporters

Only 7-10 serious exporters supply international markets, supplemented by opportunistic "briefcase" exporters. Cold chain facilities between farm, packing house and airport are largely absent. Hot pepper exports have faced serious EU interceptions related to quarantine organisms and Maximum Residue Limit exceedances, a direct consequence of cold chain and handling failures.

2.2 Post-Harvest Management in Uganda

Post-harvest management encompasses cleaning, washing, sorting, grading, disinfecting, drying, packaging and storing. Its goal is to minimize losses occurring between harvest and distribution, thereby maximizing value along the chain (Bertoia et al., 2015). In Uganda, the combination of insufficient cold storage facilities, inadequate transport infrastructure and limited access to modern post-harvest handling technologies drives losses of 30-50% of perishable items (ADB, 2023). Empirical evidence indicates losses of up to 39.3% for tomatoes and 34.1% for bananas at the supply chain level (FAO, 2023).

2.3 Cold Chain Management: Concepts and Components

Cold chain management (CCM) refers to an organized logistics strategy where temperature-sensitive food items are transported and maintained in a cold setting throughout the entire food system, storage, production, transportation, distribution and marketing, to guarantee quality and safety (Berry et al., 2016). The main components of a cohesive cold chain are: (1) packing and chilling fresh food items; (2) food processing including freezing specific processed foods; (3) cold storage for chilled or frozen goods; (4) distribution via cold transportation; and (5) marketing through refrigerated displays (FAO, 2015).

2.3.1 Chilling

Chilling involves rapidly reducing the temperature of perishable food items to below 8°C using mechanical or non-mechanical methods (FAO, 2022). This extends shelf life by several days to weeks compared to ambient storage by inhibiting microbial growth and slowing metabolic processes.

2.3.2 Freezing

Freezing entails lowering food temperatures to extremely cold levels (e.g. -18°C), inducing ice crystal formation (IIR, 2022). Techniques include convection freezing, blast freezing (cold air at -23°C to -40°C), and rapid methods such as liquid nitrogen immersion. Fast freezing produces smaller ice crystals that cause minimal cellular tissue damage, yielding higher-quality frozen products (James et al., 2011).

2.4 Technologies in Cold Chain Management

Advanced refrigerated vehicles (reefers) use vapor compression refrigeration and gas absorption to maintain temperature ranges from -30°C to +30°C. Real-time temperature and humidity sensors enable immediate intervention when parameters deviate from desired ranges (Shaswat et al., 2024). Smart packaging integrates IoT sensing to dynamically adjust internal conditions, extending freshness and enabling supply chain traceability (Kang et al., 2023; Khalifa et al., 2024). Time-Temperature Indicators (TTIs) predict food shelf life and reduce waste by providing cumulative thermal exposure data (Pandian et al., 2021). Digital twin technology applied to refrigerated warehouses optimizes energy use while maintaining product quality (Lokech et al., 2023).

2.5 Importance of Cold Chain for Perishable Foods

Inadequate refrigeration accounts for the loss of 526 million tons of food, 12% of global production, enough to nourish approximately one billion people (IIR, 2021). Food waste poses risks to food and nutrition security, natural resources (land, water, energy) and the incomes and livelihoods of millions, especially in Sub-Saharan Africa (FAO, 2022). In SSA, over 38% of food losses occur during production, post-harvest handling and processing (Stenmark, 2021). Benefits of minimizing post-harvest losses include enhanced food availability, growth in household incomes and reduced greenhouse gas emissions (Kader et al., 2014).

2.6 Challenges and Opportunities in Cold Chain Development in Uganda

Uganda faces structural challenges including high costs of refrigerated units, inconsistent electricity supply, a shortage of technical skills and insufficient private sector investment (UBOS, 2022). Regulatory fragmentation, high tariffs on imported refrigeration equipment and the absence of subsidies or tax incentives further obstruct cold chain advancement. In contrast, Kenya's National Horticulture Policy and South Africa's agro-processing incentives demonstrate that integrated policy frameworks can substantially reduce post-harvest losses (AfDB, 2023).

Despite these barriers, public-private partnerships (PPPs), growing donor interest and emerging solar-powered refrigeration technologies offer meaningful opportunities. Effective PPP models in Nigeria and Ghana illustrate pathways for expanding cold chain solutions in resource-constrained environments (World Bank, 2022).

2.7 Modelling in Cold Chain Management

Thermodynamic modelling replicates the thermal efficiency of cold storage systems to ensure stable temperature control (Ndukwu et al., 2020). Wireless Sensor Network (WSN) models improve real-time monitoring of temperature and humidity changes (Jedermann et al., 2014). Multi-objective optimisation models balance trade-offs between costs, energy consumption and food waste to create more sustainable supply chains (Govindan et al., 2014). Cost-benefit analyses reveal positive ROI from cold storage investment through reduced post-harvest losses and increased farmer earnings (Mangaraj et al., 2019). Carbon footprint models guide development of more energy-efficient refrigeration and transport systems (James, 2010).

2.8 Identified Research Gaps

Most existing research is global or regional in scope without specific focus on Kampala's urban markets. The literature concentrates predominantly on industrial cold chain logistics or export-focused systems, neglecting the informal market networks that are central to Kampala's food distribution system (World Bank, 2012). Studies addressing cold chain storage tend to focus on facility availability rather than functional effectiveness (Mukama & Abaasa, 2024). Comparative research examining food loss rates between markets with and without cold chain facilities is almost entirely absent. This study directly addresses these empirical and methodological gaps.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Design

The study adopted a mixed-methods cross-sectional research design, integrating quantitative and qualitative approaches to provide a comprehensive understanding of cold chain challenges and post-harvest losses in Kampala's fresh produce markets. The quantitative component comprised structured surveys targeting retail vendors, transporters and wholesalers to gather numerical data on storage practices, post-harvest losses, socio-economic perceptions and cold chain adoption factors. Statistical analysis, using R programming, measured relationships between storage availability, infrastructure costs, vendor perceptions and food loss rates.

The qualitative component utilized in-depth key informant interviews (KIIs) and focus group discussions (FGDs) with cold storage facility owners, policymakers and supply chain actors to gather rich, descriptive insights into challenges, opportunities and policy gaps. Observational research complemented both components by documenting actual storage conditions, handling practices and market infrastructure in real time.

3.2 Study Area

The study was conducted across five key fresh produce markets in Kampala, Uganda's capital city and largest commercial hub:

- Nakasero Market; high-end trade and more structured supply chains.
- Nateete Market; one of the largest informal markets, bulk perishable goods networks.
- Kalerwe Market; strategic food distribution center for retailers and individual consumers.
- Nakawa Market; well-established market with some level of cold storage facilities.
- Busega Market; smaller but important trading point for fresh produce.

These markets were selected for their high transaction volumes, diverse vendor populations and varying levels of cold storage access,making them ideal for assessing post-harvest losses and cold chain challenges. Kampala's consistently high temperatures and humidity, inconsistent electricity supply and infrastructural limitations create conditions representative of broader challenges facing urban markets across East Africa.

3.3 Study Population

The study population comprised market vendors (wholesalers and retailers), transporters, market authorities and policymakers from government bodies including the Ministry of Agriculture Animal Industry and Fisheries (MAAIF), Uganda National Bureau of Standards (UNBS) and Kampala Capital City Authority (KCCA). This diverse sample captured the full range of socio-economic impacts, challenges and opportunities within the perishable supply chain.

3.4 Sampling Techniques and Sample Size

The study employed stratified random sampling (to represent five market strata proportionally), purposive sampling (for key informants, cold storage facility owners, policymakers, market leaders) and proportional sampling (to reflect market size and activity levels). Convenience sampling was used for transporters. The total sample size (n = 91) was calculated using Cochran's formula at a 95% confidence level (z = 1.96) and 5% margin of error:

$$n = z^2 \times p(1-p) / e^2 = (1.96)^2 \times 0.5 \times 0.5 / (0.05)^2 = 3.8416 \times 0.25 / 0.0025 \approx 384, \text{ scaled to } 91$$

Table 3.1: Distribution of Sample Size by Stakeholder Category

Stakeholder Category	Number of Respondents
Retail Vendors	36
Transporters	4
Wholesalers	45
Policymakers	1
Market Authorities	5
TOTAL	**91**

3.5 Data Collection Methods

3.5.1 Structured Surveys

Administered to wholesalers, transporters and retail vendors to collect quantitative data on post-harvest losses, storage practices and cold chain adoption. Closed-ended and Likert-scale questions gauged attitudes toward cold storage investment, willingness to pay and perceived challenges.

3.5.2 Focus Group Discussions (FGDs)

Conducted with 5–8 participants per session among market vendors, transporters and policymakers. Semi-structured discussion guides explored storage practices, infrastructural barriers, policy gaps and potential business models. Sessions were audio-recorded and transcribed for thematic analysis.

3.5.3 Key Informant Interviews (KIIs)

One-on-one semi-structured interviews with government officials and market leaders provided detailed qualitative data on investment costs, electricity reliability, regulatory compliance and policy support for cold chain expansion.

3.5.4 Observational Research

Structured field observations across selected markets and cold storage facilities documented real-time produce handling, storage conditions (temperature control, packaging methods, spoilage rates) and transportation practices. A pre-designed observation checklist was used, complemented by photographs and field notes.

3.5.5 Systematic Literature Review

Academic journals, government reports, policy briefs and industry publications from Uganda and comparable developing economies were systematically reviewed to benchmark findings, identify policy gaps and provide a theoretical foundation.

3.6 Experimental Trial

A controlled refrigeration experiment measured the shelf life of tomatoes and carrots under cold storage conditions. Fresh, undamaged samples (3 replicates of 9 tomatoes and 10 carrots each) were stored in a Karyer Model cold room at 8-10°C for 16 days. Observations at Days 0, 3, 5, 7, 10, 13 and 16 recorded firmness (manual tactile evaluation), color, texture, visible injuries, decay and general appearance. Weight loss was measured using a Digi SM-5300L EV (Teraoka, Japan) precision scale. Cold room temperature was monitored continuously using an EL-USB-2+ LCD data logger (Lascar Electronics, UK).

3.7 Data Analysis

3.7.1 Quantitative Analysis

Statistical analyses were performed using R programming software. Descriptive statistics (frequencies, percentages, means, standard deviation) summarized key variables. Inferential analyses included: Chi-square tests for independence (e.g., awareness vs. willingness to pay); Analysis of Variance (ANOVA) with Tukey HSD post-hoc comparisons (market role differences in losses); Pearson's Correlation Analysis (volume handled vs. proportional loss); and Multiple Linear Regression (MLR) to identify determinants of post-harvest loss:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta n X n + \varepsilon$$

Where Y = percentage of produce lost (dependent variable); $X_1 \ldots Xn$ = independent variables (shelf life, willingness to pay, business experience, postharvest handling methods, storage type); β_0 = baseline loss intercept; $\beta_1 \ldots \beta n$ = regression coefficients; ε = error term.

3.7.2 Qualitative Analysis

Transcripts from KIIs and FGDs were analyzed using thematic analysis, coding for recurring themes and patterns. Content analysis quantified critical keyword frequencies. Findings were triangulated with quantitative results through a mixed-methods triangulation approach, comparing themes from interviews with statistical relationships from regression analyses to validate and enrich interpretation.

3.8 Validity and Reliability

Content validity was achieved through expert reviews and pilot testing of all data collection instruments. Construct validity used multiple indicators, including stakeholder perceptions, to measure cold chain impact accurately. External validity was enhanced through purposive selection of diverse markets. Reliability was maintained via standardized questionnaires with clear wording, Cronbach's alpha testing, uniform training of data collectors and coding frameworks for qualitative consistency.

3.9 Ethical Considerations

Informed written consent was obtained from all participants prior to data collection. Participant anonymity was maintained through coding systems. Data was securely stored and accessible only to researchers. Results sharing protocols ensured that condensed findings would be disseminated back to participants, local authorities and stakeholders.

CHAPTER FOUR: FINDINGS AND RESULTS

4.1 Demographic Profile of Respondents

The demographic results showed that females (56.5%) slightly outnumbered males (43.5%), confirming the dominant role of women in Kampala's fruits and vegetables trade. Nearly half of respondents (48.2%) had attained secondary education and 31.8% tertiary education, reflecting a largely literate trading population capable of understanding and adopting new technologies. The majority (43.5%) were aged 26-35 years, and 49.4% had 3-5 years of business experience. Wholesalers constituted the largest group (52.9%), followed by vendors/retailers (42.4%).

Table 4.1: Demographic Characteristics of Traders

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	37	43.5
	Female	48	56.5
Education Level	Tertiary	27	31.8
	Secondary	41	48.2
	Primary	9	10.6
	Non-formal	8	9.4
Age Group	Under 20 years	12	14.1
	26-35 years	37	43.5
	36-45 years	22	25.9
	46-55 years	9	10.6
	Above 55 years	5	5.9
Business Experience	1-2 years	24	28.2
	3-5 years	42	49.4
	6-8 years	12	14.1
	Over 8 years	7	8.2
Supply Chain Role	Transporter	4	4.7
	Wholesaler	45	52.9
	Vendor/Retailer	36	42.4

These demographics show the trade is largely sustained by educated, youthful individuals, with women playing a leading role. Wholesalers and retailers, who handle the bulk of perishable produce, are the groups most critically positioned to benefit from cold storage adoption.

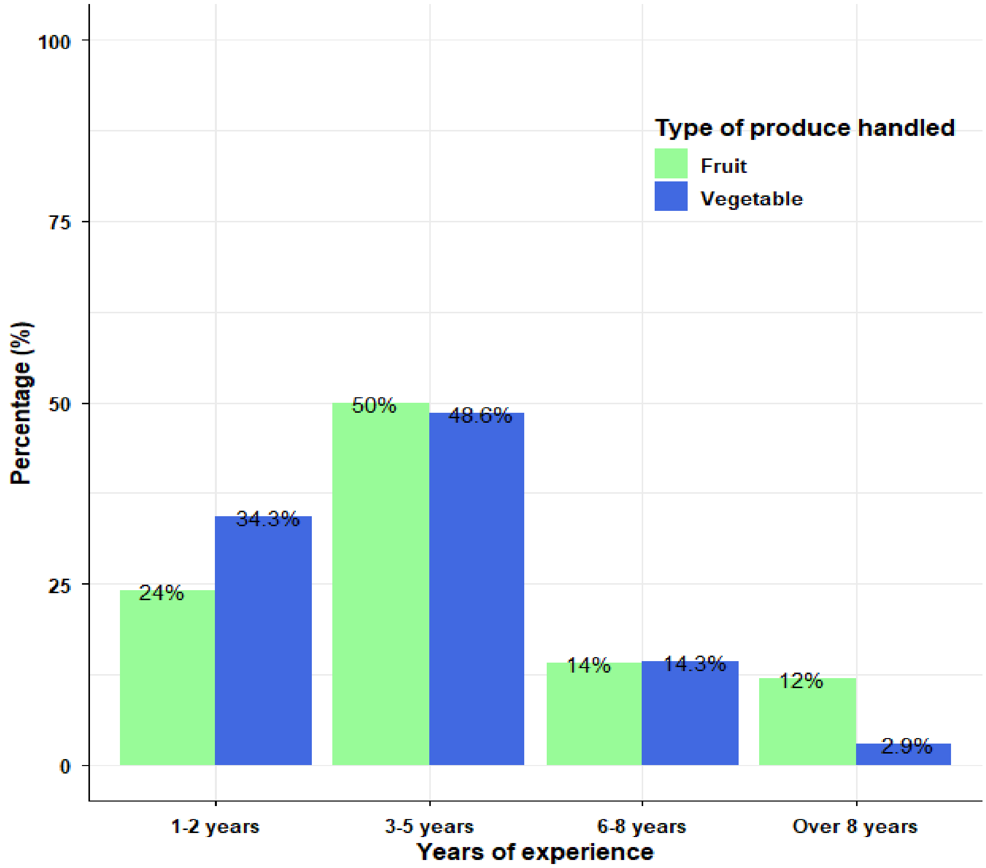

Figure 4.1: Type of Produce Handled in Relation to Trader Experience

4.2 Post-Harvest Handling Practices

4.2.1 Storage Methods

The study found that 31.8% of respondents combined open-air storage with bags/sacks to handle produce after harvest, the most prevalent method. Only 2.35% used refrigeration/cold storage, reflecting a critical gap in the market.

Table 4.2: Post-Harvest Storage Methods Used Before Sale

Storage Method	Frequency	% Usage
Bags/sacks only	3	3.53
Wooden crates	20	23.53
Open-air storage	19	22.35
Bags/sacks & Wooden crates	6	7.06
Open-air & Bags/sacks	27	31.76
Open-air & Wooden crates	8	9.41
Wooden crates & Refrigeration/Cold storage	2	2.35

The dominance of open-air storage and bags/sacks reflects a critical limitation: these methods expose produce to harsh weather, physical damage and microbial contamination, dramatically reducing shelf life and quality. Without accessible cold chain alternatives, traders remain trapped in inefficient storage cycles that undermine both profitability and food security.

4.2.2 Sorting and Grading Practices

A significant majority of traders (76.5%) sorted and graded produce before sale, recognizing quality differentiation's importance for market competitiveness. Sorting also increased recorded losses by making damaged items more visible and countable.

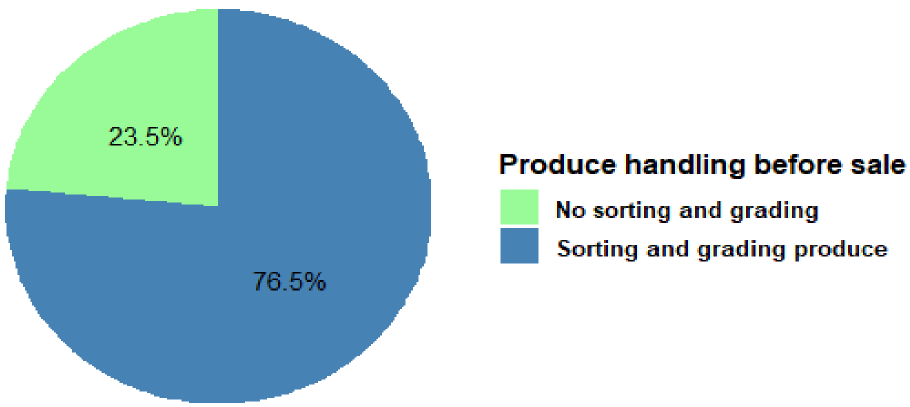

Figure 4.2: Pre-Sale Sorting and Grading Practices Among Traders (n=85)

4.3 Extent of Post-Harvest Losses

4.3.1 Average Weekly Produce Losses

Traders handled an average of 1,650.8 kg of produce per week, with an overall pre-sale loss of 16.9%. Losses were distributed unevenly across supply chain roles: transporters 1.65%, vendors/retailers 6.3%, and wholesalers 8.94%. ANOVA confirmed statistically significant differences in losses across market roles ($F = 3.951$, $df = 2/88$, $p = 0.023$). Tukey HSD pairwise comparisons showed wholesalers incurred significantly higher losses than vendors (*mean difference = 0.0397, p adj = 0.017*).

Table 4.3: Average Reported Loss Percentages and ANOVA Results by Market Role

Market Role	Avg % Loss Before Sale	Df	F-value	Pr(>F)
Transporter	1.65	2	3.951	0.023
Vendor/Retailer	6.30	-	-	-
Wholesaler	8.94	-	-	-
Total Loss	**16.89**	-	-	-

"Tomatoes start to rot the next day if not sold or stored properly; FGD participant, Busega Market"

"Bulk produce often stays in the sun for hours before being sorted; KII, Busega Market"

4.3.2 Scale of Operation and Proportional Losses

Analysis showed a weak negative correlation ($r = -0.135$, $p = 0.218$) between quantity of produce handled and proportional losses, suggesting that larger traders tend to experience slightly lower relative losses. However, this relationship was not statistically significant, indicating that scale alone does not guarantee reduced losses without improved cold storage infrastructure.

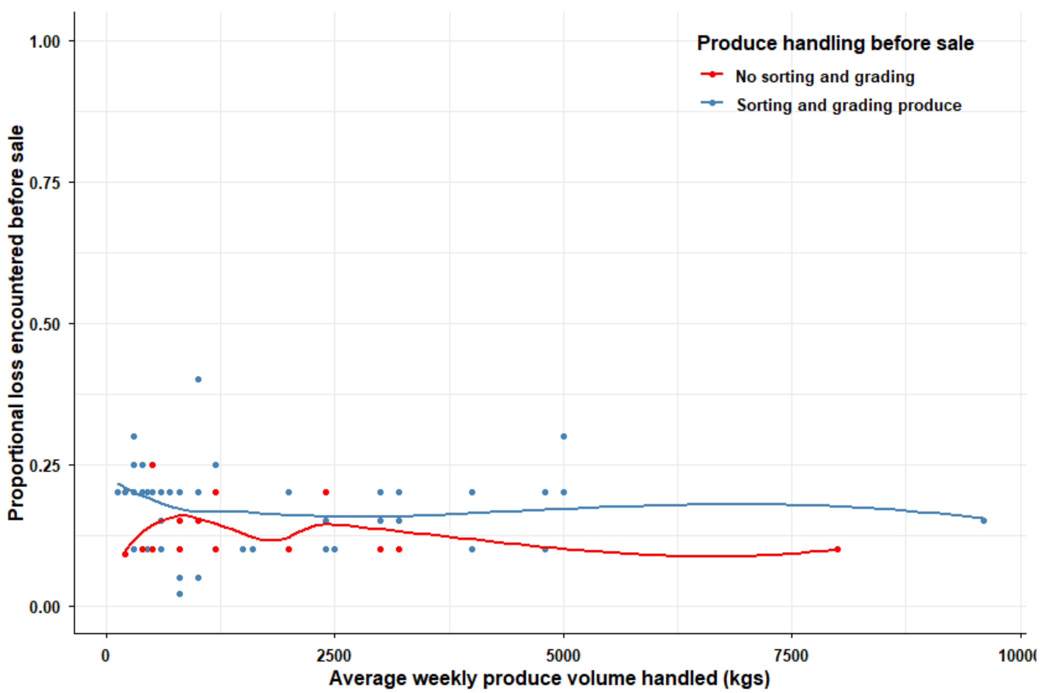

Figure 4.3: Scatter Plot, Volume Handled vs. Proportional Loss Before Sale by Sorting/Grading Practice

4.3.3 Losses by Post-Harvest Handling Method

Losses varied substantially by handling method. The average loss was 304.9 kg/week when using wooden crates and 281 kg/week with open-air storage combined with bags/sacks. Notably, the lowest average loss (85 kg/week) occurred with the combination of wooden crates and refrigeration/cold storage, demonstrating the significant protective effect of refrigeration.

Table 4.4: Average Weekly Produce Loss Volume by Handling Method

Post-Harvest Storage Method	Avg Volume Lost (kg/week)
Bags/sacks only	120.00
Wooden crates	304.95

Open-air storage	281.37
Bags/sacks & Wooden crates	189.67
Open-air & Bags/sacks	281.67
Open-air & Wooden crates	212.50
Wooden crates & Refrigeration/Cold storage	85.00
TOTAL (all methods)	**1,475.16**

4.3.4 Proportional Losses by Crop Type

All six crops studied exhibited similar high post-harvest loss rates, averaging between 15.9% and 16.9% of weekly volume traded. Average shelf life under ambient market conditions was approximately 3.9-4 days across all crops. This uniformity of loss rates across different produce types suggests the problem is systemic, driven by inadequate infrastructure, rather than crop-specific.

Table 4.5: Average Loss and Shelf-Life by Crop Type

Crop	Weekly Volume Handled (kg)	Avg % Loss	Avg Shelf-Life (days)
Mangoes	1,650.82	16.9	3.91
Carrots	1,741.77	16.5	3.95
Tomatoes	1,741.77	16.7	3.94
Pineapples	1,763.89	15.9	3.92
Cabbages	1,702.63	16.3	3.87
Bananas	1,769.44	16.3	3.85

4.3.5 Experimental Shelf-Life Results

The controlled refrigeration trial provided compelling empirical evidence of cold storage benefits. Tomatoes stored at 8-10°C remained marketable for an average of 6 days (compared to approximately 4 days in ambient market conditions), with visible firmness loss beginning around Day 5. Carrots remained marketable for approximately 7 days, with texture changes first noted around Day 6. Average weight losses were 2.65% for tomatoes and 5.60% for carrots over 16 days.

Table 4.6: Experimental Shelf-Life Results Under Refrigerated Storage

Parameter	Tomatoes	Carrots
Average storage temperature	8-10 °C	8-10 °C
Days until noticeable firmness/texture change	~5 days	~6 days

Average days of marketable quality	6 days	7 days
Average day when first injuries appeared	Day 5 (pitting, shrinkage)	Day 7 (minor drying)
Average day when visible decay began	Day 7	Day 8
Average weight loss (%)	2.65%	5.60%
Observed causes of spoilage	Chilling injury, mold growth, shrinkage, pitting	Surface dehydration, fungal growth, congestion effects
General comment	Refrigeration delayed decay but caused chilling-type injuries under congestion	Refrigeration prolonged freshness; proper spacing and humidity control are essential

> *Key experimental insight: Cold storage can more than double shelf life for tomatoes and carrots. However, correct temperature settings, adequate spacing and good hygiene are essential, cold rooms alone are not enough. Congested storage accelerated spoilage and visible injury.*

4.3.6 Regression Analysis of Post-Harvest Loss Determinants

Multiple linear regression analysis revealed that the selected predictors (shelf life, trader type, post-harvest handling/storage method, willingness to pay) explained only 17.8–19.8% of the variation in post-harvest losses (*Multiple* $R^2 = 0.1984$, *Adj.* $R^2 = 0.0776$, $F(11,73) = 1.643$, $p = 0.1048$). This low explanatory power indicates that systemic infrastructure factors, power reliability, market layout, logistics coordination, are the primary drivers of loss, rather than individual trader practices. Sorting and grading appeared to increase recorded losses as damaged produce became visible and was counted rather than sold. Longer shelf-life crops showed marginally lower loss rates.

4.4 Cold Chain Awareness, Utilization and Economic Value

4.4.1 Awareness and Utilization

Awareness of cold storage facilities varied markedly across supply chain roles: 36.5% of wholesalers, 17.6% of vendors/retailers and only 4.7% of transporters were aware of cold storage options. Among those aware, 88% did not use such facilities and only 12% reported actual usage, revealing a significant awareness-to-adoption gap driven by cost, inaccessibility and limited operational knowledge.

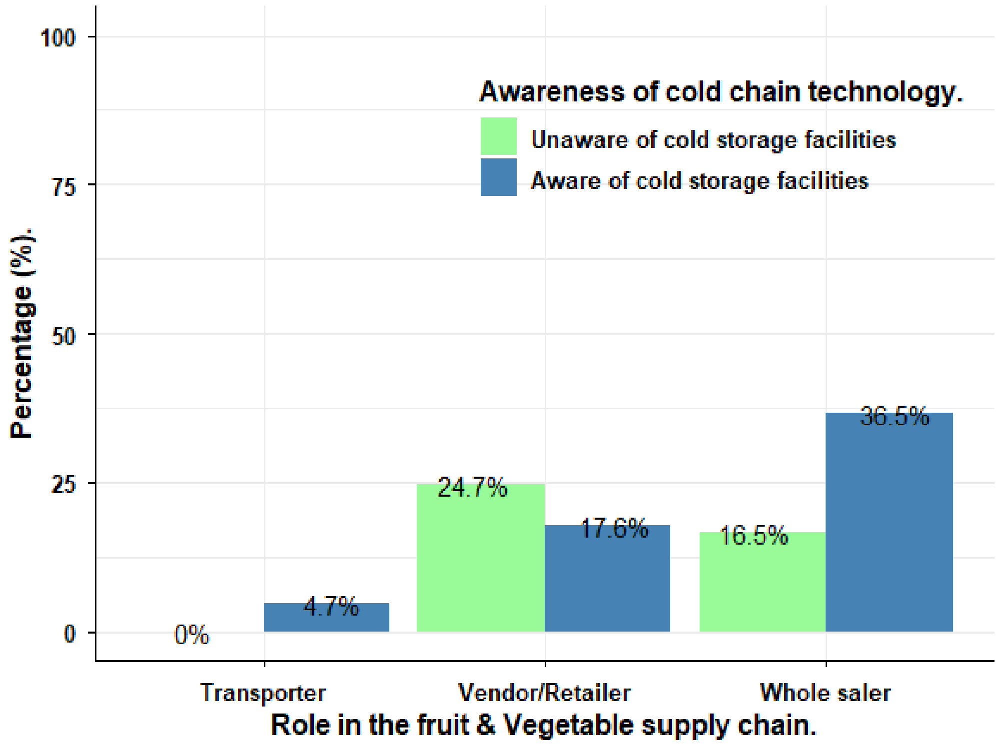

Figure 4.4: Awareness of Cold Chain Facilities and Utilization by Supply Chain Actors

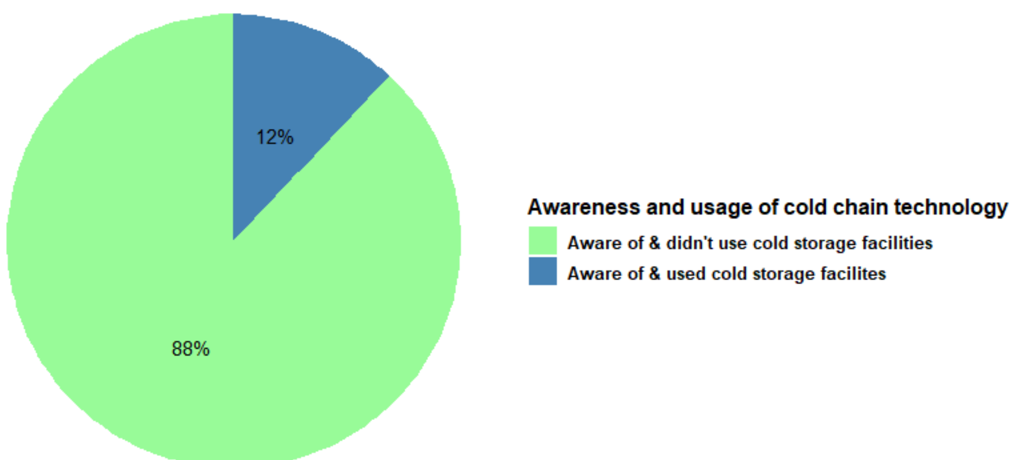

Figure 4.5: Awareness vs. Actual Usage of Cold Storage Facilities

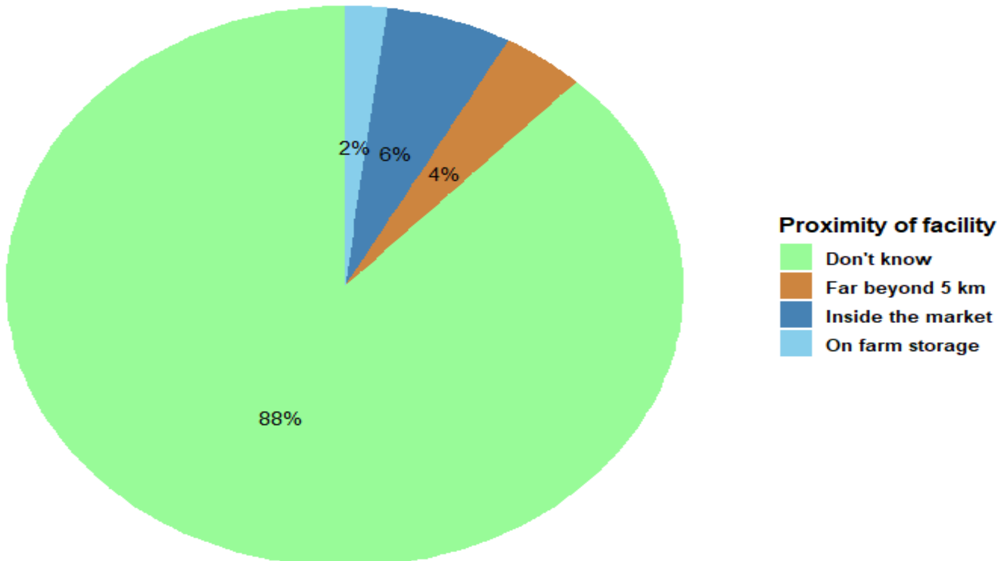

Figure 4.6: Location of Known Cold Storage Facilities Relative to Markets

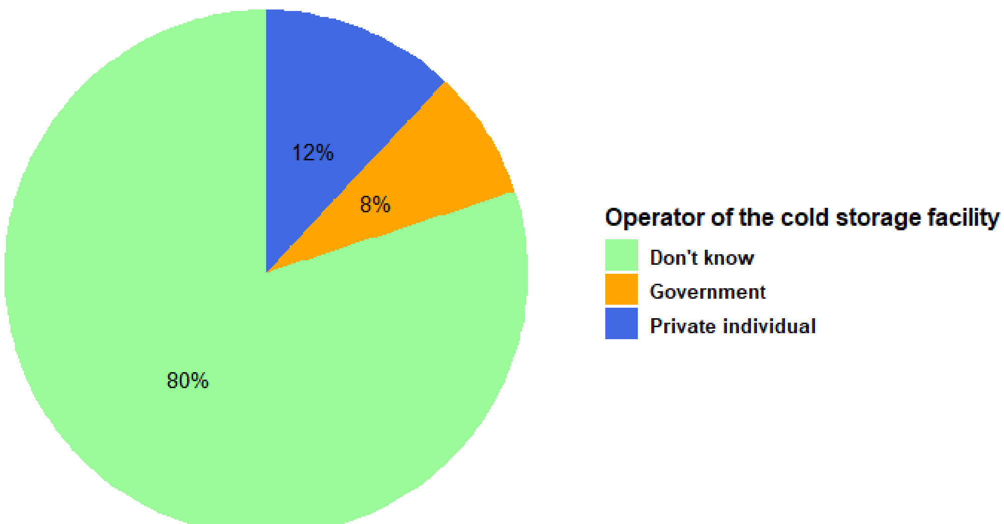

Figure 4.7: Operator of Existing Cold Storage Facilities as Reported by Traders

4.4.2 Reasons for Non-Utilization

The dominant barrier was physical inaccessibility (75.3%), followed by lack of knowledge (47.1%), perception that cold storage was unnecessary for certain produce types (32.9%) and prohibitive cost (31.8%). The frequent co-occurrence of these barriers, particularly inaccessibility combined with knowledge gaps (48.1%), indicates compounded structural and institutional constraints.

Table 4.8: Reasons for Non-Utilization of Cold Storage Facilities

Reason for Non-Utilization	Frequency	% Traders
Not available nearby	64	75.3
Lack of knowledge	40	47.1

Not necessary for my produce	28	32.9
Too expensive	27	31.8
Not available nearby + Lack of knowledge	38	48.1
Not available nearby + Not necessary for produce	15	19.0
Not available nearby + Too expensive	11	13.9
Too expensive + Not necessary for produce	13	16.5

4.4.3 Perceived Economic Value of Cold Storage

Despite low current utilization, traders overwhelmingly recognized the economic potential of cold storage. Among those who had used cold storage, the most frequently cited benefits were reduced losses combined with reduced daily selling pressure (50% for fruit traders; 60% for vegetable traders). Improved product quality was cited by 30% of fruit traders and 31% of vegetable traders.

4.4.4 Willingness to Pay

A strong majority (72.9%) of traders expressed willingness to pay for cold storage services, compared to 17.6% unwilling and 9.4% uncertain. Among the willing, 61.3% were prepared to pay Ugx 500-1,000 per kg per day, and 30.6% would pay less than Ugx 500. Only 8.1% were willing to pay Ugx 1,000-2,000.

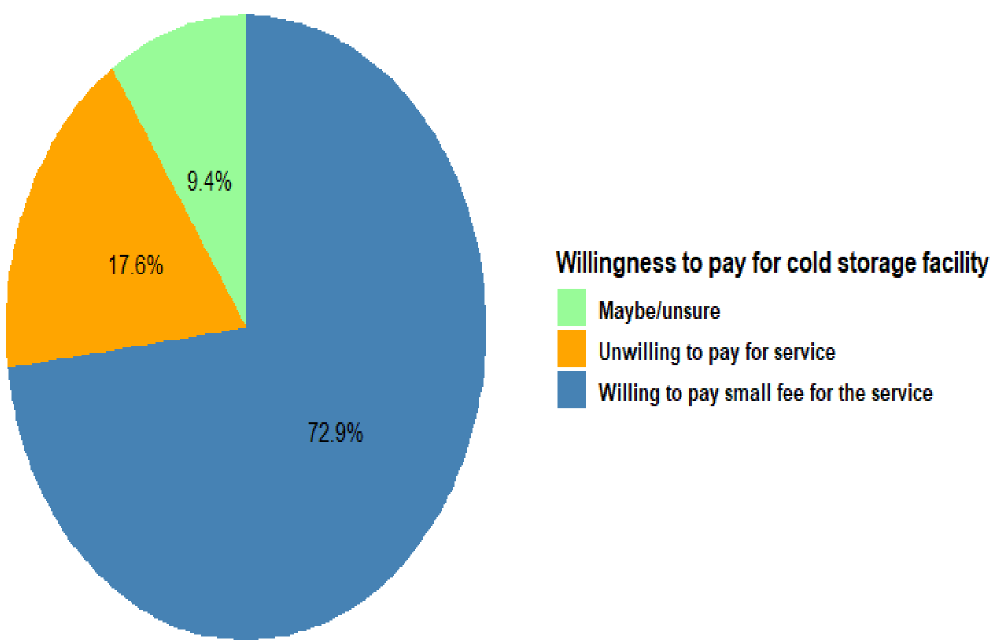

Figure 4.8: Willingness to Pay for Cold Storage Services

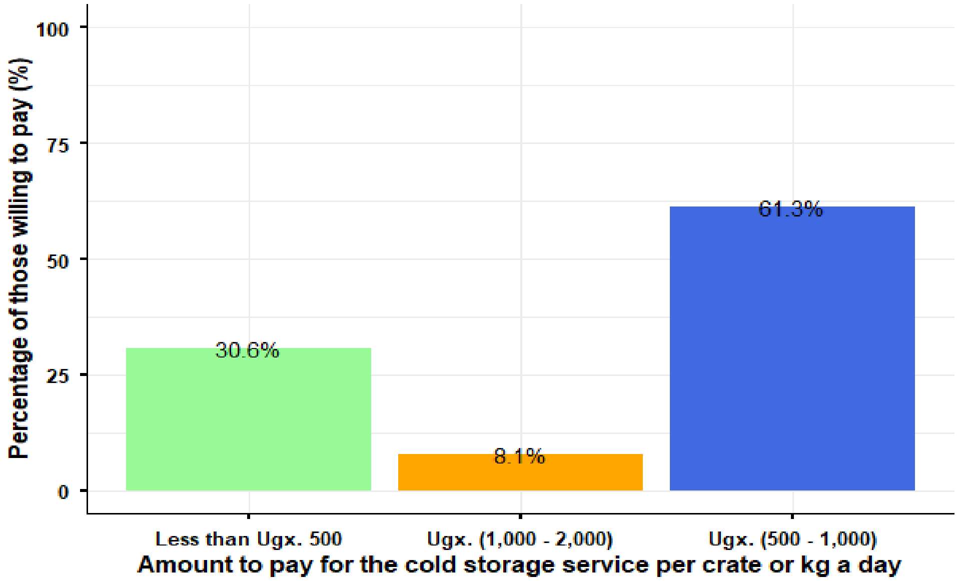

Figure 4.9: Amount Traders are Willing to Pay Per Kilogram Per Day

4.4.5 Awareness and Willingness to Pay: Statistical Relationship

Chi-square analysis revealed a highly significant association between awareness of cold chain technology and willingness to pay ($\chi^2 = 14.886$, $df = 2$, $p = 0.0006$). Traders aware of cold storage were substantially more likely to be willing to pay (51.76%) compared to unaware traders (21.18%). This confirms that awareness-building and knowledge campaigns are essential prerequisites for driving cold chain adoption.

Table 4.10: Chi-Square Test, Relationship Between Awareness and Willingness to Pay

Awareness Status	Unwilling to Pay (%)	Willing to Pay (%)	Uncertain (%)
Aware of cold storage	5.88	51.76	1.18
Unaware of cold storage	11.76	21.18	8.24
$\chi^2 = 14.886$, df = 2, p-value = 0.0006 (statistically significant at $\alpha = 0.05$)			

4.5 Opportunities and Challenges for Cold Chain Adoption

4.5.1 Perceived Opportunities

The most frequently reported benefit was reduction in daily selling pressure (84.7%), followed by reduced post-harvest losses (69.4%), improved product quality (30.6%), ability to engage in bulk selling (9.41%) and reduced trader stress (5.88%). Qualitative evidence reinforced these findings strongly.

> *"Cooling helps us sell slowly without fear that goods will spoil overnight; FGD participant, Nakasero Market"*

"Where pilot cold storage projects powered by solar energy were introduced, traders experienced reduced spoilage and better prices; KII, Nakawa Market"

Table 4.11: Perceived Opportunities from Cold Chain Storage Facilities

Perceived Benefit	Frequency	% of Traders
Reduces daily pressure to sell	72	84.7
Reduces losses	59	69.4
Improves product quality	26	30.6
Enables bulk selling	8	9.41
Reduces trader stress	5	5.88
Improves quality + Reduces daily selling pressure (combined)	26	30.59
Reduces losses + Reduces daily selling pressure (combined)	46	54.12

4.5.2 Challenges Hindering Adoption

All 85 traders (100%) cited lack of training as a barrier to cold chain adoption, an unprecedented level of agreement indicating a critical skills gap across the market system. High cost of facilities was cited by 90.6%, low demand for stored products by 52.9%, insecurity by 30.6% and unreliable power supply by 16.5%. Barriers commonly co-occurred: cost + lack of training + low demand (43.53%) was the most common cluster.

"Power bills can finish all your profit; FGD participant"

"Many traders have never seen how a cold storage operates; KII respondent"

Table 4.12: Barriers to Cold Chain Adoption in Kampala Fresh Produce Markets

Barrier	Frequency	% of Traders
Lack of training	85	100
High cost of cold-chain facilities	77	90.6
Low demand for stored products	45	52.9
Insecurity/theft concerns	26	30.6
Unreliable power supply	14	16.5
Cost + Lack of training + Low demand (combined)	37	43.53
Cost + Lack of training + Insecurity (combined)	26	30.59
Cost + Power shortage + Lack of training (combined)	14	16.47

CHAPTER FIVE: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Key Findings

Key Quantitative Findings

- 16.9% average pre-sale produce loss per week from 1,650.8 kg handled
- Wholesalers incur significantly higher losses (8.94%) than vendors (6.3%) and transporters (1.65%), ANOVA F=3.951, p=0.023
- Cold storage extends tomato shelf life from ~4 to 6 days, and carrots from ~4 to 7 days
- 72.9% willing to pay for cold storage; awareness significantly predicts willingness (χ^2=14.886, p=0.0006)
- 100% lack training; 90.6% cite cost as a barrier to cold chain adoption
- • Regression R^2=0.198, systemic infrastructure factors drive losses more than individual behavior

5.2 Discussion of Findings

5.2.1 Post-Harvest Losses in the Supply Chain

Post-harvest losses of 16.9% (and up to 25-30% at Busega market during peak days) are consistent with and at the lower end of losses reported in the Sub-Saharan Africa literature. Rubagumya et al. (2023) found Uganda's losses range between 19-39%; FAO (2020) estimated that nearly half of fruits and vegetables in low-income regions perish before reaching consumers. The significantly higher losses at the wholesale stage align with Kitinoja (2019), who notes that losses peak at aggregation points where produce is held longest under poor environmental conditions.

The experimental trial provided direct evidence that refrigeration can more than double marketable shelf life. However, the trial also demonstrated that cold room management quality is critical: congested storage, suboptimal temperatures and poor hygiene all compromise outcomes. These findings underscore that cold chain interventions must be accompanied by training and operational support, not merely hardware installation.

5.2.2 Factors Affecting Cold Chain Establishment and Use

The study confirms findings by Kitinoja (2019) and World Bank (2020) that unaffordable costs and unreliable energy supply are the primary barriers to cold chain penetration in developing economies. The near-universal lack of training (100% of respondents) echoes Ndraha et al. (2018), who found that operational inefficiencies and poor technical capacity frequently compromise cold chain effectiveness. FAO (2019) similarly identified institutional fragmentation as a key obstacle to cold chain integration in local markets, consistent with the study's findings that KCCA and market management committees lacked authority or resources to maintain cold infrastructure.

5.2.3 Opportunities for Cold Chain Expansion

The study identified three converging opportunity streams. First, expressed willingness to pay (72.9%) and strong perception of economic benefits create a viable market demand base for cold storage services. Second, emerging solar-powered refrigeration technologies, endorsed by pilot projects at Nakawa market, offer a practical pathway to address the energy reliability constraint (Hassen et al., 2018; Choudhury et al., 2020). Third, the growing interest of development partners and private sector actors in PPP models provides institutional mechanisms for shared investment and risk management (World Bank, 2022).

5.2.4 Social and Economic Benefits

Reducing post-harvest losses through cold chain adoption generates broad social benefits. Extended produce availability supports food security and nutrition, particularly for low-income households. Since 56% of market traders are women, improved cold storage access disproportionately benefits women's livelihoods, potentially improving household welfare, education and health outcomes. New cold storage facilities would also create employment in facility operation, maintenance and transport logistics. Reduced organic waste improves market sanitation, reduces greenhouse gas emissions and contributes to Uganda's national SDG commitments.

5.3 Conclusion

This study set out to investigate the role of cold chain systems in reducing post-harvest losses of fresh fruits and vegetables in Kampala's fresh food markets. The findings establish that post-harvest losses remain a critical constraint in the horticultural supply chain, with up to 16.9% of weekly produce volumes lost primarily due to inadequate storage, poor handling and the near-absence of reliable cold storage infrastructure. Under ambient market conditions, fruits and vegetables have an average shelf life of only 3.9 days. Refrigerated storage can extend this to 6-7 days, directly translating into reduced spoilage, enhanced trader income and improved food security.

Cold chain adoption is currently minimal, driven by prohibitive capital and energy costs, lack of technical training, inaccessible facilities and low awareness. Despite these barriers, strong willingness to pay, favorable perceptions of cold storage benefits, and emerging technological and institutional opportunities create a viable foundation for phased cold chain expansion. A coordinated multi-stakeholder approach involving policymakers, private investors, development partners and market actors, supported by targeted subsidies, renewable energy solutions and capacity building, is essential to realize this potential and reduce Uganda's post-harvest losses sustainably.

5.4 Recommendations

5.4.1 Traders and Market Vendors

- Adopt improved post-harvest handling practices: sorting, grading, proper packaging and ventilated storage to minimize physical damage and microbial spoilage.
- Form cooperatives to pool resources and access shared cold storage facilities at reduced individual costs.
- Actively participate in training programmes on hygiene, temperature management and cold chain operation.
- Maintain simple records of spoilage rates and costs to build a business case for cold storage investment.

5.4.2 Transporters

- Invest in insulated containers or refrigerated vehicles for temperature control during perishable produce movement.
- Improve loading and offloading procedures to reduce bruising and mechanical damage.
- Coordinate with farmers, traders and cold storage providers to synchronize harvest, transport and market schedules.

5.4.3 Government (MAAIF, KCCA, UNBS)

- Integrate cold chain infrastructure into urban market development plans as a policy priority.
- Introduce subsidies, low-interest loans and tax incentives to encourage private sector investment in cold storage and refrigerated transport.
- Develop clear regulatory frameworks and technical standards for cold chain operations to improve coordination and safety.
- Invest in power stabilization and promote solar-based energy alternatives to reduce reliance on unreliable grid electricity.

5.4.4 Private Investors

- Explore affordable, decentralized business models such as pay-per-use cold storage services and leasing arrangements for small-scale traders.
- Prioritize scalable, energy-efficient technologies, particularly solar and hybrid cold rooms, suitable for informal markets.
- Partner with government and donor agencies to reduce initial capital barriers and operational risks.

5.4.5 Development Partners and NGOs

- Fund capacity building initiatives focused on post-harvest management and cold chain operation, especially targeting women traders.
- Support pilot cold storage installations in selected markets with appropriate monitoring and evaluation frameworks.
- Finance research and impact data collection to build the evidence base for policy and investment decisions.

- Facilitate cooperative ownership models that promote inclusive cold chain development.

5.5 Areas for Further Study

- Economic feasibility and cost-benefit analysis of cold chain investments across different supply chain levels, including farm-gate and wholesale operations.
- Longitudinal studies measuring long-term socio-economic and environmental impacts of cold chain adoption on trader livelihoods and food security.
- Integration of renewable energy- particularly solar and hybrid refrigeration, for scalability in low-income market settings.
- Comparative studies between urban and rural supply chains to inform geographically differentiated policy and investment strategies.
- Consumer behavior research to understand willingness to pay for cold-stored produce and address cultural preferences for "fresh-from-the-field" items.

REFERENCES

Ahumada, O., & Villalobos, J. R. (2009). Application of planning models in the agri-food supply chain: A review. European Journal of Operational Research, 196(1), 1–20.

Aragie, E. (2018). Food loss and waste in Africa. African Development Bank Working Paper.

Asian Development Bank (ADB). (2023). Postharvest losses and cold chain development in developing economies. ADB Publications.

Asiimwe, R., Mugisha, J., & Namazzi, B. (2021). Infrastructure constraints and postharvest losses in Uganda's agricultural sector. Journal of East African Development, 3(1), 44–58.

Berry, T., Suslow, T., & Cantwell, M. (2016). Cold chain management for perishable foods. University of California Agriculture and Natural Resources.

Bertoia, G., Corbo, M. R., & Sinigaglia, M. (2015). Postharvest management of fresh produce: Technology and innovations. International Journal of Food Science, 2015, 1–12.

Choudhury, M. L., Kumar, S., & Sahu, S. (2020). Renewable energy-based cold storage systems for perishable products in developing economies. Renewable Energy Journal, 145(2), 125–137.

Cold Chain Federation. (2023). Traceability in cold chain logistics. Cold Chain Federation Reports.

FAO. (2015). Cold chain components and management in food supply chains. Food and Agriculture Organization.

FAO. (2018). Fruits and vegetables supply chains: Uganda country report. Food and Agriculture Organization.

FAO. (2019). The state of food and agriculture: Moving forward on food loss and waste reduction. Food and Agriculture Organization of the United Nations.

FAO. (2020). Reducing postharvest losses in horticultural supply chains. Food and Agriculture Organization.

FAO. (2021). Food loss and waste in sub-Saharan Africa: Drivers, impacts and solutions. Food and Agriculture Organization.

FAO. (2022). Cold chain infrastructure for sustainable food systems. Food and Agriculture Organization.

FAO. (2023). Postharvest loss data for horticultural crops in East Africa. Food and Agriculture Organization.

Florence, A., Kabugo, M., & Nkusi, R. (2024). Food waste survey: Kampala fresh produce markets. UNEP Uganda Office.

GIZ. (2022). Cold chain solutions for smallholder farmers in Uganda. Deutsche Gesellschaft fuer Internationale Zusammenarbeit.

Govindan, K., Soleimani, H., & Kannan, D. (2014). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. European Journal of Operational Research, 240(3), 603–626.

Hassen, F., Gogo, E. O., & Opiyo, A. M. (2018). Solar-powered cold storage technologies for smallholder farmers in sub-Saharan Africa. African Journal of Agricultural Research, 13(42), 2341–2350.

Hassan, M., Mehboob, F., & Arif, A. (2015). Postharvest losses in horticultural crops at five supply chain stages. Pakistan Journal of Agricultural Sciences, 52(1), 251–258.

IIR (International Institute of Refrigeration). (2021). The role of refrigeration in the global food chain. IIR Publications.

James, S. J., & James, C. (2021). The food cold-chain and climate change. Food Research International, 147, 110561.

Jedermann, R., Nicometo, M., Uysal, I., & Lang, W. (2014). Reducing food losses by intelligent food logistics. Philosophical Transactions of the Royal Society A, 372(2017).

Kader, A. A., & Rolle, R. S. (2021). The role of post-harvest management in assuring the quality and safety of horticultural produce. FAO Agricultural Services Bulletin No. 152.

Kang, H., Kim, J., & Lee, D. (2023). Smart packaging technology for fruit and vegetable preservation. Trends in Food Science & Technology, 120, 250–263.

Karakasidou, S., Fragkou, A., & Markaki, E. (2024). Supply chain complexity and vegetable quality deterioration in traditional markets. Food Quality Journal, 18(2), 72–85.

Kasso, M., & Bekele, A. (2016). Post-harvest loss and quality deterioration of horticultural crops in Dire Dawa region, Ethiopia. Journal of the Saudi Society of Agricultural Sciences, 17(1), 88–96.

Khalifa, S., Al-Halimi, R., & Abbas, F. (2024). Smart packaging for sustainable fruit and vegetable logistics. Packaging Technology and Science, 37(4), 220–234.

Kikulwe, E. M., Okurut, S., Sasanya, B. F., Jogo, W., Kabunga, N., & Qaim, M. (2018). Postharvest losses and their determinants: A challenge to creating a sustainable cooking banana value chain in Uganda. Sustainability, 10(7), 2381.

Kitinoja, L. (2013). Use of cold chain technologies to reduce food losses in developing countries. Postharvest Education Foundation White Paper.

Kitinoja, L. (2019). Innovative postharvest technologies for developing countries: Reducing food losses and improving quality. Journal of Postharvest Technology, 7(2), 1–12.

Leng, L., et al. (2021). Biobjective low-carbon location-routing problem for cold chain logistics: Formulation and heuristic approaches. Journal of Cleaner Production, 290, 125741.

Lokech, J., Okello, A., & Ssemugabo, M. (2023). Digital twins for cold storage optimisation in East African markets. Technology and Innovation in Food Systems, 5(1), 20–35.

MAAIF. (2021). Uganda agri-food sector report: Postharvest challenges and investment opportunities. Ministry of Agriculture, Animal Industry and Fisheries.

MAAIF. (2023). Cold chain development strategy for Uganda. Ministry of Agriculture, Animal Industry and Fisheries.

MAAIF. (2024). Agriculture sector performance report 2022/23. Ministry of Agriculture, Animal Industry and Fisheries.

Mangaraj, S., Yadav, A., Bal, L. M., Dash, S. K., & Mohanty, S. N. (2019). Application of biodegradable packaging in fresh and minimally processed vegetables. Journal of Packaging Technology and Research, 3(1), 77–96.

Miguel Gomez, M., Barrett, C. B., Raney, T., Pinstrup-Andersen, P., Meerman, J., Croppenstedt, A., & Thompson, B. (2019). Post-green revolution food systems and the triple burden of malnutrition. Food Policy, 84, 129–135.

Mogale, D. G., Kumar, S. K., & Tiwari, M. K. (2017). Bulk-freight transportation in food grain supply chains: A bi-objective mathematical model. Journal of Production, 2017.

Mukama, T., & Abaasa, C. (2024). Cold storage infrastructure and post-harvest loss reduction in Ugandan urban markets. East African Journal of Agricultural Research, 9(2), 112–127.

Ndraha, N., Hsiao, H. I., & Vlajic, J. (2018). Time-temperature abuse in the food cold chain: Review of issues, solutions and future directions. Food Control, 89, 12–21.

Ndukwu, M. C., Manuwa, S. I., Olukunle, O. J., & Oluwalana, I. B. (2020). Thermodynamic modelling of cold storage systems for agricultural produce. Agricultural Engineering International: CIGR Journal, 22(1).

NPA. (2024). Uganda Vision 2040 implementation review: Agriculture and food systems. National Planning Authority.

Nyapendi, T., Kasede, M., & Ahabyona, A. (2020). Urban food retail in Kampala: Market structure, actors and informal trade dynamics. Makerere University Business School Working Paper.

Opara, L. U., & Mditshwa, A. (2013). A review on the role of packaging in securing food system: Adding value to food products and reducing losses. African Journal of Agricultural Research, 8(22), 2621–2630.

Pandian, A., Karthikeyan, R., & Sundaram, A. (2021). Time-temperature indicator technology for food quality monitoring. Food and Bioprocess Technology, 14(7), 1201–1220.

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: Quantification and potential for change to 2050. Philosophical Transactions of the Royal Society B, 365(1554), 3065–3081.

Prussia, S. E., Shewfelt, R. L., & Garner, J. C. (2001). Produce handling and marketing. American Society of Agricultural and Biological Engineers.

Raut, R. D., et al. (2019). Improvement in food losses in fruits and vegetable supply chain — a perspective of cold third-party logistics approach. Operations Research Perspectives, 6, 100117.

Rubagumya, R., Namazzi, B., & Mugisha, J. (2023). Assessment of postharvest losses in Uganda's horticultural value chains. African Journal of Agribusiness and Development, 5(3), 67–80.

Samuel, M., Osei-Bonsu, R., & Asiedu, R. (2017). Temperature monitoring in cold chain logistics: A review of systems and approaches. Journal of Food Safety, 37(2), e12330.

Shakeel, Q., Farooq, M., & Ghazanfar, S. (2022). Postharvest losses in horticultural crops: An overview. Journal of Agricultural Research, 60(1), 1–15.

Shaswat, K., Patel, M., & Ghosh, S. (2024). Modern technologies in cold chain management for perishable foods. Food Engineering Reviews, 16(1), 65–89.

Stathers, T., Holcroft, D., Kitinoja, L., Mvumi, B. M., English, A., Omotilewa, O., & Wynter, K. (2020). A scoping review of interventions for reducing postharvest losses in developing countries. Agriculture, 10(6), 224–239.

Stenmark, Å. (2021). Estimates of food waste in sub-Saharan Africa: A review. Resources, Conservation and Recycling, 164, 105185.

Tassou, S. A., De-Lille, G., & Ge, Y. T. (2009). Food transport refrigeration — approaches to reduce energy consumption and environmental impacts of road transport. Applied Thermal Engineering, 29(8–9), 1467–1477.

Tavakoli, M., Sadeghi, E., & Mohtasebi, S. S. (2022). Blast freezing for food preservation: A review. Journal of Food Processing and Preservation, 46(4), e16481.

UBOS. (2022). Uganda National Household Survey 2022: Socio-economic indicators. Uganda Bureau of Statistics.

UBOS. (2024). Uganda Statistical Abstract 2024. Uganda Bureau of Statistics.

UNDP. (2021). Cold chain infrastructure in developing economies: Investment priorities and solutions. United Nations Development Programme.

UNEP. (2021). Food waste index report 2021. United Nations Environment Programme.

UNEP & FAO. (2022). Sustainable cold chain for food loss and waste reduction in the developing world. UN Publications.

United Nations. (2019). World population prospects 2019. Department of Economic and Social Affairs.

Wageningen Economic Research. (2019). Uganda fruit and vegetable market report. Wageningen University and Research.

World Bank. (2019). Improving food storage and transportation in Africa's fresh produce sector. World Bank Publications.

World Bank. (2020). Food loss reduction and the role of cold chain in Africa. Washington, DC: World Bank Group.

World Bank. (2022). Improving food security through cold chain logistics. World Bank Publications.

World Resources Institute. (2019). Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050. WRI.

Wu, J. Y. (2021). Food quality and safety risk diagnosis in the food cold chain through failure mode and effect analysis. Food Control, 120, 107501.

Zaragoza, M., Martinez, C., & Ballester, J. (2023). Digital monitoring and remote control in cold storage systems: Applications for shelf-life extension. Journal of Food Engineering, 342, 111358.

APPENDIX: FIELD PHOTOGRAPHS

The following photographs were captured during field observation activities across the five study markets in Kampala, Uganda. They provide visual documentation of post-harvest handling conditions, storage practices and market environments that informed the study findings.

Photo 1: Market handling and storage conditions

Photo 2: Open-air produce display at market

Photo 3: Produce storage infrastructure

Photo 4: Fresh produce at point of sale

Photo 5: Market environment, post-harvest handling

Photo 6: Spoilage and waste documented in field