ASSESSMENT OF THE COLD CHAIN CAPACITY USED IN BULK HANDLING OF PERISHABLE AGRICULTURAL PRODUCE IN UGANDA

BY

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DECLARATION

I declare that this dissertation is my original work and has not been wholly or partially submitted for any other degree or professional qualification.

Signed………………………………………

Date……………………………………...

APPROVAL

This is to certify that Abaasa Paula carried out this research work titled "Assessment of the cold chain capacity used in handling perishable agricultural produce in Uganda" under our supervision. We approve the submission of the work for the award of Master of Science in Food Technology.

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DEDICATION

To my husband Ronald, you have been a supporter of all my endeavors. I greatly appreciate your partnership, sacrifices and unwavering belief in my potential. I hope this achievement will fulfil the dream you envisioned for me.

To my children, Victoria and Solomon. You have made me stronger, better and more fulfilled than I could have ever imagined. I love you deeply with all my heart.

To my parents, Mr and Mrs Baryahikayo, for the endless love, support and encouragement throughout my pursuit for education. I am beyond blessed to call you my parents.

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ABSTRACT

High food post-harvest losses negate the efforts geared towards improving food security and livelihoods of the population. There has been increased interest in addressing challenges associated with food post-harvest losses in policy circles, academia, and the private sector. Of the several mitigation measures suggested, investment in the food cold chain has been repeatedly pointed out as a solution to extensive postharvest losses worldwide, especially for perishable agricultural produce.

This study assessed the cold chain capacity used in bulk handling of perishable agricultural produce (milk, meat, fish, fruits and vegetable) in the 16 cities of Uganda (Arua, Gulu, Jinja, Mbarara, Mbale, Masaka, Hoima, Entebbe, Lira, Kampala, Fort Portal, Kabale, Moroto, Nakasongola, Wakiso, and Soroti). Furthermore, the study monitored temperature and relative humidity management of the cold chain facilities and lastly assessed knowledge, attitude and practices of perishable produce retailers towards the cold chain.

A total of 51 cold chain facilities used for bulk handling of perishable agricultural produce were found in 09 out of the 16 cities. These were spread out across the cities of Kampala, Wakiso, Mbarara, Fort Portal, Entebbe, Gulu, Masaka, Soroti and Jinja, with Kampala having the highest proportion (47.37%). The total bulk refrigerated storage space in the 16 cities was 39849.25 m^3 serving a total 'within city' local population of about 8.8 million people which translates to a refrigerated storage capacity of 4.50 m^3 per 1,000 inhabitants. The private sector owned the highest proportion (75.44%) of the cold chain facilities and only 21.05% were publicly owned. Generally, the temperatures of the cold chain facilities were not managed effectively as they varied significantly from the respective set point(s) of the cold rooms over the study period. Majority (51.4%) of the perishable produce retailers had no knowledge of the cold chain and 71.56% reported absence of nearby cold chain storage options.

Therefore, there is inadequate refrigerated storage capacity for bulk handling of perishable agricultural produce in Uganda and this presents a need for investment in this sector by both public and private players. Cold chain operators need to actively monitor and manage the cold storage temperature and humidity. Interventions should target sensitization of perishable produce retailers on the paramount importance of cold chain management. These interventions will contribute to reduction of post-harvest losses in perishable agricultural produce.

CHAPTER ONE

1.0 INTRODUCTION

1.1. Background

The global population is estimated to reach 8.5 billion people in 2030, 9.7 billion people in 2050, and almost 11 billion people by 2100 (UNDP, 2019). Currently, Africa has the highest population growth, and it is estimated that between now and 2050, the population of sub-Saharan Africa will double (UN, 2011). In Uganda, the current population is estimated at 43.7 million people with a population growth rate of 3.1% (UBOS, 2022). The projected population growth means that there will be an increased demand for food, which will in turn put pressure on food systems.

In addition to population pressure, the magnitude of global food wastage and loss remains a concern worldwide. It is estimated that one-third to one-half of the total food produced globally is wasted (FAO, 2015). This loss occurs along the food chain, that is, production, post-harvest handling, processing, distribution, retail, and during consumption (Gustavsson et al., 2011). In sub-Saharan Africa, where a huge population proportion is rural based, the focus of food value chain actors is on post-harvest (between farmers' fields and consumers' plates) loss reduction where most of the food loss occurs (Sheahan and Barrett, 2017). Among the foods that are lost in sub-Saharan Africa, cereals account for 10 to 20%, 27% for meat, 55% for fruits and vegetables, and 25% for milk (Gustavsson et al., 2011). From the above figures, it is clear that perishable foods are the most wasted in the region. The main cause of these food losses are largely poor temperature-time management, poor packing containers, poor handling, and lack of knowledge about quality and safety management of perishable food products (Kitinoja et al., 2011).

With the global population estimated to reach 9.7 billion people by 2050, a reduction in food loss and wastage provides an opportunity to reduce the pressure on food production without increasing the burden on land, water and environmental pollution (Searchinger et al., 2013). If food loss and wastage is mitigated, USD 936 billion (FAO, 2014) would be saved and over 4.4 gig tonnes of carbon dioxide (FAO, 2015) arising from food loss and wastage would not be emitted into the environment. Among the various food loss and wastage mitigation solutions methods described by Kitinoja et al. (2011), investment in temperature management (cold chains) in the food supply chains would be necessary for the reduction of the post-harvest losses of perishable food products in sub-Saharan Africa. Investment in cold chains would reduce the population pressure on food systems through reduction of food loss and wastage thus minimising the need to increase food production by 60% by 2050 (MAAIF, 2018).

A cold chain is an uninterrupted temperature-controlled system of refrigerated goods between upstream suppliers and consumers designed to maintain the quality and safety of food products (Montanari, 2008; Taoukis et al., 2016). Perishable foods such as meat, fruits, vegetables, milk, fish, etc., have limited shelf life thus making them spoil, decay, or even become unsafe for human consumption (Rawat, 2015). This is because these foods are physically, bio-chemically and microbiologically unstable (Singh and Anderson, 2004). Physical instability can occur due to bruising, shrinkage or wrinkling caused by loss of moisture, colour changes due to enzymatic activity among others. Biochemical processes such as oxidation, enzymatic browning among others render perishable foods unacceptable for consumption (Rawat, 2015). Preservation of perishable foods along the supply chain is achieved in cold chains by reducing food product temperature and maintaining a constant optimal temperature from postharvest until the food reaches the final consumer (Gligor et al., 2018). Therefore, to avoid the physical, biochemical, and microbiological changes, there is a need for a cold chain (Kitinoja, 2013; Ndraha et al., 2020). Reduction of the food product temperature by 10 °C results in doubling of the food product shelf life. Therefore, rapid removal of food product heat by cooling followed by maintenance of an optimal temperature is critical in perishable food product preservation (Gustavsson et al., 2011).

In 2019, over 68.1% of the Ugandan working labour force was involved in agriculture, where perishable food products were grown and marketed (UBOS, 2019). However, up to 40% of the fruit and vegetable still goes to waste especially along the supply chain (FRA, 2020). When compared to the developed world with 200 m^3/1000 people refrigeration capacity, the refrigeration capacity of the developing world is only 19 m^3/1000 people (Kitinoja, 2014).

Unfortunately, several challenges such as limited access to energy, high maintenance costs, inadequate logistics arrangements, low traded volumes of food commodities, and poor compliance to standards are key barriers to this critical investment (Drame and Meignien, 2016). However, Uganda`s infrastructure has greatly improved, by November 2021, the country had over 21,020 km of tarmac roads and 1,276.7 MW of electricity (ERA, 2021; UNRA, 2021).

1.2. Problem statement

The lack of adequate food cold chain systems in Uganda, just like many sub-Sahara African countries is a major cause of losses estimated at about 25% to 30% for animal products and 40% to 50% for roots, tubers, fruits and vegetables (Gustavsson et al., 2011). These losses have a tandem effect of leading to deteriorating food and nutrition security, lost market opportunities, increased carbon footprint, and wastage of natural resources like water, land, and energy (Drame and Meignien, 2016). Scholars have cited cold chain systems development as a solution to reducing the post-harvest losses of perishable food products in sub-Saharan Africa including Uganda (Gunasekera et al., 2017; Kitinoja et al., 2019; Becerra-Sanchez and Taylor, 2021; Rajapaksha et al., 2021; Anand and Barua, 2022).

However, there is limited information on the status of cold chain systems in Uganda and their operating capacity, which might be limiting interventions in this sector.

1.3. Objectives

1.3.1. General objective

To assess the cold chain capacity, management, and utilization in the bulk handling of perishable food products value chain in Uganda.

1.3.2. Specific objectives

1. To locate and characterise the refrigerated warehouses and walk-in cold rooms used for bulk of handling milk, meat, fish, fruits, and vegetables in the 16 cities of Uganda.
2. To monitor the temperature and relative humidity management in the refrigerated warehouses and walk-in cold rooms.
3. To establish the knowledge, attitude, and practices of perishable produce retailers towards the cold chain systems.

1.4. Research Questions

1. Is there adequate refrigerated storage capacity for handling perishable foods (milk, meat, fish, fruits, and vegetables) in the 16 cities of Uganda?
2. Does temperature and relative humidity of the refrigerated warehouses and cold rooms vary ($p<0.05$) from the recommended set points?
3. Is there is a mismatch among knowledge, attitudes and practices of perishable produce value chain actors towards the cold chain?

1.5. Justification

Globally, it is estimated that one-third to a half of the food produced goes to waste. In Uganda, it is estimated that about 40-50% of the fruits and vegetables produced are lost due to poor post-harvest handling that includes poor time-temperature management. Development of cold chain systems in Uganda will contribute to improving the food product shelf life, reducing the economic and ecological burden of food losses and wastage, and reducing the burden on water and land resources required to constantly increase food production to meet demand. Additionally, investment in the food products cold chain systems contributes to Uganda achieving the Sustainable Development Goals 2 (no hunger) and 3 (good health and wellbeing).

CHAPTER TWO

2. 0 LITERATURE REVIEW

2.1. Cold chain and cold chain management

A cold chain is an uninterrupted-temperature controlled transport and storage system of refrigerated goods between upstream suppliers and consumers designed to maintain the quality and safety of food products (Montanari, 2008; Taoukis et al., 2016). Some scholars have referred to cold chain as "equipment processes and information management system used to maintain chilled and frozen foods" (Montanari, 2008; Joshi et al., 2011). Additionally, cold chain management refers to all efforts (people, equipment and infrastructure) used to maintain a constant optimal temperature throughout the food supply chain (Ndraha et al., 2020). Cold chains normally start right after harvest and include value chain steps like harvest, collection, packing, processing, storage, transport, marketing and ends when the food product reaches the final consumer (Kitinoja, 2013). Cold chains are particularly crucial in the postharvest management of perishable foods.

Perishable foods are foods that have a short shelf life, easily spoil thus becoming unsafe for consumption. Spoilage of these foods can be physical (shrinkage, colour changes, moisture loss), bio-chemical (oxidation, enzymatic browning) or microbiological (growth of spoilage and pathogenic microflora) (Ndraha et al., 2020). Among the factors that affect spoilage of perishable foods, temperature is a very critical factor that can be controlled by cold chains.

Temperature has a significant effect on the quality of food products because each food crop has an inherent rate of respiration and an optimal temperature range to reduce the ripening and senescence rate. Similarly, the rate of biochemical and microbial changes is determined by the temperature of the food product (Singh and Anderson, 2004). Perishable foods therefore require optimal temperature throughout the supply chain to minimise postharvest losses.

Perishable foods can be sub-divided into two types; living products (such as fruits, vegetables, live seafood etc.) and non-living food products (such as meat, dairy, blood, etc.) and all these categories require optimal temperatures to avoid spoilage (van Donselaar et al., 2006). In case the temperature is not maintained at an optimal level or a temperature abuse happens, then the perishable food products are likely to be spoilt. Uganda produces, consumes, and markets a considerable volume of perishable food produce annually. Table 2.1 shows the annual production trends of selected perishable food products in Uganda and Table 2.2 shows the importance of using cold chain storage in increasing the shelf life of perishable food. Table 2.2 clearly shows that without refrigeration for example, milk that would have lasted for 2 weeks lasts only a few hours and mangoes that would have lasted for 3 weeks remain useful nutritionally for less than a week.

Table 2.1 Production trends of selected perishable food products in Uganda

Perishable food product	**Annual production quantities (metric tonnes)**			**Reference**
	2016	2017	2018	
Fresh whole fish	467,528	366,531	345, 803	(UBOS, 2021a)
Meat (Beef, Mutton and pork)	278,210	275,545	282,656	(UBOS, 2021b)
Sweet potatoes	1,910,718	1,094,632	1,484,163	(UBOS, 2022a)
Potatoes	171,271	299,338	327,332	(UBOS, 2022a)
Plantain bananas (all types)	3,395,875	4,616,978	6,494,057	(UBOS, 2022a)
Milk	1634000 litres	1614000 litres	2,040,000 litres	(UBOS, 2021c)

Table 2.2 Storage potential of selected perishable food products with and without refrigeration (Kitinoja, 2014)

Variable	Without refrigeration	With refrigeration
Fresh whole fish	< 1 day	8 - 10 days at 0 °C
Cut fresh meats	1-2 days	3 - 4 weeks at -2 °C
Minced meats (ex: ground beef)	A few hours	7 days at -2 °C
Milk	A few hours	Up to 2 weeks at 2 - 4 °C
Hard Cheeses	< 1 week	6 months to 1 year at 0 °C
Fresh green vegetables (i.e., lettuces, cabbage etc.)	A few days	1 month at 0 °C
Potatoes	< 2 months	5 - 10 months at 4-12 °C
Tomatoes –firm ripe	< 1 week	1-3 weeks at 8-10 °C
Onions pungent types	< 1 month	Up to 8 months at 0 °C
Mangoes	< 1 week	2-3 weeks at 13 °C
Apples	< 2 weeks	3-6 months at -1 °C
Fresh cut fruits	A few hours	< 2 weeks at 0-5 °C
Frozen fish	A few hours	6 months at -18 °C
Frozen poultry	A few hours	4 months at -18 °C
Ice cream	A few minutes	months at -28 °C

2.2. Overview of the food cold chain

Fig. 2.1 shows the main operations involved in a food cold chain which generally starts immediately after harvesting and ends with the perishable food product in the consumer`s refrigerators. The food is likely to go through more than one storage and distribution centres depending on the market location. Markets that are located furthest from the point of production will require land, sea or air transport in order for the food to arrive to the target market. Therefore, it is very critical that cold chain management is effective so that the perishable food is delivered to the target market in the best possible quality and safety (Ndraha et al., 2020).

2.2.1. On farm and initial cooling

Pre-cooling happens right after harvesting to reduce on the residual heat in the perishable food product. This is done by initial cooling technologies that are used to reduce to food product temperatures to target levels. These unit operations are discussed in detail in section 2.3.

2.2.2. Transportation

Transportation of perishable foods is popularly done by road (cars or trucks) although other means such as rail, sea and air are available (James et al., 2006). Overall, the maintenance of optimal temperatures during perishable food transportation by any means remains a universal challenge. Many scholars have reported temperature abuses in Greece, Canada, California and many other countries (Koutsoumanis et al., 2010; Pelletier et al., 2011; McKellar et al., 2014). Road or sea transport usually provide satisfactory temperatures that are within the optimal range however, they have an inherent challenge of taking a lot of time over long distances. This might not be favourable for short shelf-life food products. In such scenarios, air transport is an alternative because of its fast speed however; care should be taken because air transport is a biggest culprit of temperature abuse owing to the fluctuating temperatures encountered during flight and ground operations (Gómez-López, 2012).

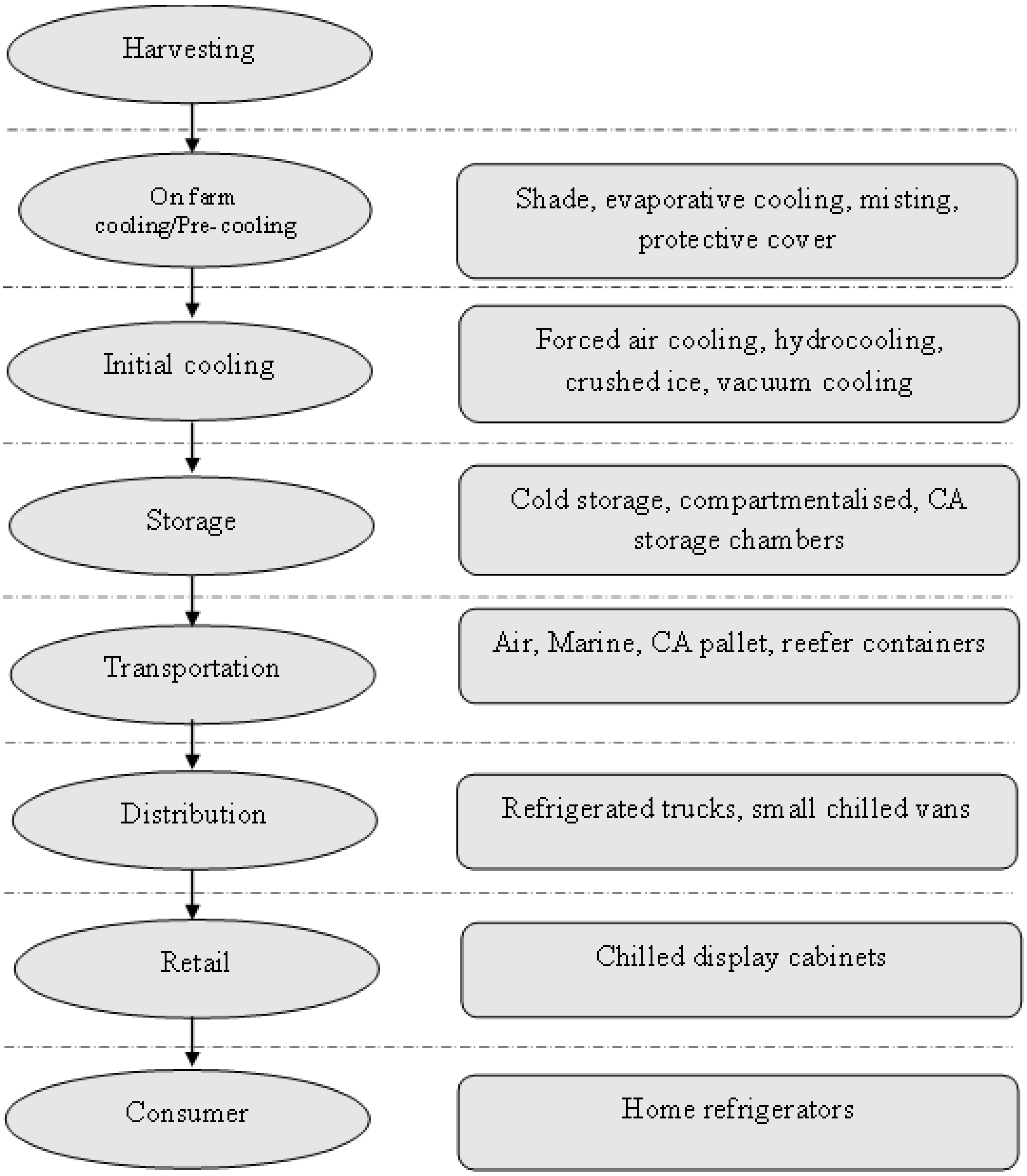

Figure 2.1. Components of the food cold chain with various possible temperature maintenance solutions (Gómez-López, 2012; Mercier et al., 2017)

Rail transport is majorly used to long distances exceeding 400 km and for delivery times exceeding 2 days between markets that are connected by a rail line (Tsamboulas, 2008). This therefore makes rail transport unpopular for the delivery of perishable food products. The other inhibiting factor is that rail transport is time consuming compared to all the other forms of transport (Mercier et al., 2017). The final means of transport is known as intermodal transportation. This refers to the movement of perishable food products in a single loading unit along a cold chain within two or more modes of transport (for example; road, sea and rail). Intermodal transportation is carried out with the help of intermodal transport containers such as refrigerated containers also known as reefers. Reefers are very versatile; they can accommodate a wide range of temperature settings and can carry refrigerated cargo weighing between 20-25 tons. When transported on a ship, reefers can be connected to ship’s power supply and if they are being transported on rail or road, they are connected to a power source like a generator or vehicle electrical system.

2.2.3. Retail

When the perishable food products arrive at the retailer, they are placed in display cabinets and or the refrigerated storage room (Mercier et al., 2017). However, the current refrigeration systems used in retail display cabinets is often set at optimal temperature but the actual temperature inside the cabinet usually varies depending on the location of the load and the load charge (Montanari, 2008). Numerous refrigeration equipment used in retail operate in high temperature environments thus inducing high temperature variability in these facilities (Gómez-López, 2012).

2.3. Cold chain technologies

2.3.1. Pre-cooling

This technology refers to the pulp temperature removal from horticultural food products right after harvesting by conduction or convection (Kitinoja, 2014; Mercier et al., 2017). Nunes et al. (2014) reported that the period right after harvest is important because the perishable food products are at their highest temperature, and they lose their shelf life at a faster rate. They also reported that immediate precooling of perishable food products improved the shelf life of these products significantly.

Precooling helps in attaining lower temperatures that can be maintained during transportation (James et al., 2006). During the pre-cooling, the target temperature is dependent on the type of perishable food product. Additionally, the amount of energy used in precooling is dependent on the initial temperature of the harvested perishable product, that is, if the temperature is high, a lot more energy will be required to cool it and vice versa (Kitinoja, 2014). It is also dependent on the type of packaging and whether products are packaged before the precooling process or not (Mukama et al., 2017).

There are a number of pre-cooling techniques such as forced air-cooling, hydro cooling, room cooling, vacuum cooling, and cryogenic cooling. Forced air cooling is carried out by creating an air pressure differential on either side of the pallet allowing cooled air to circulate from the outside through warmer product and back into the room after being re-cooled (Mukama et al., 2017) whereas hydro cooling achieves a cool product by use of chilled or cold water. Room cooling involves the placing of a food product in a cold room or a cooler whereas cryogenic cooling involves the use of nitrogen or dry ice to reduce the product temperature through evaporative cooling. Finally, vacuum cooling a fastest temperature reduction technique that involves evaporating of moisture in the food product thus reducing the food product temperature (Kitinoja, 2014).

2.3.2. Chilling

Chilling refers to the lowering of the perishable food product to a temperature of less than 8 °C by use of mechanical or non-mechanical means (Kitinoja, 2014). Techniques discussed in 2.3.1 can also be used during the chilling process although the temperature is much lower. Chilling the food products reduces the product temperatures to temperatures below 8 °C thus improving on their shelf life for more days to weeks compared to similar fresh product. Chilled temperatures slow down the growth of microorganisms although pathogens with low infectious doses still remain a threat to food safety (Gómez-López, 2012).

2.3.3. Freezing

Freezing is an ancient food preservation technique that involves the drastic reduction of the food product temperature to very low temperature like -18 °C leading to the formation of ice crystals (Kitinoja, 2014). There are quite many methods of freezing including *Plate freezing* where packed products are held between very cold plates and the freezing speed is aided by pressure application between the plates, *Blast freezing*, a freezing technique where very cold air is passed over food product packages as they move through a tunnel or when stacked in a cold room. This is a popular method in refrigerated warehouses in large industrial food processing plants and usually, the cold air temperature is -23 °C or preferably between -34 to - 40 °C and the velocity is at 305610 m/min or higher (Kitinoja, 2014).

Other very rapid freezing techniques such as liquid nitrogen (conductive freezing) are used for commercial freezing although these are super expensive processes. These cooling techniques result into better quality food products when compared to the other freezing techniques. This is because the quality of frozen products is related to the size and distribution of the ice crystals formed which are affected by the freezing rate. Therefore, rapid freezing rates produce small sized crystals which cause limited damage to cellular tissue (Kiani and Sun, 2011; James et al., 2015). Various systems of liquid nitrogen such as immersion, shift pressure, ultrasound assisted, tunnel, plate or batch operations are available although care should be taken to prevent employee exposure to environments that lack oxygen.

2.3.4 Evaporative cooling

The evaporative cooling system (ECS) is one of the cheapest and oldest cooling technologies (Kapilan et al., 2023). Evaporative cooling storage structure (ECSS) is a double wall structure having space between the walls which is filled with porous water absorbing materials called pads which are kept constantly wet by applying water (Jha and Kudos, 2006). Evaporative cooling is an adiabatic process, in which ambient air is cooled as a result of transferring its sensible heat to the evaporated water carried with the air (Vala et al., 2014). Evaporative cooling storage system is easy to operate, efficient and affordable most especially for peasant farmers in developing countries who may find other methods of preservation quite expensive and unaffordable.

Evaporative cooling is the simplest and cheapest method for extending shelf life of fruits and vegetables (Okunade and Ibrahim, 2011). It has many advantages over refrigeration system as it does not require high initial investment as well as operational cost is negligible (Vala et al., 2014). It can be quickly and easily installed as its simple in design. Its maintenance is easy. It can be constructed with locally available materials in remote area and most important, it is eco-friendly as it does not need chlorofluorocarbons (Niyomvas and Potakarat, 2013). Therefore, Evaporative cooling storage structure is an alternative of mechanical refrigeration system (Kapilan et al., 2023).

2.4 Temperature and humidity management in cold chains

2.4.1. Time-temperature management

The management of temperature in a cold chain is very critical because it determines the risk potential, shelf life and final quality of the cold chain stored product, which has been processed and packaged under good hygiene and good manufacturing practices (Montanari, 2008). An ideal time-temperature situation is one whereby the set optimal temperature remains the same throughout the supply chain; however, this is not always the case. Quite frequently, temperature abuses occur in the food cold chain, both intentional and unintentional, and strain on transit cold chains as goods are transported through different ecological zones. This has potential of altering the food product safety and quality (Mercier et al., 2017; Ndraha et al., 2020). Properly controlled cold chains begin with harvest of produce at the coldest times of the day and then immediately precooling to remove any field heat on arrival at the pack house /cold store, followed by maintenance of these optimum conditions throughout the chain to the final consumer (Mukama et al., 2017).

Temperature abuse is defined as “an unacceptable deviation from the optimal temperature or optimal temperature regime for a given food product for a certain period of time, considering ambient temperature and the type of activities food products are exposed to (Ndraha et al., 2020). The biggest culprit of temperature abuse is door opening when loading and/or offloading although other factors such as mishandling and mismanagement of temperature controls, inadequate equipment and tools, position of the products, inappropriate food precooling and local heat sources in the cold chain facility among others, could cause temperature abuse (Mercier et al., 2017; Ndraha et al., 2018).

Fig. 2.2 below shows examples of temperature abuse of food products being delivered at refrigeration and frozen temperatures. The figure shows that during temperature abuse, there was a noticeable food surface and food centre temperature deviations from the set point, which could have been as a result of any of the conditions listed above.

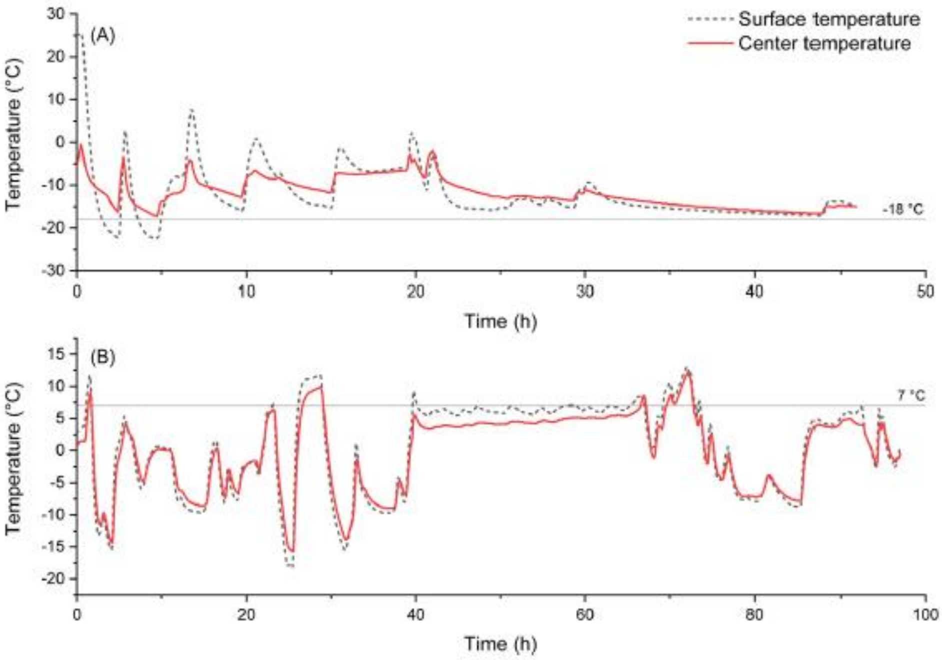

Figure 2.2 Temperature abuse of food products being delivered at refrigeration and frozen temperatures (Ndraha et al., 2020)

Measurement, tracking and monitoring of perishable food products' temperature provides detailed historic and current information, which can be able to communicate temperature abuses to supply chain members thus enabling timely corrective actions to be carried out. Currently, popular technologies like radio frequency identification (RFID) tags, wireless sensor networks (WSN) and time-temperature integrators (TTIs) are used to measure, record and monitor the perishable food product temperature (Koutsoumanis and Gougouli, 2015; Kumari et al., 2015). The evolvement of these tools (RFID and WSN) has gained a lot of popularity because of their ability to accurately record data, convenience and the fact that they are inexpensive (Ndraha et al., 2020). However, these tools still suffer from shortcomings like longer times to load large data, limited reading range, limited real time delivery, sensing capability and limited signal attenuation due to high water activity of the food products (Ruiz-Garcia and Lunadei, 2011; Fescioglu-Unver et al., 2015).

TTIs, just like RFID tags and WSN are able to visualise the time-temperature history of food products in a cold chain (Arias-Mendez et al., 2014). These can be divided into biological, chemical or physical systems depending on the working principle (Koutsoumanis and Gougouli, 2015; Wu et al., 2015). TTIs have a shortcoming of underestimating the remaining shelf life of the food product since their response is not always aligning with the food quality changes (Bobelyn et al., 2006).

2.4.2. Cold chain storage temperature ranges for perishable products

Perishable food product storage temperatures can generally be sub-divided into four categories, that is, frozen (≤ -18 °C) like fish, meat etc., cold chilled (0 – 1 °C) like meat products, poultry products, seafood etc., medium chilled (5-8 °C) like fruits, vegetables, milk etc., exotic chilled (10-15 °C) like ready to eat foods like sandwiches (Ndraha et al., 2018, Tsai and Lin, 2019). Table 2.3 below shows some of the optimal storage temperatures of common perishable food products.

Table 2.3. Storage temperatures of common perishable food products (Ndraha et al., 2020)

Food product	Optimal temperature range
Ready-to-eat cooled food (i.e., rice ball, sandwich, etc.)	≈ 18 °C
Exotic chilled food (i.e., fruit and vegetables)	≈ 10 – 15 °C
Chilled foods (i.e., fresh vegetables, juice, milk, etc.)	≈ 0 – 7 °C
Cold-chilled foods (i.e., meat products, poultry products, seafood, etc.)	≈ 0 °C ± 2 °C
Frozen foods (i.e., frozen vegetables, frozen meat, frozen seafood, etc.)	≤ -18° C
Deeply frozen temperature foods (i.e., fish, etc.)	≤ -30° C

Many scholars have reported about the complexity of definite optimal storage temperatures or temperature ranges for perishable food products in cold chain facilities due to the differences in practices, different capabilities of supply chain members and different influences of external factors (like climatic conditions, regulations, or market requirements) in the cold chain environment (Ndraha et al., 2018; Ndraha et al., 2020). Therefore, the determination of optimal storage conditions would require process optimization to determine which temperature provides the best shelf life in terms of quality and safety.

2.4.3. Time-humidity management

It has been reported that there is a direct relationship between the relative humidity and the transpiration rate that happens in the food product (Deo, 2014). Transpiration refers to the loss of moisture from fruits and vegetables. This normally includes the moisture transport from the fruit or vegetable skin, evaporation from the skin and convective mass transfer of the moisture to the surrounding environment (Lufu et al., 2019). The loss of moisture from a food product most especially fresh fruits and vegetables is detrimental to product freshness, weight and appearance (Mukama et al., 2019). When the cold chain temperatures are low and relative humidity high, the rate of respiration and thus transpiration is reduced and therefore senescence is delayed. It is therefore critical to store and transport perishable food products at low temperatures and high relative humidity to lower the rate of transpiration (Lerma-Carrillo et al., 2021).

The use of refrigeration is popular in maintaining low temperatures however, it reduces the moisture content (low humidity). In order to mitigate this challenge, humidification equipment(s) need to be installed to control the cold chain humidity. Examples of humidification methods vary from advanced equipment like advanced spinning disc aspirators to conventional methods like blowing air over a water full bucket, keeping the floor wet among others (Deo, 2014). The recommended relative humidity for storage and transportation of fresh food is 90-95% (Table 2.4) according to Lufu et al., (2020). However, caution should be taken to avoid growth of microorganisms because this humidity condition is very favourable for microbial growth. Additionally, product-packaging designers should consider the effect the humidity will have on the packaging material to prevent package collapse and associated produce damage during storage and transportation in these high humidity environments (Mukama et al., 2019).

Table 2.4. Influence of storage relative humidity (RH) on fruit water loss (Lufu et al., 2020)

Fruit	**Storage condition**	**RH (%)**	**Water loss (%)**
Pomegranate (cv. Wonderful)	20° C, 30 days	65	29.1
		95	5.8
Apples (cv. Jonagold)	20° C, 18 days	30	6.0
		65	4.0
		95	1.0
Apples (cv. Braeburn)	20° C, 18 days	30	5.3
		65	3.8
		95	1.0
Grape tomatoes (cv. Lobello F1)	10° C, 20 days	70	4.8
		80	2.2
		92	1.4
Pear (cv. Kontoula)	20° C, 5 days	70	3.1
		80	2.4
		95	1.2
	10° C, 6 days	70	2.2
		80	1.8
		95	0.5
Strawberries (cv. Elsanta)	10° C, 5 days	76	4.2
		86	3.1
		96	2.3

2.5. Benefits of the cold chain

Global climatic changes have caused most nations to reduce agricultural production volumes. The challenge is even bigger for perishable food products like fruits and vegetables because they easily spoil on account of increased respiration rate, micro-organisms, weight loss, colour changes and loss of firmness (Mukama et al., 2020). This challenge has led to an increase in the attention towards the use cold chain systems in the global supply chains to improve food access and availability in all parts of the globe (James and James, 2010).

Generally, cold chain systems have a number of advantages for the agricultural sector. First, cold chain systems reduce the physical and microbiological spoilage of perishable food products, which eventually lead to wastage and toxicities (Chen et al., 2010; James and James, 2010). Kitinoja, (2013) detailed the advantages of using cold chains some of which included decreasing the microbiological activity, reduction in the ethylene production which slows down the ripening rate, delaying of natural senescence, reduction in the loss of texture, prevention of browning, reduction in transpiration thus less shrinkage and maintaining flavour and nutrients. Summarily, the cold chain conditions create a positive impact on the safety, shelf life and the final product quality (Montanari, 2008).

2.6. Environmental sustainability of cold chains

Many consumers are aware and concerned of the sustainability issues in the food supply chains. The most pressing issue to consumers is reducing the impact of food production and distribution to the environment (Food Insight, 2019). Even though cold chain systems help keep the perishable food products safe and of good quality, these systems consume energy thereby emitting emissions. By far, cold chain management and preservation are the popular methods of improving the shelf-life and quality of food products (Floros et al., 2010) however, the cold chain systems have had environmental sustainability concerns. The use of refrigeration in food supply chains is a major consumer of global energy accounting for up to 15% of the global electricity consumption (Coulomb, 2008; Gwanpua et al., 2015). With over 400,000 and 1,000,000, reefer containers and refrigerated vehicles respectively currently in use, post-harvest transportation of perishable food products consumes a substantial amount of energy (Gac, 2002). Furthermore, refrigeration is a critical contributor to ozone depletion and warming of the globe arising from the direct emissions from refrigerant leakages and indirect emissions from burning of fossil fuels during the production of electricity which is used to power refrigeration equipment (Tsai and Lin, 2019). The largest proportion of environmental carbon dioxide emissions irrespective of market region or the refrigeration system used, was due to indirect emissions (Tsai and Lin, 2019).

Globally, food losses that are caused by the lack of cold chain systems were estimated in 2017 at 526 million tonnes and this quantity resulted in carbon dioxide emissions of around 1,004 million tonnes (UNEP and FAO, 2022). The global cold chain systems on the other hand have led to an emission of about 340 million tonnes of carbon dioxide into the environment of which 60% of this carbon dioxide was contributed by East Asia, America and Europe (IIR, 2021). This shows that if food losses directly linked to the lack of cold chains were avoided, 664 million tonnes of carbon dioxide emissions into the atmosphere would have been avoided. Properly managed food cold chain systems help reduce on the burden of food loss and also reduce on the carbon dioxide emissions which would help reduce on the global warming effect thus achieving a more sustainable ecosystem (Tsai and Lin, 2019). Additionally, cold chains eliminate the drive to produce more food to counter the loss and wastage, which also contributes significantly to carbon emissions.

2.7. Cold chain context in sub-Saharan Africa

According to the Global Cold-Chain Alliance (GCCA), the refrigerated warehouses in the world had a total capacity of 719 million cubic metres in 2020 of which Unites states of America (156 million cubic metres), India (150 million cubic metres), and China (131 million cubic metres), contributed more than half of the capacity (GCCA, 2020). This capacity is distributed unevenly with less contribution from developing countries (Table 2.5) thus the need for support in increasing the cold chain capacity of these countries to meet their needs. The average capacity of developed nations in North America, Western Europe and Oceania was around 200 m^3 per 1,000 inhabitants whereas in developing countries like sub-Saharan nations, the capacity was averagely 19 m^3 per 1,000 inhabitants (IIR, 2021). Developing regions like sub-Saharan Africa could be able to preserve an estimate of over 144 million tonnes of perishable food products if they have the cold chain capacity equivalent to those of the developed world (IIR, 2020).

Table 2.5. Comparison of cold storage capacities of selected sub-Saharan countries (Drame and Meignien, 2016)

	Ethiopia	**United Republic of Tanzania**	**Namibia**	**South Africa**
Capacity (Litres/capita in urban areas)	2	2	5.1	15

Note: Data is for 2012 with exception of South Africa for which 2008 data was used.

Food cold chain actors in sub-Saharan Africa face a number of challenges ranging from energy access, high maintenance costs, poor logistical arrangements, weak or non-existent cold chain standards, poor compliance to cold chain standards and low volume of cold chain traded products (Drame and Meignien, 2016). Additionally, Gligor et al., (2018) reported that developing countries like those in sub-Saharan Africa face challenges like lack of quality and safety control measures, deficient infrastructure and information systems, high installation and operation costs, deficient training and operation level, deficient standardisation, social norms and the lack of government support for local businesses. Tackling each of these limitations and challenges will go a long way into stimulating investment in this sector and benefiting all perishable produce actors ultimately significantly contributing to food security.

2.8. The cold chain and United Nations Sustainable Development Goals (SDG)

The development and utilization of the cold chain systems in Uganda and other sub-Saharan countries will reduce on the post-harvest losses of perishable food products thus increasing on the farmers' incomes. This will have a direct impact on the SGD 2 (Zero hunger), SDG 8 (Decent work and economic growth) and SDG 12 (Responsible consumption and production). In addition, the development and utilisation of cold chains would have an indirect impact on the performance improvement on SDG 1(No poverty), SDG 9 (Industry, innovation, and infrastructure) and SDG 10 (Reduced inequalities). This contribution greatly signifies why investments in this sector will be of great importance in the improvement of lives of people generally and especially for sub-Saharan Africa, that is greatly lagging in the achievement of these UN goals.

2.9. Effect of knowledge, attitudes and practices on cold chain adoption

Retailers provide the link between producers and consumers, and therefore have an ability to influence decision-making at both ends of the food supply chain (Macfadyen et al., 2015). Establishing the knowledge, attitudes and practices of this segment of stakeholders along the food supply chain is important and can contribute to reduction of post-harvest loses by adopting more sustainable practices. Studies on cold chain knowledge, attitudes and practice within the food value chain have mainly focussed on the consumer side (Uçar and Özçelik, 2013; Smigic et al., 2023). Smigic et al., (2023) found that consumer practices in maintaining the cold chain were not in tandem with the fairly good level of food safety knowledge. This observation points to the importance of attitude in influencing practice in spite of knowledge. However, Uçar and Özçelik, (2013) highlighted the importance of education of stakeholders on the benefits of the cold chain in the effort to ensure adherence. Non adherent attitudes and practices coupled with inadequate knowledge could break the cold chain management system and affect the quality and safety of produce handled. Efforts to improve cold chain storage capacity and management should also address the utilisation aspect which is mainly driven by knowledge and attitude.

2.10. The role of government in prevention of food losses

Post-harvest losses are disproportionately large in Low Developed Countries (LDC) mainly due to lack of cooling facilities (Porter and Reay, 2016). Additionally, technical inefficiencies such as poor or low-technology approaches to farming, harvesting, storage, and transportation contribute to these losses and waste. The extent of the damages is further increased by lack or poor implementation of policies related to food handling (Dora et al., 2020). Food loss prevention falls under three key areas: "values" - providing people with knowledge on food waste so that they change their behaviour (attitudes and practices), "skills" - increasing abilities to be able to reduce food waste (e.g., through training), and "logistics" – improved technical efficiency in form of better product cooling systems and improved packaging and storage facilities (Thyberg and Tonjes 2016).

A joint FAO and World Bank report suggests that technologies and practices, such as postharvest grain management, pest management, enhanced storage facilities, and enabling policies could significantly reduce food loss in Africa. Therefore, there is an urgent need for more investment in improved storage, transportation, and cooling infrastructure in LDCs (Liu et al., 2013; Thi et al., 2015) coupled with an increase in producers' access to food processing, packaging, and new markets (Liu et al., 2013). Additionally, policies that address food handling should be implemented and formulated where absent.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1. Study area and scope

The study was conducted in the 16 cities of Uganda. These are; Kampala, Fort Portal, Arua, Gulu, Jinja, Mbarara, Mbale, Masaka, Hoima, Entebbe, Lira, Kabale, Moroto, Nakasongola, Wakiso, and Soroti. The study involved only cities because they are the most developed in the country with facilities like reliable electricity, roads and commerce that facilitate cold chain operations (Rafa et al., 2017). Only cold chain facilities used in bulk handling of perishable milk, meat, fish, fruits and vegetables.

3.2. Sample size determination

All cold chain facilities used in bulk handling of perishable food products (milk, meat, fish, fruits and vegetables) were surveyed.

For knowledge, attitude, and practices of perishable produce value chain actors, survey participants sample size was determined using Equation 1 known as Cochran`s formula (Cochran, 1977) since the formula is recommended for studies with infinite population.

$$n_o = (Z^2 \text{ x p x q})/ e^2 \quad (\textit{Equation 1})$$

where n_o is the estimated sample size, *Z;* is the Z-value for a specified confidence interval (1.96), *p;* is the estimated value of population variation (50% = 0.5); Statistically, 50% is the highest percentage of variation in a population, *q;* is 1-p (0.5) and *e;* is the desired level of precision (5% = 0.05).

$$n_0 = (1.96^2 \text{ x } 0.5 \text{ x } 0.5)/ 0.05^2 = 385.$$

Therefore, 385 participants were considered for the survey. These participants were distributed in the study areas depending on the population of the study area as shown in Table 3.1.

Table 3.1 Survey participants' distribution across the study area

City District	Population according to (UBOS, 2014)	Population proportion (%)	Study participants
Kampala	1,507,080	17.02	66
Fort Portal	469,236	5.30	20
Arua	782,077	8.83	34
Gulu	275,613	3.11	12
Jinja	471,242	5.32	20
Mbarara	472,629	5.34	21
Mbale	488,960	5.52	21
Masaka	297,004	3.36	13
Hoima	572,986	6.47	25
Lira	408,043	4.61	18
Kabale	528,231	5.97	23
Moroto	103,403	1.17	04
Nakasongola	181,795	2.05	08
Wakiso	1,927,460	21.78	84
Entebbe	69,958	0.79	03
Soroti	296,833	3.35	13
Total	**8,852,550**	**100.00**	**385**

3.3. Data collection

To assess the cold chain systems characteristics, the study conducted in-depth and semi-structured interviews with key stakeholders in the supply chain. Data was collected using cold systems checklist questionnaire. A quarter of the questionnaires were pretested with the cold storage facilities within Kampala to check for possible inadequacies and the feasibility of the questionnaires. This was done two weeks prior to the actual data collection process. This was aimed at helping improve on the questions in the questionnaires and eliminate questions that were unnecessary.

A semi-structured questionnaire was used to collect information about the knowledge, attitude and practices of perishable food product handlers about cold chain systems. Similarly, the questionnaire was pretested with the markets in the five divisions of Kampala to check for possible inadequacies and the feasibility of the questionnaires.

3.4. Temperature and humidity determination

The cold chain management data was collected using temperature and relative humidity data loggers (Elitech EN12830, Elitech Technology, lnc. California, USA) which were placed in the cold chain facilities for 30 days recording data every after 6 hours.

3.5. Location determination

The cold chain facility physical location was determined using a GPS device (Garmin 010-00970-00 eTrex 10 Worldwide Handheld GPS Navigator, Garmin Ltd, Kansas, USA) and the coordinates recorded.

3.6. Capacity determination

Cold chain facilities internal dimensions were measured using a tape measure (30 m Fiber Measuring Tape, Zhongya Metering Tape Co., Ltd, Zhejiang, China) to establish the operating capacity (volume in m^3) as seen in Fig. 3.1.

Figure 3.1 Measurement of cold chain facilities

3.7. Statistical analysis

The data from the surveys on cold chain systems and knowledge, attitude and practices of perishable products value chain actors was analysed using descriptive statistics. Temperature and humidity data was analysed using Stata version 16, Wilcoxon signed rank tests (to assess variations from individual set points) and the graphs were plotted using Microsoft 365 Excel application (Microsoft, Excel New York, USA).

3.8. Ethical considerations

The study was carried out following ethical procedures. An introductory letter was obtained from Kyambogo University introducing the researcher to the study participants. Consent was sought from participants before participation in the study. In addition, each questionnaire contained an opening introductory statement requesting for the participants' cooperation in providing the required information for the study. The participants were free to stop at any point if they did not wish to continue. The information provided was kept strictly confidential and only aggregate figures were reported.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1. Distribution and capacity of cold chain facilities in Uganda

4.1.1. Distribution of cold chain facilities

A total of 51 cold chain facilities used for bulk handling of perishable agricultural produce were located. These were spread out across nine cities of Uganda, namely Kampala, Wakiso, Mbarara, Fort Portal, Entebbe, Gulu, Masaka, Soroti, and Jinja (Fig. 4.1). Kampala had the highest proportion (47.37%) followed by Wakiso and Mbarara accounting for 14.04% and 10.53%, respectively. Entebbe and Fort Portal had an equal percentage of 8.77% while Gulu, Soroti, Jinja, and Masaka, had smaller percentages, ranging from 1.7 to 3.51%. (Fig. 4.2)

This is unsurprising given that Kampala is Uganda's capital. Kampala is densely populated (this provides a larger market segment) with increased economic activities, infrastructural development and higher market demand for refrigerated storage facilities (Rafa et al., 2017). It is worth noting that the city's closeness to Entebbe International Airport also enables it to contribute to logistics required in international business. Wakiso is the most densely populated city in Uganda hence having a large market segment (UBOS, 2014). The city also benefits from its closeness to Kampala and Entebbe International Airport. Wakiso is part of the broader Kampala metropolitan region, which is experiencing fast urbanization (highest GDP per capita of $3,250) (Rafa et al., 2017), resulting in an increased demand for cold storage services. The presence of multiple cold rooms in Entebbe can be attributed to the presence of Entebbe International Airport making it a vital transportation and distribution centre. Cold chain handling is required for various perishable goods that pass through the airport, including agricultural products. Uganda is an agricultural country with a significant export industry, especially for fisheries products. Mbarara, a prominent city in Western Uganda famed for milk and milk products output, acts as a link between the western, southern and central areas (DDA, 2023). This contributes to the city's comparatively larger number of cold chain facilities.

A considerable percentage (43.7%) of the cities did not have any cold rooms for bulk handling of perishable agricultural produce. These were Arua, Mbale, Hoima, Lira, Kabale, Moroto and Nakasongola. This could be attributed to lack of infrastructure and limited financial resources considering that building and operating of cold rooms is costly (Kitinoja et al., 2014). Furthermore, absence of cold storage facilities maybe due to lack of knowledge about the importance and benefits of cold storage and limited government support.

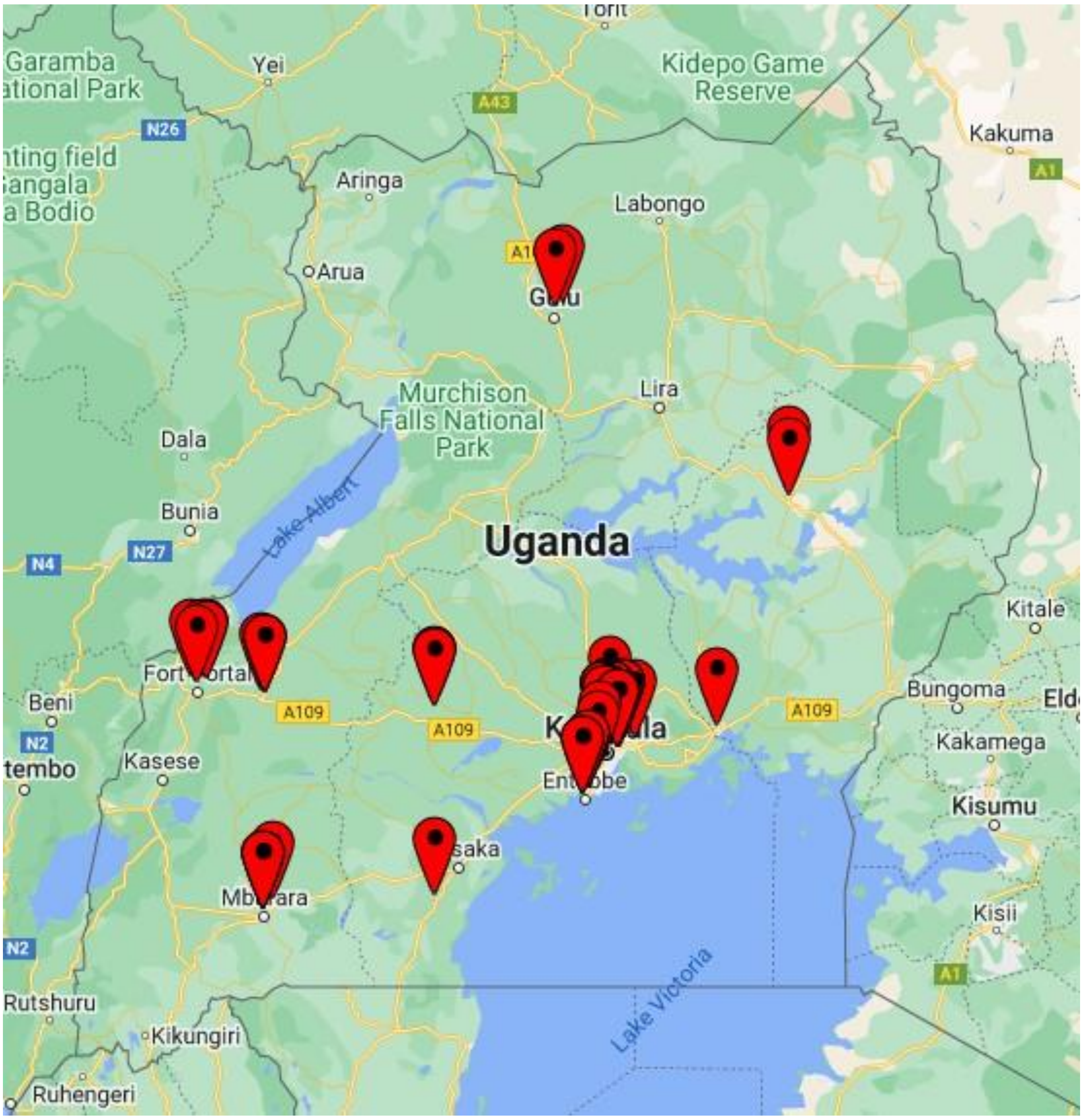

Figure 4.1: Location of bulk food cold chain facilities in the cities of Uganda

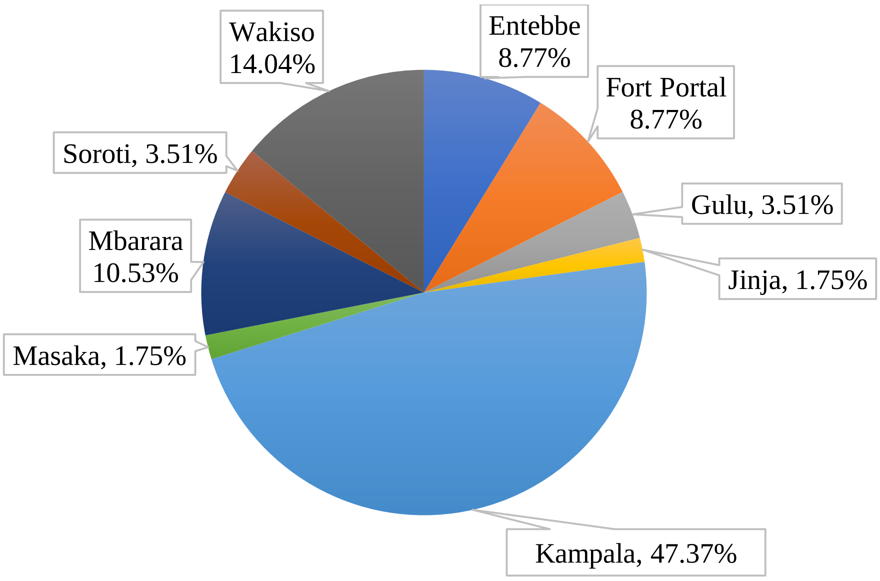

Figure 4.2: Distribution of bulk food cold chain facilities in the cities of Uganda

4.1.2. Capacity utilisation of cold chain facilities in Uganda

The total refrigerated storage space in the 16 cities was 39849.25 m^3 of which Kampala, Entebbe and Wakiso contributed more than half of this capacity. Wakiso, Arua, Gulu, Jinja, Mbarara, Masaka, and Soroti had refrigerated storage space ranging from 0.07 - 9.97 m^3 per 1,000 inhabitants. Furthermore, Mbale, Hoima, Lira, Kabale, Moroto, and Nakasongola, had no refrigerated capacity for bulk handling of perishable agricultural produce.

It is important to note that Kampala, Entebbe and Wakiso are the hub for Uganda's growing middle class economy (Rafa et al., 2017) and as the economy continues to grow there is an increasing demand for fresh and processed food products with longer shelf life.

IIR (2020) indicated that on average, the refrigerated capacity in the food value chain of developed countries was 200 m^3 per 1,000 inhabitants whereas in developing countries like sub-Saharan nations, the capacity was 19 m^3 per 1,000 inhabitants. The food bulk handling refrigerated cold chain capacity for the 16 cities in this study was 4.50 m^3 per 1,000 inhabitants.

This is 76% and 98% below the average for developing and developed countries respectively. Only Kampala and Entebbe cities with refrigerated storage capacity of 20.39 m^3 per 1,000 inhabitants and 30.47 m^3 per 1,000 inhabitants respectively (Table 4.1) surpassed the average for developing countries. This could be attributed to higher income for the inhabitants, lifestyle/cultural shifts, presence of convenience stores hence higher market demand for refrigerated storage facilities as compared to other cities. It is important to note that as much as Kampala and Entebbe cities surpass the 19 m^3 per 1,000 inhabitants reported for developing countries, it is way below the 200 m^3 per 1,000 inhabitants reported for the developed countries. This presents a need for investment in the cold chain infrastructure to address the challenge of post-harvest losses in perishable agricultural produce in Uganda with its tandem effects leading to food and nutrition insecurity, lost market opportunities, increased carbon footprint and wastage of natural resources.

Refrigerated storage space in a number of cities was much less than the capacities observed in Kampala and Entebbe, yet these upcountry districts are the main producers of perishable produce (MAIF, 2022). This means that the produce in these districts is prone to postharvest losses and the produce transported to Kampala from these upcountry production sites is prone to prolonged temperature abuse that further reduces its postharvest life. These could partly explain the large heaps of spoiled fruits and vegetables observed in the fresh foods markets of Kalerwe and Nakasero in Kampala among others. This demonstrates a need to support the establishment of cold chain infrastructure in these districts. In Moroto and Nakasongola, such facilities would boost the meat and dairy industries of the cities given that they are within sub regions that hold over 19.8% in Karamoja and 21.7% in Central of cattle population in Uganda, respectively (UBOS, 2009).

Table 4.1. Refrigerated Storage Capacity per 1000 inhabitants for the cities of Uganda

City District	Population according to (UBOS, 2014)	Refrigerated Storage Space (m^3)	Refrigerated Storage Capacity /1000 inhabitants (m^3/1000 inhabitants)
Kampala	1,507,080	30,728.27	20.39
Fort Portal	469,236	1,332	2.84
Arua	782,077	-	-
Gulu	275,613	19.90	0.07
Jinja	471,242	72.57	0.15
Mbarara	472,629	345.40	0.73
Mbale	488,960	-	-
Masaka	297,004	72	0.24
Hoima	572,986	-	-
Lira	408,043	-	-
Kabale	528,231	-	-
Moroto	103,403	-	-
Nakasongola	181,795	-	-
Wakiso	1,927,460	2,189.39	1.14
Soroti	296,833	2958	9.97
Entebbe	69,958	2,131.72	30.47
Total	**8,852,550**	**39,849.25**	**4.50**

4.2. Characteristics of cold chain facilities

4.2.1. Ownership of the cold chain facilities

The private sector owned 75.44% of the cold chain facilities, the public owned 21.05% and the public-private partnership was responsible for 3.51% of cold chain facilities (Fig. 4.3).

The unevenness in the ownership of the cold chains could be attributed to the fact that private sector investments are primarily driven by profitability and return on investment. Cold chain infrastructure can enable the private sector to maintain the quality and safety of perishable goods throughout the supply chain and therefore by investment in the cold chain, private companies can reduce post-harvest losses, minimize spoilage and ensure the availability of high quality products ultimately maximizing their profits (Rajapaksha et al., 2021; Anand and Barua, 2022). On the other hand, the low development in the public sector could be attributed to limited public sector resources since public sector investments are often constrained by limited financial resources and competing priorities therefore, government may be facing challenges in allocating sufficient funds to infrastructure development, including cold chains. Public investments in Uganda are typically directed towards sectors like security, healthcare, education and basic infrastructure, which are considered for the overall socio-economic development (Ssenoga & Matovu, 2010; World Bank, 2020).

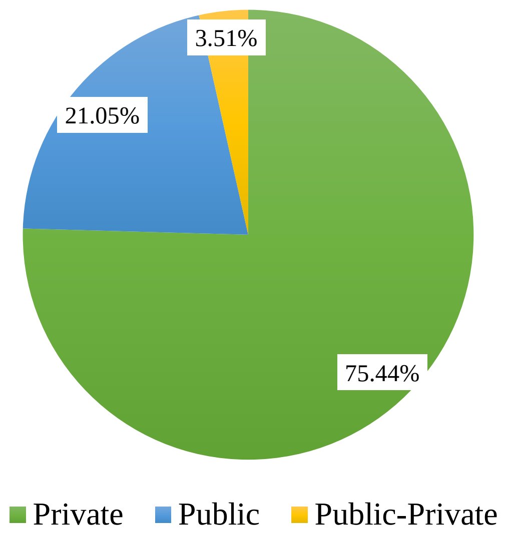

Figure 4.3: Ownership of cold chain facilities used for bulk handling of perishable food in the cities of Uganda

4.2.2. Source and destination of foods stored in cold chain facilities

Approximately 75.44% of the food stored in cold chain facilities was from the domestic market (Table 4.2). This is unsurprising given the fact that agriculture is the major economic activity in the country and hence a significant portion of the stored food is sourced from the local market. Most fruits and vegetables have peak harvest seasons when supply is abundant. During this season of plenty, producers should store their surplus in the cold chain to maintain the product quality to be able to supply both in and out of season or for even an extended period within season for price control.

Approximately, 17.51% of the food held in cold chain facilities is reported to originate from both the domestic and foreign markets. This indicates that some facilities store a combination of locally produced and imported food items to cater for the diverse needs of the population. Only 7.02% of the food stored in cold chains was from foreign markets. This can be attributed to Uganda's agricultural potential boasted by favourable climate and diverse agro-ecological zones (Dijkxhoorn, 2019) that allow for cultivation of a wide range of crops, livestock rearing and fish production.

A considerable amount of food (43.86%) held in cold chain facilities in Uganda is intended for both domestic and export markets (Table 4.2). This indicates that certain facilities serve the dual purpose of meeting needs of the domestic market while facilitating export of perishable commodities to foreign markets. About 31.58% of the food stored in cold chain facilities is for domestic market. This infers that a major portion of food stored in the cold chain is intended to meet the growing needs of Uganda's population. This has been driven by a significant increase in the production of perishable agricultural produce, urbanization and changing lifestyles that has come with increase in demand for processed and convenience foods. It is important to note that there is a significant growth in the retail sector, supermarkets, restaurant chains, hypermarkets and convenience stores have cropped up and these stock a wide range of perishable products.

Additionally, a significant portion (24.56 %) of the stockpiled food is earmarked for export markets. This demonstrates that certain facilities specialize in storing and processing food products strictly for the international market. Products intended for export have specific quality standards and requirements set by importing countries for example the European Union has General Health and Food Safety guidelines for all food imports. Cold rooms provide controlled storage conditions such as temperature and humidity, which help maintain the quality, safety and freshness of the products.

Table 4.2. Source and destination of foods stored in the bulk cold chain facilities in the cities of Uganda

Variable	Category	Proportion(%)
Food product source	Both	17.51
	Domestic market	75.44
	Import	7.02
Food product destination	Both	43.86
	Domestic market	31.58
	Export	24.56

4.2.3. Foods stored in the cold chain facilities in Uganda

Fish accounted for the highest percentage (24.56%) of foods held in the cold chain (Fig. 4.4). This could be attributed to the highly perishable nature of fish; additionally most fish processors target the export market. Uganda exported 29,000 MT of fish in 2022 (UFPEA, 2023). The world fish export market relies heavily on cold chain management. Milk and other dairy products accounted for 21.05% of the foods held in the cold chain. Dairy products are also highly perishable and can spoil easily if not stored appropriately. Storing of milk in the cold chain helps maintain its freshness, flavour and nutritional quality by slowing down the growth of bacteria and other microorganisms that cause spoilage. Fruits and vegetables made up 19.30% of the storage and meat and poultry products constituted 14.04% of the cold room storage.

Multiple foods represented 21.05% of the cold room storage. This category represents cold rooms that stocked more than one type of perishable product. However, it is important not to mix perishable product categories in the cold chain for several reasons. Different perishable products have unique specific temperature requirements for optimal storage and preservation (Kitinoja, 2014). Mixing different product categories in the cold chain may lead to cross contamination and temperature inconsistencies which compromise the quality and safety of products. Mixing incompatible products can result in either inadequate cooling or freezing damages (Kitinoja, 2014). Certain perishable products can release aromas and flavours that may be absorbed by other products in close proximity, which alters the taste and quality of affected products (Wang et al., 2021). Therefore, to ensure the integrity, quality and safety of perishable products, it is best to store products separately based on their specific temperature, handling and storage requirements.

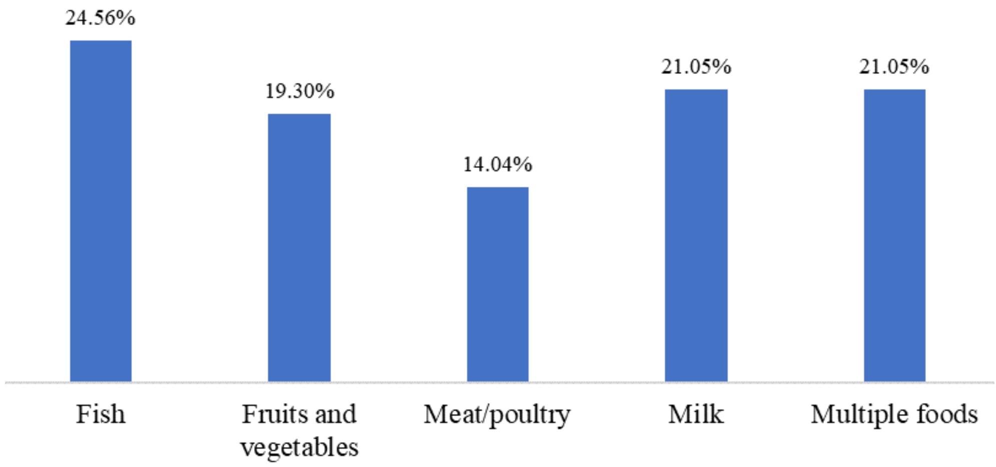

Figure 4.4. Distribution of foods held in cold chain facilities in the cities of Uganda

4.2.4. Process steps and technology applied by cold chain facilities in Uganda

Chilling accounted for about 17.54% of the cold chain process steps (Table 4.3). Here, the temperature of the food is reduced to a certain degree above freezing. This procedure helps to reduce bacterial development while preserving the quality and freshness of perishable foods (Kitinoja, 2013). Both chilling and pre-cooling accounted for approximately 12.28%. Pre-cooling occurs soon after harvest to eliminate field heat and improve the shelf life of the crop before further processing or storage. In 1.75% of the cold chain process steps, freezing was documented. This entails reducing the temperature of the food below its freezing point to prevent bacterial growth and enzymatic activity, this low percentage could be because frozen products are not popular on the Ugandan market. Approximately 54.39% of the process steps involved both freezing and chilling. The combination of freezing, chilling, and pre-cooling, accounted for 12.28% of the steps while, a small portion (1.75%) of the process steps, involved the combination of freezing and pre-cooling.

Room cooling is the most often used cold chain technique accounting for 33.33%. It entails keeping the food in a temperature-controlled room or facility and adjusting the air temperature to the perishable items' ideal storage conditions. In 3.51% of cold chain technology applications, blast freezing was applied. This rapid freezing method uses high-velocity air to rapidly drop the temperature of the product, preserving the food's flavour, texture and nutritional content. Forced air convection accounted for nearly 3.51% of cold chain technology, here fans are used to circulate cooled air around the food. This promotes homogeneous cooling and keeps the temperature uniform throughout the storage space. Around 35.09% of cold chain facilities employed a combination of room cooling and blast freezing methods. The utilization of room cooling and forced air convection methods was observed in 17.54% of cold chain facilities. Approximately 3.51% of the facilities implemented all three methods, including room cooling, forced air convection and blast freezing. Furthermore, 1.75% of cold chain facilities utilized a combination of various methods, such as room cooling, forced air convection, hydro cooling and blast freezing. These measures are essential in extending product shelf life, maintaining product freshness, nutritional integrity, and market appeal of perishable products.

Table 4.3. Distribution of process steps and technologies used by cold chain facilities in Uganda

Variable	Category	Proportion (%)
Cold chain process step	Chilling	17.54
	Chilling, Pre-cooling	12.28
	Freezing	1.75
	Freezing, Chilling	54.39
	Freezing, Chilling, Pre-cooling	12.28
	Freezing, Pre-cooling	1.75
Cold chain technology	Blast freezing	3.51
	Forced air convection	3.51
	Forced air convection, Blast freezing	1.75
	Room cooling	33.33
	Room cooling, Blast freezing	35.09
	Room cooling, Forced air convection	17.54
	Room cooling, Forced air convection, Blast freezing	3.51
	Room cooling, Forced air convection, Hydro cooling, Blast freezing	1.75

4.3. Temperature and relative humidity monitoring of the refrigerated warehouses and walk-in cold rooms

All data logged refrigerated warehouses and walk-in cold rooms had temperatures that varied significantly from the set points ($p<0.05$) (Table 4.4). Entebbe 1 with a set temperature of 10 °C, experienced fluctuations ranging from 8 to 21.3 °C. The facility handled fruits and vegetables. The recommended storage temperature for exotic chilled fruit and vegetables is 10-15 °C (Ndraha et al., 2020). The temperature of the facility went over the maximum allowable temperature for about 1/3 of the temperature-logged period (Fig. 4.5). Entebbe 2, set at 4 °C, had recorded temperatures ranging from 1.1 to 14 °C. This facility held chilled foods that have a recommended temperature range of 0 to7 °C (Ndraha et al., 2020). This also had temperature of the facility about 1/3 the logged period above the maximum allowable temperature (Fig. 4.6).

Similarly, in Kampala, the cold rooms also showed notable variations from their set point temperatures. Kampala 1, set at -18 °C, experienced temperatures ranging from -23.2 °C to -3.9 °C, while Kampala 2, with the same set temperature, fluctuated between -19.1 °C and -4.4 °C. Both facilities handled frozen foods that have recommended storage temperatures of ≤-18 °C (Ndraha et al., 2020). While the facility in Kampala 1 had the storage temperature values above -18 ° C for about ¼ the data logged period (Fig. 4.7), Kampala 2 had temperatures above the set point for ¾ of the data logged period (Fig. 4.8). This shows that this facility is largely inefficient in temperature management and not ideal for frozen storage. Temperature fluctuations during cold handling deteriorate food threatening its safety and quality (Reid and Perez-Albela, 2006; Porras-Amores et al., 2014). An ideal time-temperature situation is one whereby the set optimal temperature remains the same throughout the storage period (Bogdanovska et al., 2019). Temperature variations also increase energy consumption owing to the fact that when the temperature rises above the desired set point, the cooling system needs to work harder to bring it back to the desired level. Temperature variations also put additional stress on the refrigeration equipment leading to increased wear and tear. Additionally, it leads to uneven cooling with some areas being colder than others hence rendering certain areas of the cold room unsuitable for storing temperature-sensitive items (Reid and Perez-Albela, 2006).

The variations observed in the cold storage facilities can be attributed to; long periods of opening cold room doors during times of loading and offloading, overloading or poor arrangement of the goods which can impede air circulation, turning off of equipment when not in use (this is only energy efficient if the cold facility will be off for a long time considering that it will be more expensive if the intervals are short as the refrigeration system will take more energy to re-cool the storage facility) (Mercier et al., 2017; Ndraha et al., 2018). Inadequate insulations in the walls, ceiling or floor can allow heat to enter/escape leading to temperature variations, improper airflow that can be caused by blocked air vents and improperly positioned fans and equipment malfunction (Reid and Perez-Albela, 2006; Porras-Amores et al., 2014; Bogdanovska et al., 2019). External influences can also affect the temperature in the cold rooms, for example, changes in ambient temperature, humidity levels or exposure to direct sunlight can affect the performance of the cooling system and cause temperature fluctuations.

Table 4.4. Temperature variation from set points in data logged cold facilities in the selected cities of Uganda

Walk in Cold room	Set Temperature (°C)	Minimum Temperature (°C)	Maximum Temperature (°C)	z	p-value
Entebbe 1	10	8	21.3	11.418	<0.0001
Entebbe 2	4	1.1	14	5.9	<0.0001
Kampala 1	-18	-23.2	-3.9	-3.919	0.0001
Kampala 2	-18	-19.1	4.4	9.698	<0.0001
Wakiso 1	-18	-19.4	-11.8	2.357	0.0184
Wakiso 2	-22	-36.9	10.8	4.581	<0.0001

In Wakiso, the two cold rooms also displayed significant deviations from their set temperature (Table 4.4). Wakiso 1 fluctuated between -19.4 °C and -11.8 °C, while Wakiso 2 ranged from -36.9 °C to 10.8 °C. Similar to Kampala 2, Wakiso 1 also had temperatures fluctuate above the recommended ≤18 °C for frozen storage for ¾ of the data logged period (Fig. 4.9) while Wakiso 2 fluctuated above the recommended for about ½ of the logging period (Fig. 4.10). To minimize temperature variations in the cold rooms; it is important to regularly maintain and inspect the refrigeration equipment, minimize times the doors are left open, ensure proper insulation and sealing, optimize airflow and monitor the arrangement of goods (Mercier et al., 2017; Ndraha et al., 2018).

While all facilities monitored and recorded temperature as part of their routine quality control procedures, it is important to note that the cold room managers did not monitor neither had relative humidity regulators in their facilities. This could be attributed to the fact that temperature has a larger impact on food safety and quality compared to relative humidity. Relative humidity is mainly crucial in the cold chain context with produce that is prone to high moisture losses, especially fruit and vegetables (Mukama et al., 2019; Lufu et al., 2020). The loss of moisture from fresh fruits and vegetables is detrimental to product freshness, weight and appearance (Mukama et al., 2019). When the cold chain temperatures are low and relative humidity high, the rate of respiration and thus transpiration is reduced and therefore senescence is delayed. The average relative humidities recorded for the data logged cold facilities were 79.50±9.32% (Fig. 4.5), 84.18±7.92% (Fig. 4.6), 84.57±1.58% (Fig. 4.7), 81.44±9.48% (Fig. 4.8), 85.71±5.27% (Fig. 4.9), and 78.39±14.13% (Fig. 4.10) for Entebbe 1, Entebbe 2, Kampala 1, Kampala 2, Wakiso 1 and Wakiso 2, respectively. The recommended relative humidity for storage and transportation of fresh fruit and vegetables is 90-95% (Lufu et al., 2020). Relative humidity in cold storage is maintained using humidification equipment like advanced spinning disc aspirators, blowing air over a water full bucket, keeping the floor wet among others (Deo, 2014).

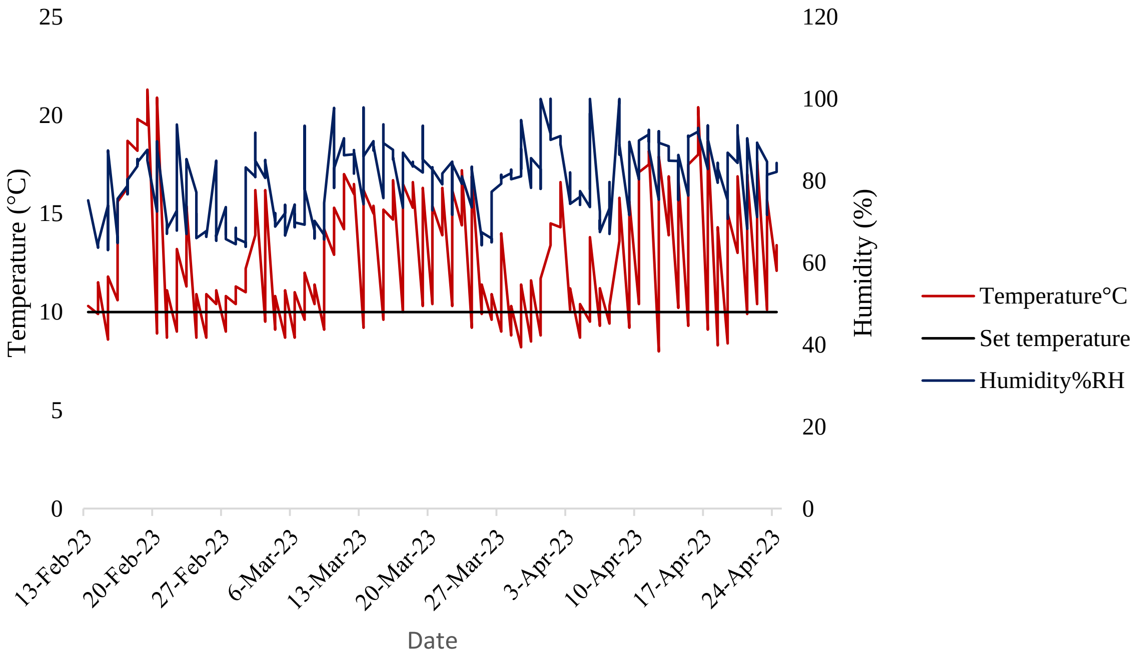

Figure 4.5. Temperature and humidity variation over a period of three months at Entebbe 1 cold facility

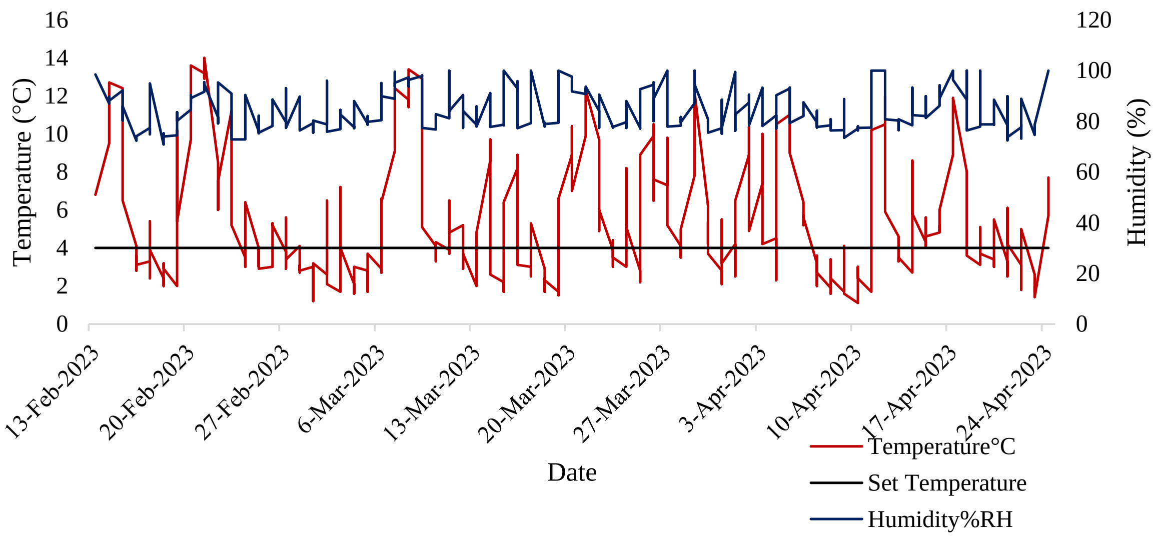

Figure 4.6. Temperature and humidity variation over a period of three months at Entebbe 2 cold facility

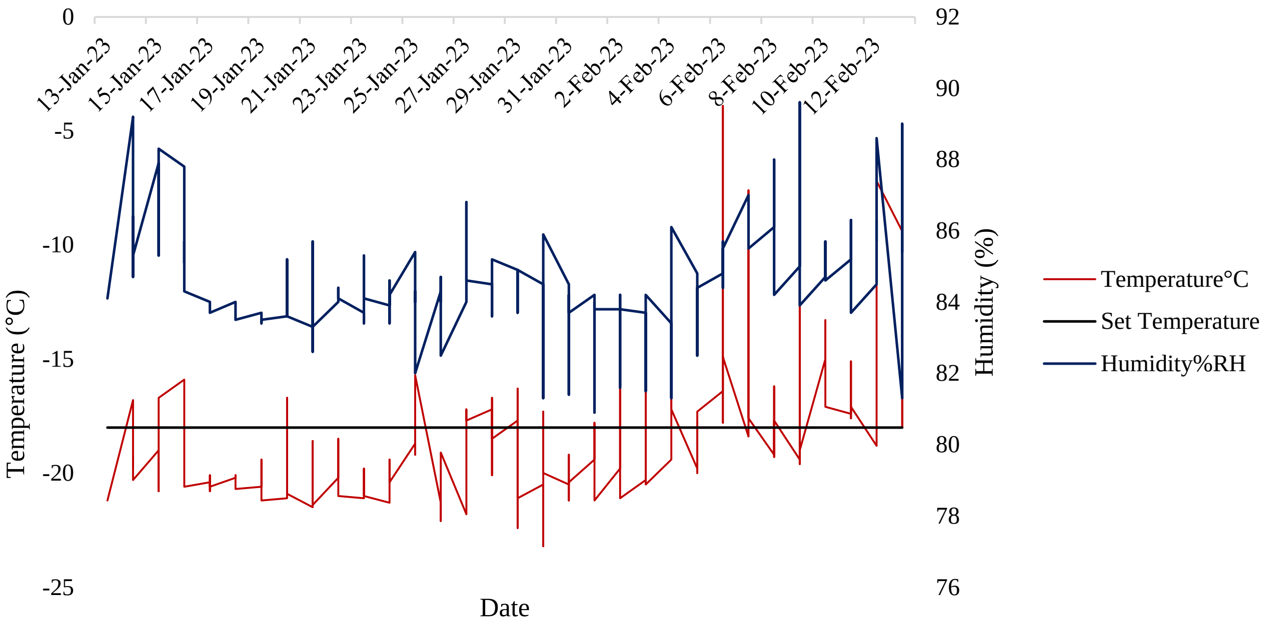

Figure 4.7. Temperature and humidity variation over a period of 30 days at Kampala 1 cold facility

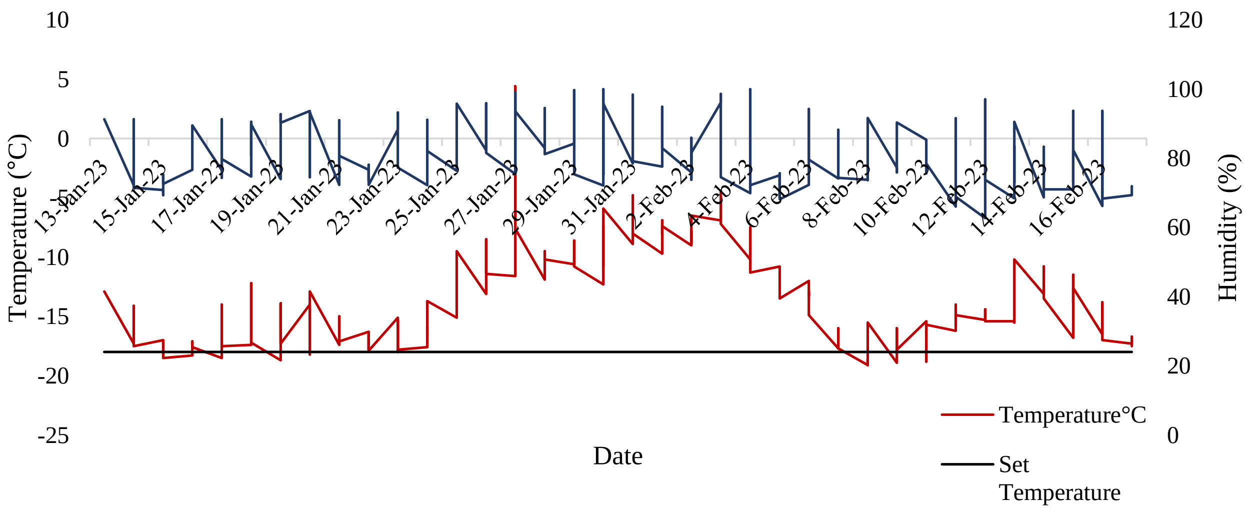

Figure 4.8. Temperature and humidity variation over a period of 30 days at Kampala 2 cold facility

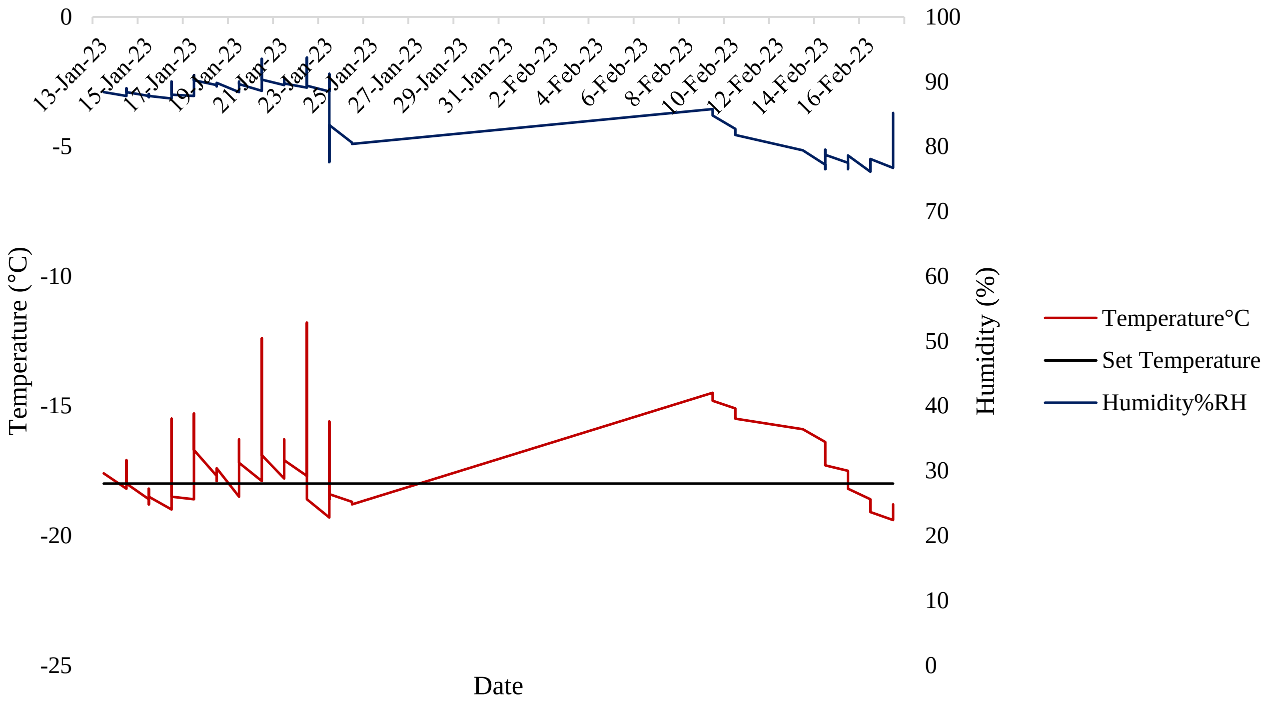

Figure 4.9. Temperature and humidity variation over a period of 30 days at Wakiso 1 cold facility

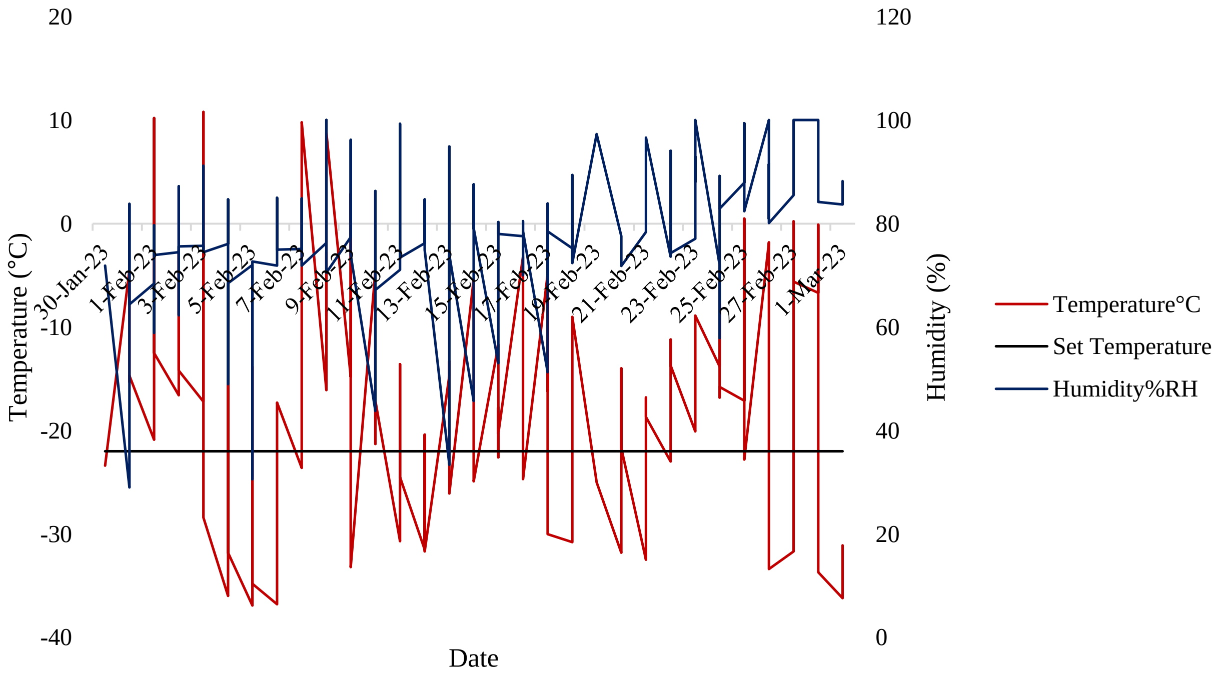

Figure 4.10. Temperature and humidity variation over a period of 30 days at Wakiso 2 cold facility

4.4. Knowledge and practices of perishable food products retailers value chain

4.4.1. Socio-demographic characteristics of participants

Majority (57.57%) of the participants were male while 42.43% were female (Table 4.5). The participants in the age group of 26 to 35 accounted for 52.75% of the total. This indicates that a significant portion of the surveyed individuals were in the young adults to middle age category (Lawton et al., 1992), which may suggest their active involvement in the perishable food products value chain. Other age groups, such as 18 to 25, 35 to 50 and >50 also had notable representation. The largest (58.94%) group consisted of individuals with secondary school education. Furthermore, participants with primary school education constituted 27.52% of the sample. The majority (66.51%) of participants reported a daily income of Ugandan Shillings (UGX) less than or equal to 300,000/=. This suggests that a significant portion of actors in the perishable food products value chain have a low-income level. These findings can contribute to a better understanding of the diverse perspectives and experiences of actors involved in the perishable food products value chain, which can inform targeted interventions, policies and initiatives aimed at improving knowledge and practices in the industry and cold chain management adoption.

Table 4.5. Socio demographic characteristics of participants

Variable	Category	Proportion (%)
Sex	Female	42.43
	Male	57.57
Age group (YRS)	18-25	21.1
	26-35	52.75
	35-50	20.64
	>50	5.5
Education status	Bachelors, Masters or PhD	0.92
	None	5.5
	Primary school	27.52
	Secondary school	58.94
	Tertiary institutions	7.11
Daily income (UGX)	1000001 - 2000000	3.21
	2000001 - 4000000	0.23
	300001 - 500000	20.41
	500001 - 1000000	8.49
	=<300000	66.51
	=> 4000000	1.15

4.4.2. Proportion of participants who have heard of cold chains and what they know about them.

Table 4.6 indicates that 48.62% of participants had heard about the cold chain. Nearly half (48.62%) of the surveyed population is familiar with the concept, while the other half (51.38%) lacks knowledge or awareness of the cold chain (Table 4.6). Among the participants who had some knowledge about the cold chains, 44.44% associated the cold chain with cooling and preservation of perishable foods. This suggests that a significant portion of individuals recognize the importance of temperature control in maintaining food quality, safety and prolonged product shelf life. Other responses demonstrate a more specific understanding of the cold chain. For example, 14.14% of participants mentioned that the cold chain is used for storing meat for long periods, 9.09% of participants stated that the cold chain is for keeping food fresh.

It is important to note that some participants provided more specific associations, such as storing fish to keep it fresh (4.04%), storing fruits (1.01%) and storing chicken for long periods (1.01%). These responses highlight the diverse range of products that can benefit from cold chain practices. Overall, the data illustrates that while a significant portion of the surveyed population had some understanding of the cold chain, there is room for improvement in terms of comprehensive knowledge and awareness. Educational efforts can focus on enhancing understanding of the broader aspects of the cold chain, including its role in preserving various perishable food products while ensuring their quality and safety. Through increased awareness and knowledge, stakeholders can work together to strengthen the implementation and effectiveness of the cold chain in Uganda's perishable food products value chain.

Table 4.6. Proportion (%) of participants who had heard of cold chains and what they knew about them

Variable	Category	Proportion (%)
Ever heard about the cold chain?	No	51.38
	Yes	48.62
What exactly they know about the cold chain	Cold chains work like refrigerators for food stuffs	2.53
	Cold stores for foods like meat, milk and vegetables	1.01
	Cold stores for foods like fish, meat and milk	6.06
	Cold stores for foods like meat, milk and juice	1.01
	For transportation of milk	0.51
	For cooling and preservation of perishable foods	44.44
	For cooling products and extending their shelf life	1.01
	For keeping fish fresh during transportation	3.03
	For keeping food and drinks cool	4.55
	For keeping food fresh	9.09
	For storing fish, meat, fruits and vegetables	6.57
	For storing chicken for long periods	1.01
	For storing fish to keep it fresh	4.04
	For storing fruits	1.01
	For storing meat for long periods	14.14

4.4.3. Proportion of participants who understand which items must be stored in cold rooms

Only 0.46% of participants stated that only chicken must be kept cold throughout the supply chain (Table 4.7). Fish and/or fish products only were indicated as goods that require cold chain storage by about 2.52%. This demonstrates an understanding of the perishable nature of fish and the need for temperature control in preserving its freshness. Around 1.15% of participants mentioned that fruits and vegetables and/or related products should be kept in the cold chain. Approximately 4.82% of the participants recognized the need for cold chain storage for meat and/or meat products only. A significant percentage (30.96%) of participants identified milk and/or milk products as items that require cold chain storage. This indicates a strong understanding of the need for temperature control to preserve the freshness and quality of dairy products. It is noteworthy that (37.84%) acknowledged that multiple products, including milk, meat, fish and fruits and vegetables require cold chain storage.

Overall, the data reveals varying levels of awareness regarding the specific products that necessitate cold chain storage. While there is a relatively higher understanding of the need for cold chains for items like milk and meat, there is need to educate stakeholders about the importance of cold chain storage for other perishable products such as chicken, fish, fruits and vegetables.

Table 4.7 Proportion (%) of participants who understand which items must be stored in cold rooms

What products require to be kept in the cold chain?	Proportion (%)
Chicken	0.46
Fish and or fish products	2.52
Fish and or fish products, Fruits and vegetables and or related products	2.75
Fruits and vegetables and or related products	1.15
Meat and or meat products	4.82
Meat and or meat products, Fish and or fish products	8.03
Meat and or meat products, Fish and or fish products, Fruits and vegetables and or related products	1.38
Meat and or meat products, Fruits and vegetables and or related products	0.46
Milk and or milk products	0.69
Milk and or milk products, Fish and or fish products	1.83
Milk and or milk products, Fruits and vegetables and or related products	0.46
Milk and or milk products, Meat and or meat products	6.19
Milk and or milk products, Meat and or meat products, Fish and or fish products	30.96
Milk and or milk products, Meat and or meat products, Fish and or fish products, Fruits and vegetables and or related products	37.84
Milk and or milk products, Meat and or meat products, Fruits and vegetables and or related products	0.46

4.4.4. Understanding of the processing stages where cold chains are necessary

Cold rooms are essential at all levels of the value chain, according to 15.6% of participants (Table 4.8). This implies a thorough awareness of the necessity for temperature control throughout the whole value chain process including harvest/slaughter, transportation, processing, distribution and retail. The highest percentage (34.86%) of participants, identified retail (market) as the stage at which cold rooms are required. This reflects a common understanding that maintaining proper temperature control at retail locations is crucial to preserve the quality and safety of perishable food products. Transportation was indicated by about 6.19% of participants as the stage that needs the usage of cold rooms. Approximately 6.19% of participants indicated distribution. This demonstrates an understanding of the need of maintaining optimal temperature conditions when storing and transporting perishable food items across the distribution network. A minority of participants, ranging from 0.23 to 2.98% highlighted specific combinations of stages that necessitate the use of cold rooms.

Overall, the data reveals a general recognition that cold rooms are required at multiple stages of the value chain, with a particular emphasis on retail (market) and transportation.

Table 4.8. Proportion (%) of participants that are aware of processing stage where cold chains are necessary

At what stage do you think the cold room is required?	Participants (%)
At all stages	15.6
At harvest or slaughter	0.23
At harvest or slaughter, Distribution, Retail (market)	0.92
At harvest or slaughter, Retail (market)	1.83
At harvest or slaughter, Transportation	0.23
At harvest or slaughter, Transportation, Distribution, Retail (market)	0.92
At harvest or slaughter, Transportation, Processing	0.23
At harvest or slaughter, Transportation, Processing, Distribution	0.92
At harvest or slaughter, Transportation, Processing, Distribution, Retail (market)	0.46
At harvest or slaughter, Transportation, Processing, Distribution, Retail (market), All the above	0.46
At harvest or slaughter, Transportation, Processing, Distribution, Retail (market), All the above	0.69
Distribution	1.15
Distribution, Retail (market)	6.19
Processing, Distribution	0.92
Processing, Retail (market)	0.23
Retail (market)	34.86
Transportation	6.19
Transportation, Distribution	2.98
Transportation, Distribution, Retail (market)	11.01
Transportation, Processing	0.23
Transportation, Processing, Distribution	0.46
Transportation, Processing, Distribution, Retail (market)	2.06
Transportation, Processing, Retail (market)	0.69
Transportation, Retail (market)	10.55

4.4.5. Beliefs and attitudes of participants towards usage of cold chain facilities

Majority (94.27%) of the participants agreed that cold chain-handled products last longer compared to non-cold chain handled products (Table 4.9) while only 5.73% of participants disagreed. This shows a strong awareness of the effect of cold chains on perishable products among cold chain actors. The largest (71.56%) of participants reported absence of nearby cold chain storage options. Only 28.44% of participants indicated that cold chain facilities were available. This correlates with the low investments in bulk handling cold facilities observed in section 4.1 of this study. Among the participants, 18.12% stated that they store their products in cold chain facilities, while majority (81.88%) did not utilize such facilities for storage purposes. A substantial proportion (76.15%) of participants expressed that cold chain systems are an added expense they cannot afford, while 23.85% disagreed with the statement. Majority (82.57%) of participants expressed their readiness to utilize cold chain facilities while 17.43% stated otherwise. In terms of customer behaviour, 80.5% of participants believed that customers would be willing to purchase cold chain-stored produce, while 19.5% had reservations about customer preferences. Most (84.4%) participants agreed that cold room facilities are environmentally friendly while 15.6% held a different opinion. Overall, the results reflect varying attitudes and perceptions among participants regarding the effectiveness, affordability, and environmental impact of cold chain facilities. The results from the study indicate that the value chain actors understand the relevance of the cold chain process step in the preservation and extension of perishable produce shelf life. It is worth noting that the actors would be willing to store their products in the cold chain if they were available.

Table 4.9. Beliefs and attitudes of participants towards usage of cold chain facilities

Variable	Yes	No
	Participants (%)	Participants (%)
Do you think cold chain handled products last longer than non-cold chain handled products?	94.27	5.73
Is there any cold chain facility nearby, where you could store your perishable goods if need be?	28.44	71.56
Do you store products there?	18.12	81.88
Cold chain systems are an added expense that I can't afford	76.15	23.85
If available, would you store your produce in a cold chain?	82.57	17.43
Do you think customers would buy cold chain stored produce?	80.5	19.5
Do you think cold room facilities are environmentally friendly?	84.4	15.6
Do you use any cold chain?	37.33	62.67

4.4.6. Alternative methods for ensuring optimal temperature of perishable goods for non-cold chain users

Among participants who did not use any cold chain facilities, various alternative methods undertaken to preserve product integrity and shelf life were mentioned. Majority (75.90%) of the participants indicated that they stored their perishable goods under a shade to protect them from direct sunlight (Fig. 4.11). Followed by 16.53% who sprinkled water on their perishable goods to keep them cool and maintain freshness. A small proportion (5.77%) used a combination of both storage under shade and sprinkling with water to maintain the optimal temperature of perishable goods. Only 1.25% and 0.59% of the participants stated that they use ice placed in floaters and keep matooke aerated. These responses demonstrate the resourcefulness and creativity of individuals who do not have access to cold chain facilities. While these alternative methods may not provide the same level of temperature control and consistency as cold chain systems, they reflect the efforts made by individuals to preserve the quality and shelf life of their perishable goods.

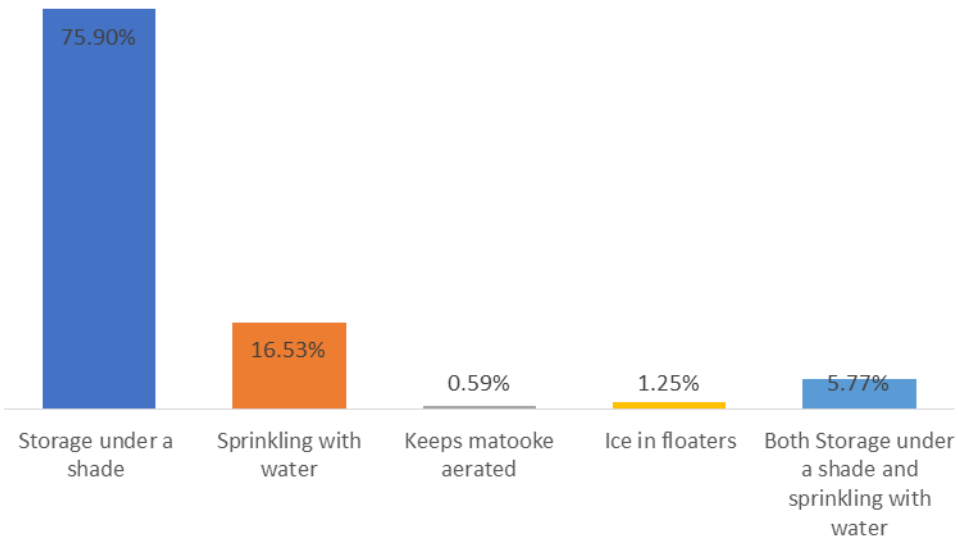

Figure 4.11. Alternative methods for ensuring optimal temperature of perishable goods for non-cold chain users

4.4.7. Cold chain processes, product separation and temperature monitoring among cold chain users

Among cold chain users, 68.29% of participants reported using chilling as their primary cold chain process (Table 4.10). Only 10.97% mentioned utilizing a combination of chilling and freezing, participants that rely solely on freezing as their cold chain process accounted for 20.74%. In terms of product separation during cold storage, 86.5% of the participants separated food products based on type during cold storage while 13.5% did not.

Regarding temperature monitoring of the cold chain facility, 39.49% of the participants actively monitored the temperature of the cold chain facility while 60.51% did not.

These findings indicate that chilling is the most commonly used cold chain process and that majority of participants separate food products based on type during cold storage indicating a recognition of the importance of proper categorization. However, a considerable number of participants did not monitor the temperature of the cold chain facility, which could potentially affect the quality and safety of perishable products stored therein, therefore it is crucial to emphasize the importance of temperature monitoring when using the cold chain.

Table 4.10. Distribution of cold chain processes, product separation, and temperature monitoring among cold chain users

Variable	Category	Proportion(%)
For those that use cold chain, which of the following cold chain processes do you use for your perishable products?	Chilling	68.29
	Chilling,	10.97
	Freezing	20.74
During cold storage, do you separate food products depending on product type?	No	13.5
	Yes	86.5
Do you ever read temperature of the cold chain facility?	No	60.51
	Yes	39.49

4.4.8. Average duration of food product in the cold chain

A big (91.93%) proportion of participants reported keeping their food products in the cold chain for less than one week (Fig. 4.12). Approximately 3.73% of the participants mentioned an average duration of 1 to 3 weeks and only 2.48% and 1.86% of the participants reported an average duration of one month and longer than one month respectively. These findings suggest that the majority of participants keep their food products in the cold chain for less than a week, which is a relatively short storage period. This correlates with chilling being the most used cold chain process. Chilled products last a few weeks long in cold storage while freezing storage has the ability for produce storage for several months (Ndraha et al., 2020).

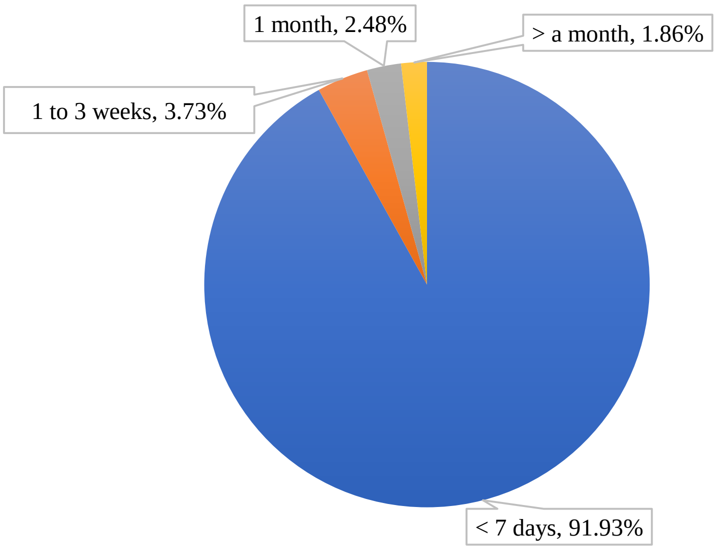

Figure 4.12. Average duration of products in the cold chain facilities in the cities of Uganda

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

The study assessed and characterised the cold chain capacity utilized in bulk handling of perishable agricultural produce (milk, meat, fish, fruits and vegetable) in the 16 cities of Uganda. Furthermore, the study monitored temperature and relative humidity management of the cold chain facilities and lastly assessed knowledge, attitude and practices of perishable food products retailers towards the cold chain.

A total of 51 cold chain facilities were found to be in only 09 of the 16 cities. Kampala had the highest (47.37%) proportion followed by Wakiso and Mbarara which accounted for 14.04% and 10.53% respectively. The total refrigerated storage space in the 16 cities was 39849.25 m^3 of which Kampala, Entebbe and Wakiso contributed more than half. This translated into an average storage capacity of 4.50 m^3 per 1000 inhabitants which is less than 19 m^3 per 1,000 inhabitants reported for developing countries and much less than 200 m^3 per 1,000 inhabitants for developed countries. This finding highlights the insufficient cold storage capacity for bulk handling of perishable produce in Uganda. Absence of cold chain facilities in 07 of the cities indicates critical capacity gaps in the Ugandan perishable produce sector and thus the need for investment.

A vast (75.44%) segment of the cold chain facilities was owned by the private sector hence making availability of cold chain services to the public limited. There was a significant variation of temperature from the respective set points for each of the cold rooms that were monitored. Values above maximum allowable temperatures for specific handled produce were found to vary from between 1/3 to ¾ of the logged storage period. This calls for active monitoring and management of temperature and relative humidity of the facilities by the cold chain operators. Majority (71.56%) of perishable produce retailers did not utilize cold chain facilities mainly because they were unavailable however, 82.57% were willing to utilise these facilities if availed.

5.2. RECOMMENDATIONS

There is urgent need for investment in cold chain infrastructure, technology, and human capital for bulk handling of perishable agricultural produce in Uganda by both the government and private sector players. This will help reduce the postharvest losses in the country and improve food and nutrition security. This could involve exploring options such as community-based cold storage solutions, government subsidies or incentives for cold chain infrastructure development and public-private partnerships to increase the availability of cold chain services particularly in rural areas.

Cold chain users should actively monitor the temperature and relative humidity of their cold chain facilities. Training programs and guidelines should be provided to promote proper temperature and relative humidity monitoring practices and ensure that perishable goods are stored within the recommended temperature and relative humidity ranges. Educational campaigns should be undertaken among perishable produce retailers to dispel misconceptions, address affordability concerns, and promote the value proposition of cold chain systems in ensuring food safety and reducing post-harvest losses.

Further research is recommended to study the available capacity of the mobile cold chain infrastructure (refrigerated trucks, reefers, etc.) used in perishable produce handling that is associated with the static cold chain facilities in Uganda.

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APPENDIX 1

COLD CHAIN SYSTEMS CHECKLIST

<table>
<tr><td colspan="4">SECTION 1: COLD CHAIN SYSTEM IDENTIFICATION INFORMATION
Please fill in the spaces provided</td></tr>
<tr><td>1.1</td><td>Date: __/__/__ (DD/MM/YY)</td><td>1.5</td><td>GPS Location:</td></tr>
<tr><td>1.2</td><td>Facility ID:</td><td>1.6</td><td>Researcher ID:</td></tr>
<tr><td>1.3</td><td>Equipment ID:</td><td>1.7</td><td>Researcher signature:</td></tr>
<tr><td>1.4</td><td>City:</td><td></td><td></td></tr>
<tr><td colspan="4">SECTION 2: COLD CHAIN SYSTEM OPERATION
Please tick (✓) or circle (O) the right response</td></tr>
<tr><td>2.1</td><td>Cold chain ownership</td><td colspan="2">Private
Public
Other
Specify: ---------------------</td></tr>
<tr><td>2.2</td><td>Food product handled by the cold chain</td><td colspan="2">Meat/Poultry
Milk
Fish
Fruits and Vegetables
Other
Specify: ---------------------</td></tr>
<tr><td>2.3</td><td>Food product source</td><td colspan="2">Import
Domestic market
Both
Other
Specify: ---------------------</td></tr>
<tr><td>2.4</td><td>Food product destination</td><td colspan="2">Export
Domestic market
Both
Other
Specify: ---------------------</td></tr>
<tr><td colspan="4">SECTION 3: COLD CHAIN SYSTEM SPECIFICATIONS
Please tick (✓) or circle (O) the right response</td></tr>
<tr><td>3.1</td><td>Cold chain system</td><td colspan="2">Warehouse
Walk-in cold room
Other
Specify: ---------------------</td></tr>
<tr><td>3.2</td><td>Cold chain system process step</td><td colspan="2">Freezing
Chilling
Pre-cooling
Other
Specify: ---------------------</td></tr>
<tr><td>3.3</td><td>Cold chain system process step technology</td><td colspan="2">Room cooling</td></tr>
</table>

		Forced air convection Hydro cooling Vacuum cooling Blast freezing Other Specify: ---------------------
3.4	Rated capacity	 --------------------- m^3
3.5	Utilised Capacity	 --------------------- m^3
3.6	Power source	Solar energy National grid Hybrid Other Specify: ---------------------
3.7	Presence of an alternative power source	Yes Specify: ---------------------- b) No
SECTION 4: COLD CHAIN SYSTEM MANAGEMENT *Please tick (✓) or circle (O) the right response*		
4.1	How is temperature monitored?	Offline temperature reading Online temperature reading Other Specify: ---------------------
4.2	How is humidity monitored?	Offline humidity reading Online humidity reading Other Specify: ---------------------

APPENDIX 2

KNOWLEDGE AND PRACTICES OF ACTORS IN THE PERISHABLE FOOD PRODUCTS VALUE CHAIN

Dear Sir/Madame,

I am Abaasa Paula, (Telephone: +256701137088), a student in the Department of Food Technology, Kyambogo University conducting a study titled "*Assessment of the cold chain capacity used in handling perishable agricultural produce in Uganda*". You have been identified as a resourceful person in this study and you are kindly requested to spare some of your valuable time to respond to these questions. The information provided will be kept strictly confidential and for academic purposes. Only aggregate figures will be reported. I will be grateful if you complete this questionnaire as your opinion will help in providing valuable information about the cold chain systems in Uganda.

You are free to stop at any point if you do not wish to continue with it.

Thank you very much for your time and participation.

SECTION 1: IDENTIFICATION INFORMATION *Please fill in the spaces provided*			
1.1	Participant ID:	1.5	Village:
1.2	Interview Date: / / (DD/MM/YY)	1.6	District:
1.3	Facility Name:	1.7	Division:
1.4	Research assistant:	1.8	Signature:
SECTION 2: DEMOGRAPHY *Please tick (✓) or circle (O) the right response*			
2.1	Sex	Male Female	
2.2	Age Group	18-25 26-35 36-50 ≥ 51	
2.3	Education Status	None Primary school Secondary school Tertiary Institutions Bachelors, Masters or PhD	
2.4	Daily income from sale of perishable products	≤ 300,000/= 300,001 – 500,000/=	

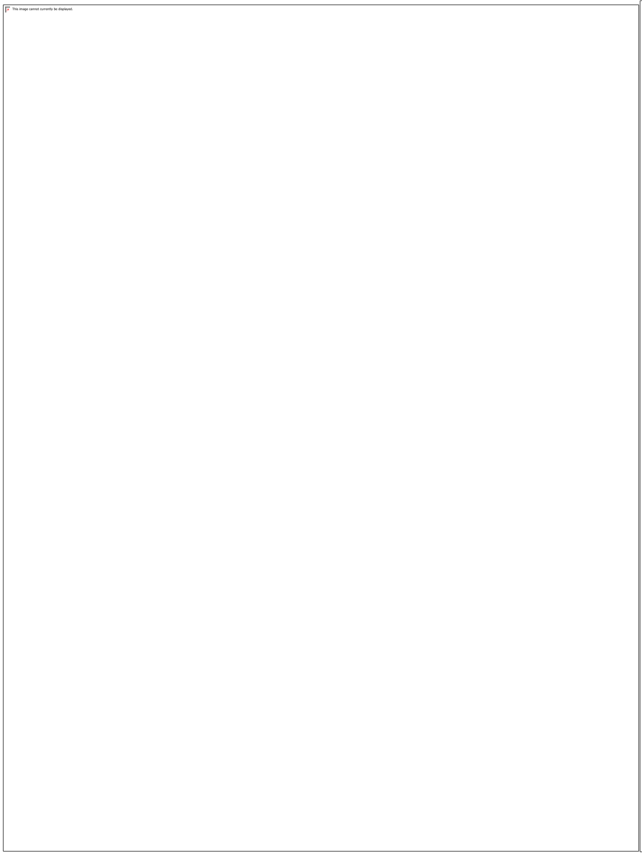
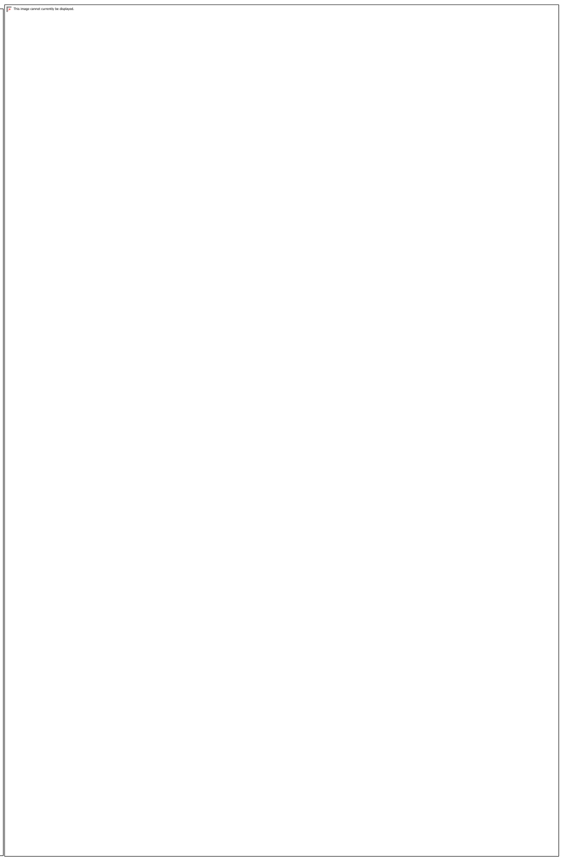
		500,001 – 1,000,000/= 1,000,001 – 2,000,000/= 2,000,001 – 4,000,000/= ≥ 4,000,001/=
SECTION 3: PERISHABLE PRODUCT HANDLER`S KNOWLEDGE OF COLD CHAIN SYSTEMS *Please tick (✓) or circle (O) the right response*		
3.1	Have you heard about the cold chain?	a) Yes b) No
3.2	If yes, could you please tell me what you know about it. *(Write answer in the space provided)*	
3.3	What products require to be kept in the cold chain?	Milk and or milk products Meat and or meat products Fish and or fish products Fruits and vegetables and or related products Others: Specify------------------------------
3.4	At what stage do you think the cold chain is required?	At harvest/slaughter Transportation Processing Distribution Retail (market) All the above
3.5	Do you think cold chain handled products last longer than non-cold chain handled products?	Yes No
3.7	Is there any cold chain facility nearby, where you could store your perishable goods if need be?	Yes No
3.8	Do you store your products there?	a) Yes b) No
SECTION 4: PERISHABLE PRODUCT HANDLER`S ATTITUDE TOWARDS COLD CHAIN SYSTEMS *Please tick (✓) or circle (O) the right response*		
4.1	Cold chain systems are an added expense that I can't afford?	Yes No
4.2	If available, would you store your produce in a cold chain?	Yes No
4.3	Do you think customers would buy cold chain stored produce?	Yes No
4.4	Do you think cold chain facilities are environmentally friendly?	Yes No

SECTION 5: PERISHABLE PRODUCT HANDLER`S PRACTICES TO ACHIEVE OPTIMAL CONDITIONS *Please tick (✓) or circle (O) the right response*		
5.1	Do you use any cold chain facility?	Yes No
5.2	If your answer was No to question 5.1 above, how do you ensure that your perishable goods are kept at optimal temperature?	Sprinkling with water Storage under a shade Other Specify:
Answer question 5.3 and beyond only if you answered Yes to question 5.1		
5.3	Which of the following cold chain processes do you use for your perishable products? *(Circle all possible process that you use)*	Chilling Refrigeration Freezing
5.4	During cold chain storage, do you separate food products depending on product type?	Yes No
5.5	Do you ever read the temperature of the cold chain facility?	Yes No
5.6	Averagely, for how long do you keep your food product in the cold chain?	≤ 7days 1 – 3 weeks 1 month > a month

APPENDIX 3

Some of the images captured during data collection

A section of fresh foods in Soroti Main Market.



A blast freezer at one of the private cold chain facilities

A walk-in cold room at one of the central markets