Optimal Temperature in Cold Storage for Perishable Foods

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Abstract

Handling the optimal temperature of perishable food involved all stakeholders in the cold supply chain to monitored temperature range. Cold storage is deemed as one of the foremost components of the cold chain to maintaining the temperature of the perishable food. Each group of perishable food has its particular parameters of storing, which if not maintained are dangerous for the consumers and may result in the withdrawal of batches of goods from the market. This paper aims to show an overview of the optimal temperature for each group of perishable food. The grouping of perishable food is dairy product (4ºC), fish and marine product (-18ºC), leafy vegetables and citrus fruits (0-2ºC), tropical fruits (5-13ºC), frozen vegetables (-18ºC) and ice cream products (-29ºC). The awareness of the optimal temperature for each group of perishable food needs to be better understood by public sector planners and private sector investors to prevent the high cost of operation in maintaining the temperature of the cold storage which will affect the quality of the perishable food.

Keywords
Optimal Temperature, Cold Storage, Perishable food, Cold Supply Chain, and Storing.

1. Introduction
A cold chain is a special type of supply chain management, known as Cold Chain Management (CCM) has been established for temperature-sensitive and perishable food (Kuo and Chen 2010). The purpose of CCM is to manage activities related to perishable products such as dairy, meat, food, vegetables, mushrooms, fruits, flowers, and so on which must be distributed within a certain time and kept in a good condition-specific environment (Shabani et al. 2012). The logistics of the cold supply chain involved the storage and transportation system where the temperature is maintained from suppliers to the customers to sustain the quality and safety of the food products (Ndraha et al. 2018). One of the most important components in the cold chain that differentiate it from the supply chain is the refrigerated storage. This is because the appropriate control of the temperature in the cold chain is essential in the refrigerated storage/ this is because one of the best temperature-controlled sectors of the food cold chain is generally the cold storage sector (UN Enviroment and IIR 2018).

2. Characteristics of cold storage
The cold storage (Fig. 1) is regarded as one of the foremost components of the “cold chain”, which is described as the set of systems that affirms the continuation of the quality of product through the harvest stage up to the household consumer (Elansari et al. 2019).

Figure 1. Cold storage for fresh produce

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Cold storage is essential for the perishable product because all products whether chilled or frozen will be stored in cold storage at least once during their journey from production to the customer. The cold storage market is vastly varied which consists of small stores with volumes of 10-20 m^3 up to large warehouses with hundreds of thousands of cubic meters (UN Enviroment and IIR 2018).

Cold storage is a vastly practiced technique for bulk handling of the perishables between product output and marketing processing. It is one of the techniques of retaining perishable products in fresh and for a longer time by controlling temperature and humidity inside the storage system. Generally, appropriate storage practices involve temperature control, relative humidity control, air circulation, and maintenance of space between containers for sufficient ventilation and keep off inconsistent product mixes (Rahman et al. 2017). Cold storage also is normally known as keeping perishables food, pharmaceuticals, or other items under refrigeration. Refrigeration is a process of reducing the temperature and sustaining it in a given space for chilling foods, preserving certain substances, or providing an atmosphere conducive to bodily comfort. Such refrigeration suppresses both bacterial growth and adverse chemical reactions that happen in the normal atmosphere (Akdemir 2008).

It is proven that in the cold storage for perishable products, the temperature plays an important role since the main factor for sustaining the quality of products is by controlling the temperature. Temperature is an important factor because temperature affects the life of the fresh product by directly effecting the rates of biochemical activities (Xue, Zhang and Tang 2014). Elansari et al. (2019) stated that the use of low temperature through mechanical refrigeration for the storage of fresh produce apply to the perception of the thermal load. The thermal load portrays the reduction of heat released by the stored product to lower its temperature to the preferred level. In the storage of fresh produce, the ideal storage temperature is closely related to respirational intensity, as it can be reduced by lowering the temperature to a certain limit depending on the product. In other words, the slower the respiration rate, the slower the kinetics of biochemical reactions including those related to senescence.

A lower temperature implies that shelf life will be longer. If, for example, milk, ready meals, and sandwich spreads were stored at 4^0C instead of 8^0C, it would extend product shelf lives by up to weeks in some cases. A lower temperature in the cold chain could allow food producers to extend the expiry date on their products. Longer shelf life, combined with the extended expiry date on products, could reduce the in-store waste of foods having a date indication. A lower temperature in the cold chain in combination with extended shelf life marking could reduce food waste for those consumers who do not eat foods past their expiry dates (Lindberg and Jensen 2014).

From harvest or slaughter through packing, distribution, marketing, and sale, fresh foods continue to metabolize and consume their nutrients throughout their shelf life. Through the process of respiration, enzymatic breakdown and microbial degradation, carbohydrates, proteins, and other nutrients are break down into simpler compounds which often resulting in reduced quality or quantity of the foods. All of these processes are highly dependent upon temperature. As is the case for all biological processes, the higher the temperature, the faster these natural degradation processes will occur, leading to loss of colour, flavour, nutrients, and texture changes. Most of these degradation processes double their rate for each increase of 10^0C, which is known as the Q10 quotient. For example, maintaining a food's temperature at 10^0C colder than the temperature commonly experienced when handled during ambient conditions can double the shelf life of that food. Lowering temperature does have some exceptions, since some fresh horticultural perishables are susceptible to chilling injury below about 10^0C, for most of the tropical and sub-tropical crops and all fresh horticultural perishables will freeze below about -1^0C (Lisa Kitinoja 2013).

Maintaining adequately low temperature is critical, otherwise, it will cause chilling injury to the produce (Rahman et al. 2017). However, in developing countries, temperature fluctuations during storage and distribution have commonly happened. It caused the product to melt slightly and new and larger ice crystals to form when temperature drop. Figure 2 showed a photo taken during a cols assessment in Indonesia where frozen foods on pallets awaiting customs inspection were left out on an open loading dock in a seaport (Lisa Kitinoja 2013).

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Figure 2. Melting symptom in frozen foods shipments in Indonesia during a break in the old chain

Temperature control can be achieved through temperature management. Temperature management during storage can be aided by constructing square rather than rectangular buildings. Rectangular buildings have more walls, making them more expensive to cool. Temperature management can also be aided by shading buildings, painting storehouses white or silver to help reflect the sun's rays, or by using sprinkler systems on the roof of a building for evaporative cooling. The United Nations' Food and Agricultural Organization (FAO) recommends the use of Ferro cement for the construction of storage structures in tropical regions, with thick walls to provide insulation. Facilities located at higher altitudes can be effective since air temperature decreases as altitude increases. Increased altitudes therefore can make evaporative cooling, night cooling, and radiant cooling more feasible. The air composition in the storage environment can be manipulated by increasing or decreasing the rate of ventilation or by using gas absorbers such as potassium permanganate or activated charcoal (Rahman et al. 2017).

3. Groups of product in cold storage

The perishable food that needed storing in exactly specified temperature can be made up of several different groups. The grouping of foods is meat and marine products, dairy products, fruits and vegetables, and also ice cream sector and confectionery. Generally, chilled stores maintain products at temperatures between -1 and 12°C whereas frozen stores generally maintain products at temperatures below -18°C (UN Enviroment and IIR 2018).

Table 1. Optimal temperature in the cold storage of various produce

Group	Type of food	Temperature (^{0}C)	References
Dairy	Milk	≤ 4	Paludetti et al. 2018, Maciel et al. 2015, Paludetti et al. 2018, Hatt and Wilbey 1994.
	Butter	4	Ozano et al. 2007
Fish and marine product	Frozen salmon	-40	(Ottestad et al. 2011)
	Frozen sirloin	-18	(Suh et al. 2017)
	Frozen mackerel	-18	(Suh et al. 2017)
Fruits and vegetables	Leafy vegetables (cabbage, leeks, spinach)	0-2	(Lal Basediya et al. 2013)
	Citrus fruits	0-2	(Lal Basediya et al. 2013)
	Tropical fruit (Custard apple, guava, jackfruit, mango, pineapple, pomegranate)	5-13	(Lal Basediya et al. 2013) (Hawkins 1922)
	Frozen pumpkin	-7	(Zhan et al. 2019)
	Frozen green bean	-15 ,-30	(Martins and Silva 2002) (Zhan et al. 2019)
Ice cream and confectionery product	Ice cream	-28.9	(Buyck et al. 2011)

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4. The design of storage facilities

Effective storage systems have been developed with a wide scope of adaptations depending upon the available facilities. Adaptation factors include type, variety, and quantity of the product to be stored and handled, the duration of storage, the end use of the product, and marketing type. However, before considering a storage system, several aspects need to be considered. These aspects determine the economic feasibility of storage and business plan. It should be noticed that not all fresh product is responsive to immediate storage. Some product requires some pre-storage postharvest treatments such as curing and waxing. Among the factors that should be considered before selecting a particular storage system is the ambient temperature of the store, the conditions of the product before moving into the store, the regular working hours and the decision of which products will be stored, whether it is cut flowers, fruits, vegetables or mixed products (Elansari et al. 2019).

The general features of a cold store include total capacity, number and size of rooms, refrigeration system, storage, and handling equipment and access facilities. The relative positioning of the different parts will condition the refrigeration system chosen. The site of the cold chambers should be decided once the sizes are known, but as a general rule, they should be in the shade of direct sunlight. The land area must be large enough for the store, its annexes and areas for traffic, parking and possible future enlargement. A land area about six to ten times the area of the covered surface will suffice. There is a general trend to construct single-storey cold stores, despite the relatively high surface, because volume ratio influencing heat losses. The single-storey has many advantages, which are lighter construction, span, and pillar height can be increased, building on lower resistance soils is possible, and internal mechanical transport is easier (Rahman et al. 2017).

The design of storage facilities is to maximize the use of space, minimize the distance of movement, facilitate accurate location and retrieval of stock and to maintain the quality of the materials and their containers (Moran 2017). Cold stores should be designed for different types and varieties of products. They can also be designed with some small-volume rooms instead of large-volume ones to facilitate the accommodation of smaller growers. Small-volume rooms are better for storage of fresh produce due to the various fresh produce requires a specific combination of temperatures and relative humidity (RH), some produce is incompatible regarding their requirements of temperatures, RH and other factors also perishable storage rooms need regular sanitation (Elansari et al. 2019).

5. Logistics of cold storage

The distribution warehouse of perishable food in most cases has three temperature zones, ambient, cooler, and frozen. Meat and dairy product are properly protected in the cooler area with specific temperature ranges. The freezer should be at 0^{o}C or below. For larger facilities, they will have both an ambient and a refrigerated receiving dock area. Energy-efficient facilities are equipped with monitoring systems that track temperatures within each zone around the clock. The system sends a message if a temperature should go above or below the specified range of temperature, via email, text, fax, or phone, to the warehouse manager so the situation can be corrected (Hernandez 2009).

5.1 Inventory Management

Managing inventories is an important aspect of cold supply chain management. Controlling inventories of perishable products is demanding because of their limited shelf lives. A multi-dimensional inventory vector is needed in the fixed-life perishability problem to account for the age profile of items. Anticipated to perishability, there is an added cost of disposal of outdated items, and this can also lead to out-of-stock situations, if not managed properly (Chande et al. 2005).

Van Donselaar et al. (2006) stated that the management of the inventories for the perishables is aimed at lowering the significant cost factor for perishables such as a waste. Waste is produced from excessive inventories, that either need to be marked down just before the sell-by-date or thrown away after the sell-by-date. For products with a short shelf life, there are three options to lower the amount of waste:

1- Reduction of lead time
2- Demand substitution
3- Limited assortments

Based on Rai et al. (2013), the inventory relationship is strong with past demand of the product whereas freshness and demand rate is having a moderate relationship. So the retailer's policy should be designed that the past demand forms an important part of inventory management. Moreover, such measures should be taken so that physical state and freshness are maintained for a longer time as it directly affects the demand for the products.

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5.2 Information Sharing across the Supply Chain

Recent technologies and information systems enable innovative approaches to real-time monitoring of important parameters like temperature, track and trace services, and proof of delivery during the storage and delivery process. Technologies such as RFID tags, smart labels, electronic temperature loggers, and fleet management systems can be used effectively to minimize operational costs and quality failures as well as to increase customer service (Stragas and Zeimpekis 2011).

RFID technology is an emerging trend in the cold supply chain mainly used for product identification, collection, and communication of relevant data. RFID technology needs very little or no handling of products and is therefore well suited for inventory control of perishable products. The technology also assists in updating the inventory status in real time without product movement, scanning, or human involvement (Chande et al. 2005).

5.3 Distribution Center Operations

Hernandez (2009) stated that the product rotation at distribution facilities is tracked and carefully managed. When each pallet of product is received on the dock, it is assigned a "license plate" such as a bar code and unique ID number that has the description of the contents. The product is then taken to the aisle and slot into where it will be stored, and the location number is entered into the system. Received product usually is put into "reserve" slots. When the "pick" slot for that product becomes empty, warehouse staff will be directed by the computer as to which pallet need to be inserted next to make sure first-in, first-out accuracy.

6. Importance of cold storage

All cold stores have the function of storing a product at the correct temperature and to prevent quality loss as economically as possible. (UN Enviroment and IIR 2018). In chilled storage rooms, temperature control is a food safety issue where increases in temperature may be detrimental to the safety and shelf life of the food. In frozen store rooms food safety is not an issue, assuming that the temperature in the room is maintained below –10°C, which is the temperature that is generally accepted as the minimum temperature for microbe growth. Food quality changes can however occur as in most instances food is stored above its glass transition temperature (the temperature at which no further water can be frozen). For most food, the glass transition temperature is below –30°C and most frozen storage facilities will operate at between –18 and –22°C (Nesvadba 20073).

Low temperatures or cold storage have been widely applied to hinder the biological activity of horticultural commodities, to enable their handling through different supply chain components such as storage, transport, distribution over longer periods and distances, and marketing. Based on Elansari et al. (2019), the main reasons for the storage of products are not only associated with marketing, but also with maintaining the quality by considering the following:

- Minimizes decay by slowing down microorganism's progression.
- Lowers transpiration or water losses that otherwise promote unfavourable effects, such as wilting, elongation, rotting, greening, sprouting, and toughening. Such activities affect appearance, quality, and texture.
- Slows down the biological activity of fresh produce, such as the case of reducing the production and action of the natural ripening agent ethylene.
- Minimizes the surplus sale in the market, thus guaranteeing good returns to the farmers.
- Assures the accessibility of the product during the off-season.
- Reduces waste and spoilage of produce.
- Normalizes the price of the product during the season, as well as during the off-season.

7. Challenges in the cold storage warehouse

The use of the cold chain for reducing perishable food losses can be impeded by a wide variety of issues and challenges. Among these are difficult agro-climatic conditions, such as high temperatures in the humid tropics, or extreme heat in dry regions that increase the costs of cold storage construction and power. If costs and benefit assessments lead people to want to use the cold chain, its adoption can be limited by a lack of access to reliable power, equipment, resources for public and private sector investments, and a lack of qualified human resources. Currently, the need for the use of the cold chain in developing countries may be known and even accepted as cost-effective, but adoption is low due to a lack of appropriate agricultural research and development, lack of training programs for capacity building, and the absence of national organizations focusing on the cold chain (Lisa Kitinoja 2013).

Principally, all fresh produce can benefit from cold storage at an optimum low temperature that extends storage life and maintains quality. Despite this, such benefits occasionally do not compensate for the cost of mechanical

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refrigeration along with its energy and maintenance, such as in the case of the extremely low price of the produce. Another obstacle is how to generate full utilization of refrigerated space over a long period each year. The reason is that many horticultural crops are highly perishable and can only withstand very short storage time (a few days), while several others retain a longer storage life varying from less than one month to several months. Low-temperature storage in some tropical and subtropical countries, where refrigeration is crucially needed could be expensive with very limited electricity resources and limited infrastructure that make energy consumption unaffordable in such countries if it exists. Due to its capital and running expenses, cold storage adds to the cost of production, increasing the price of the product; the bigger the involvement of the storage system, the higher the added cost. Short-term storage is applied to present some marketing flexibility, although it is not worthwhile to store perishables if the price increases, plus storage would lower quality and shelf life. However, (Elansari et al. 2019). Cold stores also contribute to direct emissions through the loss of refrigerants and as such, the use of environmentally friendly low global warming potential (GWP) refrigerants is a significant issue in the current market (UN Enviroment and IIR 2018).

8. Conclusion

The use of cold is not a cure-all or a one-size-fits-all proposition but is an important component of an agricultural handling system or value chain in its entirety. Each type of fresh produce and/or food product has a specific and limited storage potential related to its physiological nature and lowest safe storage temperature, and the use of the cold chain can help reach this potential and reduce perishable food losses. Misuse of cold will lead to higher food losses along with added financial losses associated with the costs of cooling, cold storage, cold transport, and refrigerated retail market displays. At present, the term “cold chain” is used interchangeably when referring to a value chain for fresh tropical produce (at 12 to 18°C), chilled fresh produce and food products (at 0 to 4°C), or frozen food products (at -18°C). Costs are much lower, however, when investing in and utilizing a cool chain for fresh tropical and sub-tropical produce, this difference needs to be better understood by public sector planners and private sector investors. At present, the use of the cold chain is often avoided by food producers, handlers, and marketers due to its perceived high cost. Yet when 25 to 50% of foods are wasted after the harvest, the real cost of production is much higher than it should be. Using "cold" as an investment to prevent food losses can be highly cost-effective in comparison to continually increasing production to meet increasing demands for foods. Information on the costs of using the cold chain and on the expected benefits in terms of increased volumes of food available for sale, increased market value and improved nutritional value should be gathered and made readily available to potential users and investors. Most developing countries currently lack the basic infrastructure and educational program needed to support the development of an integrated cold chain for the distribution of perishable foods. The public sector should provide funding for investments in basic infrastructure to support cold chain development (i.e. electricity, roads), and for educational programs at the primary, secondary, and higher education levels to promote the value of production, handling and consumption of high quality, safe and nutritious foods. Governments should limit disincentives (for example high taxes on imported refrigeration equipment) and invest in those components of infrastructure and education that are currently missing in their development efforts involving cold chains (Lisa Kitinoja 2013).

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References

Akdemir, S. 2008. Designing of cold stores and choosing of cooling system elements. *Journal of Applied Sciences* 8(5): 788–794.

Buyck, J.R., Baer, R.J. & Choi, J. 2011. Effect of storage temperature on quality of light and full-fat ice cream. *Journal of Dairy Science* 94(5): 2213–2219.

Chande, A., Dhekane, S., Hemachandra, N. & Rangaraj, N. 2005. Perishable inventory management and dynamic pricing using RFID technology. *Sadhana - Academy Proceedings in Engineering Sciences* 30(2–3): 445–462.

van Donselaar, K., van Woensel, T., Broekmeulen, R. & Fransoo, J. 2006. Inventory control of perishables in supermarkets. *International Journal of Production Economics* 104(2): 462–472.

Elansari, A.M., Yahia, E.M. & Siddiqui, W. 2019. Storage Systems. *Postharvest Technology of Perishable Horticultural Commodities*, hlm. 401–437. Elsevier.:

HATT, B. & WILBEY, A. 1994. Temperature control in the cold chain. *International Journal of Dairy Technology* 47(3): 77–80.

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Hawkins, L.A. 1922. The Effect of Low-Temperature Storage and Freezing on Fruits and Vegetables. *American Journal of Botany* 9(10): 551.

Hernandez, J.F. 2009. Foodservice distribution: maintaining the cold chain. *Food Safety Magazine* 15(September 2009): 52–54.

Kuo, J.C. & Chen, M.C. 2010. Developing an advanced Multi-Temperature Joint Distribution System for the food cold chain. *Food Control* 21(4): 559–566.

Lal Basediya, A., Samuel, D.V.K. & Beera, V. 2013. Evaporative cooling system for storage of fruits and vegetables - A review. *Journal of Food Science and Technology* 50(3): 429–442.

Lindberg, U. & Jensen, S. 2014. How could a lower temperature in the cold chain affect food waste? *Refrigeration Science and Technology*(January 2014): 540–547.

Lisa Kitinoja. 2013. Use of cold chains for reducing food losses in developing countries The Postharvest Education Foundation (PEF) December 2013 2 Use of cold chains for reducing food losses in developing countries(13): 16.

Maciel, G. de M., Hammershøj, M., Frederiksen, P.D., Sørensen, J., Bakman, M., Poulsen, N.A. & Larsen, L.B. 2015. Dairy processing and cold storage affect the milk coagulation properties in relation to cheese production. *Dairy Science and Technology* 95(1): 101–114.

Moran, S. 2017. Warehouse Storage. *Process Plant Layout*: 179–186.

Ndraha, N., Hsiao, H.-I., Vlajic, J., Yang, M.-F. & Lin, H.-T.V. 2018. Time-temperature abuse in the food cold chain: Review of issues, challenges, and recommendations. *Food Control* 89: 12–21.

Ottestad, S., Enersen, G. & Wold, J.P. 2011. Effect of Freezing Temperature on the Color of Frozen Salmon. *Journal of Food Science* 76(7): 423–427.

Ozano, P.A.R.L., Iracle, E.V.A.N.R.M., Rause, A.N.J.K., Rake, M.A.D. & Adwallader, K.E.R.C. 2007. Effect of cold strage and packaging material on the major aroma components of sweet cream butter(2007_DB-5ms分析例).pdf: 7840–7846.

Paludetti, L.F., Kelly, A.L., O'Brien, B., Jordan, K. & Gleeson, D. 2018. The effect of different precooling rates and cold storage on milk microbiological quality and composition. *Journal of Dairy Science* 101(3): 1921–1929.

Rahman, M.A., Buntong, B., Gautam, D.M., Fellows, P., House, P., Beukes, T., Requirements, S., Definition, C., Description, C., Yaptenco, K.F., Esguerram, E.B., Rolle, R.S., Hewett, E., Krishnakumar, T., Singham, P., Bonar, H. & Balls, R. 2017. Design of cold storage for fruits and vegetables. *research Gate*(April): 107.

Rai, S.K., Singh, V. & Vaish, A. 2013. Perishable Food Inventory Management: a Retailer'S Perspective. *International Journal of Business and General Management (IJBGM)* 2(2): 1–10.

Shabani, A., Saen, R.F. & Torabipour, S.M.R. 2012. A new benchmarking approach in Cold Chain. *Applied Mathematical Modelling* 36(1): 212–224.

Stragas, N. & Zeimpekis, V. 2011. Basic Principles for Effective Warehousing and Distribution of Perishable Goods in the Urban Environment: Current Status, Advanced Technologies and Future Trends. *Intelligent Agrifood Chains and Networks*: 39–65.

Suh, S., Kim, Y.E., Shin, D. & Ko, S. 2017. Effect of frozen-storage period on quality of American sirloin and mackerel (Scomber japonicus). *Food Science and Biotechnology* 26(4): 1077–1084.

UN Enviroment & IIR. 2018. Cold chain technology brief. Cold storage and refrigerated warehouse: 8.

Xue, M., Zhang, J. & Tang, W. 2014. Optimal temperature control for quality of perishable foods. *ISA Transactions* 53(2): 542–546.

Zhan, X., Zhu, Z. & Sun, D.W. 2019. Effects of pretreatments on quality attributes of long-term deep frozen storage of vegetables: a review. *Critical Reviews in Food Science and Nutrition* 59(5): 743–757.

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