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Cold chain management in perishable commodities for minimum post-harvest losses: A review

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Abstract
For fruit and vegetable farmers selling directly to consumers, the ability to quickly chill produce after harvest and safely store it until delivery can make or break the value of a crop. Local food systems can contribute to socially, economically, and ecologically beneficial food production for local communities. In order to deliver quality produce to the consumer, local food systems must utilize rapid cooling and cold storage technology. For majority of farmers, a walk-in cooler is one of their first large capital farm expenses. The level of investment varies as per, capacity of the system, area, country and level of expertise, it may go to crores starting from lakhs. For maximum of farmers it is beyond their financial limits. The Coolbot is an innovative cooling device system, which uses an intelligent thermostat system to control a standard room air conditioner to create a small-scale cooler out of a well-insulated room.

Keywords: Cool Bot, Cooling, Fresh produce, temperature management, shelf life

Introduction
At harvest, horticultural commodities are alive and continue with the metabolic processes such as respiration and transpiration. For fruits which are harvested at physiological maturity, ripening proceeds after harvest. These processes require water, nutrients and energy reserves all of which are cut off at harvest (Alfred and Paul, 2013) [3]. Other deteriorative processes in harvested produce like ethylene evolution also hastens the rate of ripening and softening hence the fruits become unappealing to consumers. Colour changes occur as fruits are de-greened during synthesis of carotenoids to give the fruit a consumer appealing colour. Water loss from the produce causes them to shrivel (fruits) or wilt (vegetables) after the cells have lost their turgidity (Deirdre, 2015) [10].

Central to these deteriorative processes is temperature (Vorster *et al.,* 1990) [14]. It is estimated that the rate of deterioration of perishables increases two to three-fold with every 10°C increase in temperature (Kader, 2005) [15] as shown in the table below:

A study conducted on sweet cherries that were stored at different temperatures (0°C, 5°C, 10 °C and 20 °C) and their respiration rates taken showed that respiration rate increased with an increase in temperature (Carlos *et al.*, 1993 and Jobling, 2008) [16, 17]. Therefore, controlling product temperature and reducing the amount of time that a product is at sub-optimal temperature is key to maintaining the quality, improving shelf life and extending marketing period and ultimately reducing postharvest losses (Kassim *et al.,* 2013) [20].

Table 1: Effect of temperature on shelf life of fresh foods

Fresh product	Storage potential			
Fresh green vegetables	1 month at 0 °C	2 weeks at 10 °C	1 week at 10 °C	< 2 days at 30 °C
Potatoes	5-10 months at 4-12 °C	< 2 months at 22 °C	< 1 month at 32 °C	< 2 weeks at 42 °C
Mangoes	2-3 weeks at 13 °C	1 week at 23 °C	4 days at 33 °C	2 days at 43 °C
Apples	3-6 months at 1 °C	2 months at 10 °C	1 month at 20 °C	A few weeks at 30 °C

Source: Kitinoja, 2013 [38].

Q_{10}= (Rate of deterioration at temperature T + 10 °C)/ Rate of deterioration at temperature T

Temperature control in harvested horticultural produce

Temperature abuse is one of the major causes of the very high losses experienced in horticultural production (FAO, 2014) [22, 23]. It starts right from harvesting to when the product is being marketed and reaching the ultimate consumer (Nunes *et al.*, 2003) [26]. The rate of deterioration has been estimated to increase by two or threefold with every 10 °C increase in temperature within the optimum range for the commodity in question and so temperature abuse is critical and detrimental to all horticultural products (Kader and Rolle, 2004) [27]. Its detrimental effects on the shelf life of horticultural products is attributed to increased water loss, respiration rate, softening, ethylene evolution and other physiological processes which increase rate of deterioration of the fruits (Chopra *et al.*, 2003; Alfred *et al.*, 2013) [29, 3].

Post-harvest cooling and maintaining a cold chain is thus the most effective way to curb effects of high temperature on perishable horticultural commodities and by maintaining low temperatures conducive for a certain commodity, increase shelf life will be realized (Bachmann, 2000) [30].

Table 2: Theoretical relationship between temperature, respiration rate and deterioration rate of a non-chilling sensitive fresh commodity.

Temperature °C	Assumed Q_{10}	Relative velocity of deterioration	Relative shelf life	Loss per day (%)
0	-	1.0	100	1
10	3.0	3.0	33	3
20	2.5	7.5	13	8
30	2.0	15.0	7	14
40	1.5	22.5	4	25

Developed from data available in USDA Handbook 66 (Kitinoja, 2013) [38]

In developed countries, temperature management is characterized by sophisticated management system and infrastructure (Hodges *et al.*, 2010) [31]. Logistics companies and suppliers have invested in cold chains by in pursuit of accessing local markets and opening temperature controlled operations which have helped in strengthening cold chains and prolonging the product‟s shelf life (Rolle, 2006). They also complement their cold storage with other post-harvest technologies like MAP and waxing hence extending the shelf life of their produce, consequently getting longer marketing period (FAO, 2014) [22, 23]. Developing countries‟ cold chain system is characterized by poor storage facilities (FAO, 2011) [22] poorly developed and inefficient infrastructure which has caused the highest amount of deterioration in harvested produce over the years (Kitinoja, 2010). Most small scale farmers are operating below the poverty line and are unable to obtain the highly sophisticated facilities to maintain a cold chain at the farm level. A study conducted in Latin America and Caribbean countries showed poor cold chain management to be the main reason for post-harvest losses (FAO., 2015) [24].

Cold Chain Management

A cold chain refers to an uninterrupted series of activities from the production point to the consumer which maintain a given temperature range (Ilic *et al.,* 2012). Any hiccup along the cold chain may reduce its efficiency and lower the produce‟s shelf life unlike where the cold chain is maintained fully along the supply chain. A research conducted on importance of cold chain showed that fruit quality is severely reduced by breaking the cold chain even for a short duration (Blakey *et al.*, 2011) [6].

Knowing the damaging effects of high temperature on horticultural commodities necessitates clear and efficient cold chains at all stages of the supply chain so as to impede the challenge of post-harvest losses due to temperature abuse. The other component is cooling during holding which occurs after pre-cooling, during other activities like sorting and grading, packaging, transportation and even during marketing the produce, optimal temperature needs to be maintained (Ginsberg, 1985) [18]. Maintenance of cold chain is therefore very necessary so that we can preserve the commodities at their best possible quality (Kader, 2005) [15]. However, there are hitches that cause farmers and traders not to maintain the cold chain like high cost of purchase, installation and operation of the requisite infrastructure. Most small scale farmers may not be able to have on-farm cold storage facilities or even temporary shades for their produce. Cooling horticultural commodities has been shown to reduce respiration rate, transpiration rate, ethylene evolution to slow ripening, decrease activity of microorganisms and reduce changes like browning, loss of texture, flavor and nutrients. All this aims at delaying senescence and lengthening the product's shelf life (Kitinoja, 2013) [38].

Generally, cold chain management allows for maintenance of physical and biochemical properties of produce which are desirable to consumers. This is nutritionally important since the nutrients in the produce will be maintained at high levels if they are not exposed to high temperatures. Cold chain management also helps in regulating the market prices of products especially during peak season when there is so much of the specific product in the market such that it causes market glut. With a well-managed cold chain, farmers are able to store some of their produce for extended periods of time and avoid selling them at very low prices which is necessitated by fear of losing the produce due to poor storage facilities (Umali-Deininger and Sur, 2006) [48]. They then can sell the products when the supply is low and the market prices are relatively high. Consequently, both farmers and traders will benefit by selling the products at reasonable prices and since they were well stored, they will be of good quality hence having a better value of money (IBRD, 2011) [19]. It is also important since it helps farmers, traders and manufactures avoid the high wastage that occurs when there is poor maintenance of the cold chain. Avoiding losses in turn results to increased income and thus better livelihoods for all involved (IBRD, 2011) [19].

Generally, low temperature maintenance (optimum for the specific commodity) at all stages along the supply chain will result in great reduction of losses and the produce's quality will be maintained at high levels which is the goal of anyone dealing with horticultural products. The consumers will also benefit by having the products readily available at all times even during the off season period for such commodities hence giving them fresh and nutritious fruits and vegetables among other commodities that can be stored therein (Mazibuko and Oladele, 2012) [25].

Post-harvest handling practices that affect cold chain
Use of cold chain has been in use since the 1950s with aim of prolonging shelf life of horticultural commodities but it has not been fully adopted in most of the developing countries (Kitinoja, 2013) [38]. Some of the practices that farmers in developing countries can adopt to ensure their produce has reduced chances of succumbing to the high temperatures in the surrounding include the following:

Timely harvesting
Time of harvest affects the amount of field heat that accumulates in the produce. Harvesting during the hot hours of the day causes the produce to accumulate a lot of heat in it. The more the heat a produce picks from its surroundings, the more energy and time it requires to cool it down to manageable temperatures (Cantwell, 1998). Harvesting should be done during the cool hours of the morning when the temperatures are still low or in the evening.

Temporary shades after harvest
Temporary shades are important in protecting harvested produce from exposure to direct sunlight thus preventing its warming up and heat accumulation (Kitinoja, 2013) [38]. Exposure of perishable horticultural produce to direct sunlight reduces quality and shelf life (Ahmad and Siddiqui, 2016). Most of the small scale farmers don't have temporary shades for holding their harvested producing before transportation to the store/market takes place. This leads to heat build-up in the produce, thus promoting high respiration, weight loss and other deteriorative processes resulting to shorter shelf life (Saran *et al*., 2012) [43].

Pre-cooling of harvested produce
For successful storage of any horticultural commodity, pre-cooling has to be done immediately after harvest which is one of the components of a cold chain system (IIR, 2009) [32]. Its importance is to remove field heat from the produce before other handling operations are conducted so as to relieve the product of heat that could lead to faster deterioration if it stays longer in the commodity (Cantwell, 1998) [8]. The longer the commodity stays heated, the higher the rate of deterioration hence shorter shelf life (Kader, 2002). Pre-cooling enhances shelf life by suppressing enzymatic degradation, reducing respiration rate and ethylene evolution, slowing down water loss and inhibiting growth of disease causing microorganisms on the produce (Mohammed and Brecht, 2014). Produce that has not been pre-cooled immediately after harvest, deteriorates faster even after being stored at low optimum temperature. Pre-cooling is also essential in reducing the load on the cold storage facility hence little amount of energy will be required to cool the produce to required temperatures (KMUTT, 2007) [28]. Pre-cooling can be done by sprinkling water on the harvested commodities if they are not sensitive to water e.g. fruits like mangoes, apples and oranges (hydro-cooling), forced air cooling where cold air is pushed through produce containers so as to take away the heat and by room cooling.

Transportation
Refrigerated trucks mostly used by commercial farmers are expensive initially when purchasing and costly to operate. However, the small scale farmers should have a well considered means of transport to avoid temperature abuse, e.g. when using a pickup or a lorry the top should be well covered so that the produce is not exposed to direct rays of sunlight. Once in the market, temperature abuse still continues where the retailers expose their produce to direct sunlight hence making it absorb more heat. Some don't have shades where they can protect the produce from sun‟s heat during sale. Shades should be erected to prevent the produce from high water loss which results to withering due to heat from the sun which is detrimental since it increases the rate of deterioration leading to high losses (Wilson *et al*., 2011) [47].

Cooling options for harvested perishable produce
(i) Hydro-cooling
This is done by cooling a warm produce by sprinkling chilled water on the produce. It is not only more efficient and faster (15 times) than air, but also increases relative humidity around the produce hence reducing the rate of water loss (Borompichaichartkul, 2009) [7]. However, the method can only be used on commodities that are not water sensitive e.g. mangoes, apples, carrots, cucumbers and oranges. The two major ways of hydro-cooling are the immersion where the produce is place in the water and the shower type where the produce has water sprinkled on it mechanically (El-Ramady *et al.,* 2015) [21]. Since the water comes into contact with the produce, it should be sanitized to avoid microbial growth (Kader, 2004) [27].

(ii) Forced air cooling
It is achieved by passing cold air through vents in the storage containers that cools the produce as it picks up heat (El-Ramady *et al.,* 2015) [21]. However, it leads to high water loss due to reduced relative humidity around the produce. Its efficiency is 75-90 times higher than that of room cooling (Borompichaichartkul, 2009) [7]. The method has been used successfully in cooling products like, avocado, melons, cucumber, coconuts, banana and mangoes (Kader and Rolle, 2004) [27].

(iii) Room cooling
In this option, produce is packed in a cold room and cold air allowed to flow through. It is a very slow method but energy efficient and can't be used for products that require rapid cooling like strawberry but has been successfully applied in storage of less perishable products like onions, potatoes and citrus (Kitinoja *et al*., 2010) [36]. It is mostly used for products that are sensitive to chilling injury (Kitinoja *et al*., 2011) [37].

Technologies for cold storage of harvested perishable produce
(i) Conventional cold rooms
The conventional cold room has two major components which are an insulated room and a refrigeration system. The refrigeration system's two main components are the evaporator unit which is inside the cold room and the compressor unit which is outside the cold room. These components are connected using a refrigeration piping. The

cooling is facilitated by a refrigerant and controlled by thermostat which ensures the temperature is maintained near the desired set point.

(ii) Low cost alternatives to conventional rooms

The technological options for small holder farmers are the low-cost cold storage (LCCS) methods, being emphasized for use to lower and or maintaining temperature at low levels during storage. Once adopted, the LCCS technologies will allow for storage of horticultural products at a lower cost and this will increase farmers‟ income becoming more economically empowered (IBRD, 2011) [19].

Evaporative Cooling Technologies

The charcoal cooler and zero-energy brick cooler use the principle of evaporative cooling. The charcoal cooler is made by building a structure whose walls are filled up with charcoal held in by wire netting while the ZEBC is made of a double wall of bricks and the space in between filled with sand (Das and Chandra, 2001) [9]. The pads (charcoal and bricks) are wetted by a constant supply of water. As warm dry air passes through the wetted pads, water evaporates taking with it heat from the environment within the chamber hence cooling the air around the product, consequently cooling the product itself (Basediya *et al.*, 2013) [4]. The coolers should be placed in a shade and the area should be preferably windy or with good ventilation such that water vapor can easily be swept away from the product and this will hasten the rate of cooling of the product stored therein (Ngoni, 2000) [41]. Produce stored in the cool chambers has shown reduced weight loss, better firmness and reduced deterioration rate (Bhatnagar *et al.*, 1990) [5].

A study conducted in Isiolo, Kenya (Wayua *et al.*, 2012) [46] for milk storage revealed that charcoal cooler had efficiency of 74.2 to 86.7% during hottest time of the day cooling the product to 10.5 °C below the ambient temperatures. The effect of cooling could be felt up to the fourth day after removal from charcoal cooler (Younan, 2004) [49]. In Rwanda, temperature in the charcoal cooler where passion fruits were store was 7 °C lower in comparison to the temperatures outside the storage chamber. Site selection is important in setting up an evaporative cooler. The area should have adequate water to ensure the charcoal is wet at all times for it to be effective (Ngoni, 2000) [41]. The ZEBC has been found to maintain relatively low temperature and high humidity in comparison to the outside environmental factors (Islam *et al.*, 2012) [34]. Ensuring there is adequate moisture on the walls and the ground is the most effective way of promoting the cooling process within the device and also maintaining high relative humidity. The cooler has successfully extended shelf life of potatoes, tomatoes, eggplants, mangoes, bananas and spinach by 3 to 15 days as compared to products stored at ambient conditions in Orissa (Kalpana *et al.,* 2010) [35]. In India, a 20% reduction in losses and an increase in market value of vegetables by 20% from $ 1.00 to $ 1.20 were realized with an extended shelf life of 5-6 days (Susanta, 2009) [45]. In Ghana, the temperatures within the cooler were lower (22 ^{0}C to 27 ^{0}C) as compared to the ambient temperatures (26 ºC to 33 ºC). Cabbages stored within the cooler were found to be of better physical quality as compared to those that were stored at ambient temperature (Saran *et al.,* 2012) [43].

The advantages of using the two mentioned evaporative coolers is that they don't require high level of technological knowhow to construct and one can use the locally available materials to come up with either of the coolers which makes them affordable (Basediya *et al*., 2013) [4]. No electrical energy is needed to operate either of the coolers hence they provide better solutions for the small holder farmers who reside in areas without power supply (Singh and Satapathy, 2006) [44]. The great challenge however is availability of water which is mostly a scarce resource especially in areas where the technologies are being implemented. For effective cooling of the products in storage, water has to be present throughout (Kouchakzadeh *et al.*, 2013) [39].

The Coolbot™ Technology

The Coolbot is a controller for standard air conditioner which works by manipulating it (air conditioner) to cool the storage room to the desired temperature ranging from °C to 18oC depending on the optimum temperature range for stored commodity. The air conditioner is turned into an air compressor that detects the presence of so much heat in the environment and continues to run so as to reduce the temperatures. Even at very low temperatures there is no build-up of ice on the evaporator coil which may cut back airflow and impair the cooling process. Without the Coolbot™, the air conditioner alone would go as low as 18 °C but not lower than that (Kitinoja *et al*., 2010) [36].

The Coolbot has multiple sensors and one of them acts as a regulator. When the fins are about to freeze, the sensor makes the air conditioner dormant so that it can stop lowering the temperatures until freezing of the fins. The danger in frozen fins is that temperatures would so low as cause injury on the product (Dubey, 2016) [13]. It also has a microcontroller that allows the system to work even in very hot areas. The amount of electricity used is very little, especially if the storage room is insulated, as compared to when using the normal conventional cold rooms.

The Coolbot cold storage technology is a cheaper alternative for small scale farmers since operation costs are very low due to the fact that it doesn ‟t break up easily (Dubey, 2013) [12]. Apart from being environmental friendly by having low electricity consumption, the Coolbot system also has very low carbon emissions. Therefore, it will not be detrimental to the users nor have negative externalities to the environment (Dubey, 2016) [13]. The Coolbot also is more advantageous compared to using the normal coolers where one is required to use a number of fans. The multiple fans, in pursuit of lowering the temperature will dry out the product so quickly causing it to wither (e.g. vegetables) or shrivel in case of fruits which also hastens deterioration rate. While using the Coolbot fitted with an air conditioner, only one fan is used and this reduces the chances of drying out the products. The Coolbot has disadvantages though they can‟t deter one from using it for the advantages overweigh the disadvantages. It takes relatively longer time to cool down and the rate of cooling slows as the temperatures drop. For example, it takes about 20 minutes to drop the temperature from 30 °C to 7 °C and then 30 minutes to drop from 7oC to 5oC. However, this would not be so detrimental since most horticultural products can get chilling injury if they are exposed to temperatures above freezing point but below 5 °C. The system doesn't function well at a temperature of 2 °C or below. This is an advantage in disguise because the farmers wouldn't want the temperatures to be too low as to get to 0 °C since freezing injury may occur on the produce. The temperatures will remain high if the cold room is opened several times, e.g. more than 6 times in an hour and it will also use up more electricity than if the storage room was left closed for longer hours. So it can only be used in a place that is not so busy as to prompt the store to be opened frequently. This is conducive for farmers because they don't have to go into the store every now and then.

Coolbo cold storage technology has been successfully used for storage of onions which was done in comparison with the traditional storage shed. There was a reduction in losses by 25% from 30% to 5% and stored onions were sold a few months after the production period during the off-season, point at which they had a value of $1.5 more than the value when there was a market glut (Saran *et al*., 2012) [43]. It was also tested in Amity University where freshly harvested vegetables (chili, eggplants and okra) were stored in a Coolbot fitted cold room. Temperatures below 10 °C were recorded inside the storage room while in the ambient room there were great fluctuations of temperatures which ranged from 42 °C -45 °C. After the storage period, the vegetables were still firm, marketable and fresh (Dubey, 2011). A challenge encountered was fluctuations in electricity during storage period but it was arrested by having a generator as a back-up. Though the pay-back period was long (1 year), its useful life was far beyond the pay-back period and could be used for some more years even after break-even point (Saran *et al.,* 2012) [43].

Full installation of a Coolbot cold room of 1 tonne capacity costs about 3,500 USD since its cooling system is a standard air conditioner costing about 1000 USD and the Coolbot™ gadget of about 300 USD (John, 2012). Using locally available materials in its construction further reduces the cost of obtaining a Coolbot™ cold room. On the other hand, installing a conventional cold room of the same capacity requires about 10,000 USD which is more than twice the cost of installing a Coolbot™ cold room. This is due to sophisticated refrigeration system used in the conventional cold room making it expensive beyond the reach of small holder famers (Alexiades *et al*., 2014) [2]. The cost of Coolbo cold room installation can further be reduced by using locally available materials in place of the expensive conventional materials.

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.

There is a need to promote the use of cold chains as a means to prevent the waste of limited natural resources. The resources required for agricultural production (i.e. land, water, fertilizers, fuels, other inputs) are becoming more scarce and costly, and 25% to 50% of the resources used to grow these foods are being wasted when perishable foods are lost before consumption. Investments in the cold chain prevent the loss of foods after they have been produced, harvested, processed, packaged, stored and transported to markets, which greatly reduces the need for increased production to meet the predicted growth in future demand. Reducing food waste also saves the water, seeds, chemical inputs and labor needed to produce the food that is currently being lost. As local and global resources become scarcer and more expensive, preventing food losses will become even more cost effective than it is at today's resource prices. Public and private sector investors need to take into consideration how investing in the use of the cold chain can generate savings due to the reduced need for constantly increasing food production to meet rising consumer demand for perishable foods.

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