Use of cold chains for reducing food losses in developing countries

PEF White Paper No. 13-03

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Introduction

Global food losses have been documented to be on the order of 25% to 50% of production volumes, caloric content and/or market values depending on the commodity (Lipinski et al, 2013; Gustavsson et al 2011; IIR 2009). The use of "cold" handling and storage systems as an investment to prevent perishable food losses is widely used in developed countries and can be highly cost effective compared to continually increasing production to meet increasing demands for these foods. The use of cold technologies in the development of agricultural supply chains for meat, dairy, fish and horticultural products in the USA and EU countries began the early 1950s along with the growth of the mechanical refrigeration industry, but cold chains are still limited in most developing countries.

There are many technical, logistical and investment challenges as well as economic opportunities related to the use of the cold chain. The primary segments of an integrated cold chain include 1) packing and cooling fresh food products, 2) food processing (i.e. freezing of certain processed foods, 3) cold storage (short or long term warehousing of chilled or frozen foods), 4) distribution (cold transport and temporary warehousing under temperature controlled conditions) and 5) marketing (refrigerated or freezer storage and displays at wholesale markets, retail markets and foodservice operations). Policy makers in the agriculture, energy, education and food sectors must work together to promote the use of cold chain technology, improve logistics, maintenance, services, infrastructure, education and management skills, and create sustainable markets for the design, use and funding of cold chains for reducing perishable food losses.

Table 1: The Cold Chain, Food Security and Economic Development

Variable	Global	Developed countries	Developing countries
Population in 2009 (in billions of inhabitants)	6.83	1.23	5.60
Population in 2050 (forecast, in billions of inhabitants)	9.15	1.28	7.87
Refrigerated storage capacity (m^3/1000 inhabitants)	52	200	19
Food losses (all products)	25%	10%	28%
Losses of fruits and vegetables	35%	15%	40%
Losses of perishable foodstuffs due to lack of refrigeration	20%	9%	23%

Source: IIR. 2009. The role of refrigeration in worldwide nutrition (www.iifiir.org)

Fresh foods continue to metabolize and consume their nutrients throughout their shelf life, from harvest or slaughter through packing, distribution, marketing and sale. Carbohydrates, proteins and other nutrients are broken down into simpler compounds often resulting in reduced quality or quantity of the foods, through respiration, enzymatic breakdown and microbial degradation. 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 color, flavor, nutrients and texture changes. In fact, as a general rule, most of these degradation processes double their rate for each increase of 10°C (known as the Q10 quotient, which is illustrated in more detail below). For example, maintaining a food's temperature at 10°C 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°C (most of the tropical and sub-tropical crops) and all fresh horticultural perishables will freeze below about -1°C.

In addition to physiological deterioration, foods may host micro-organisms such as bacteria and fungi which can cause molds, rots or decays, and are subject to water loss which results in wilting, shriveling or darkening. Both the rate of microbial growth and the rate of water loss occur more rapidly as temperature increases. Few other interventions can so dramatically maintain the visual quality and nutritional value, and increase shelf life and ultimate market value of fresh foods as much as simply holding the foods at a lower temperature.

Cooling provides the following benefits for perishable horticultural foods:
• Reduces respiration: lessens perishability
• Reduces transpiration: lessens water loss, less shriveling
• Reduces ethylene production: slows ripening
• Increases resistance to ethylene action
• Decreases activity of micro-organisms
• Reduces browning and loss of texture, flavor and nutrients
• Delays ripening and natural senescence

Table 2: Predicted loss of storage potential increases as handling temperatures increase for fresh foods commonly handled at ambient temperatures in developing countries (rough calculations based upon Q10 coefficients)

Food product	**Storage potential**			
	at optimum cold temperature	optimum temperature + 10°C	optimum temperature + 20°C	optimum temperature + 30°C
Fresh fish	10 days at 0°C	4 to 5 days at 10°C	1 to 2 days at 20°C	A few hours at 30°C
Milk	2 weeks at 0°C	7 days at 10°C	2 to 3 days at 20°C	A few hours at 30°C
Fresh green vegetables	1 month at 0°C	2 weeks at 10°C	1 week at 20°C	Less than 2 days at 30°C
Potatoes	5 to 10 months at 4 to 12 °C	Less than 2 months at 22 °C°	Less than 1 month at 32 °C	Less than 2 weeks at 42 °C

Food product	Storage potential			
Mangoes	2 to 3 weeks at 13°C	1 week at 23°C	4 days at 33°C	2 days at 43°C
Apples	3 to 6 months at -1°C	2 months at 10°C	1 month at 20°C	A few weeks at 30°C

In general, the Q10 coefficient (an indication of the relative rate of respiration at 10°C intervals) can be used for fresh foods to estimate the shelf life under different temperature conditions.

Table 3: Theoretical relationship between temperature, respiration rate and deterioration rate of a non-chilling sensitive fresh commodity

Temperature °C	Assumed Q10	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 (2004)

Use of cold chains

A cold chain for perishable foods is the uninterrupted handling of the product within a low temperature environment during the postharvest steps of the value chain including harvest, collection, packing, processing, storage, transport and marketing until it reaches the final consumer. An integrated cold chain encompasses the management of the movement of perishable food products from the field, ranch or body of water through the entire postharvest chain to the final consumer. The primary segments of an integrated cold chain, which include 1) packing and cooling fresh food products, 2) food processing (i.e. freezing of certain processed foods, 3) cold storage (short or long term warehousing of chilled or frozen foods), 4) distribution (cold transport and temporary warehousing under temperature controlled conditions) and 5) marketing (refrigerated or freezer storage and displays at wholesale markets, retail markets and foodservice operations) can be simple or complex, low tech or high tech. Cold chain logistics is the planning and management of the interactions and transitions between these five segments, in order to keep foods at their optimum temperature for maintenance of quality, food safety and prevention of waste and economic losses. Speed is often the key to success when handling and marketing perishable foods using a cold supply chain (Kohli 2010).

The cold chain is a well-known method for reducing food losses and food waste, and has long been promoted by established industry focused organizations such as The International Institute of Refrigeration (www.iifiir.org), The World Food Logistics Organization (www.wflo.org) and the Global Cold Chain Alliance (www.gcca.org). The required infrastructure and investments in needed facilities, equipment and management skills, however, are generally lacking in developing countries. Policy studies on food make very little mention of "postharvest" aspects of agriculture in major new reports on farming or small and medium scale enterprise (SME) policy coming from international donors and grant-makers. Recent examples include the FAO's *State of Food and Agriculture 2010-11* and IFPRI's *Food Security, Farming, and Climate Change to 2050: Scenarios, results and policy options*, which when searched provide no references to postharvest problems, cold chain issues, opportunities or policy options. The

UNFAO/UNIDO manual on *Agro-Industries for Development* (da Silva et al 2009) mentions the term "cold chain" only once in a comprehensive work of 270 pages.

The UN FAO recently launched the **SAVE FOOD Initiative** which includes many partner organizations working on various means for reducing food losses and waste. One of the top priorities cited by the Global Harvest Initiative report on measuring global agricultural productivity was "Improving food system infrastructure and processing to benefit agricultural products distribution and minimize waste" (GHI 2010; p. 8). The report concludes that significant public and private investments in capital and infrastructure will be required along the entire food chain. Reports on the postharvest sector and its contributions to economic development (Mrema & Rolle 2002; Kader 2006; Winrock 2009) leave no doubt as to its importance and cost effectiveness, yet introducing a cold chain in a developing country requires the integration of a great many different elements and the continuing management of those elements. Unfortunately, most aid donors and grant programs have tended to focus on establishment of stand-alone cold storage or food processing facilities or projects rather than focusing on the longer term management of those investments and the maintenance of an integrated cold chain.

Selecting appropriate cooling technologies for use in the cold chain

There is a wide range of options and technologies for producing cold conditions for food handling, processing, storage and transport. Some are relatively simple and inexpensive, while other technologies intended to achieve the same results are more sophisticated and complex to manage. For precooling, operators can choose from simple farm-based methods such as using ice, to more complex systems for forced air, hydro-cooling or vacuum cooling. For storage, there are options for food handlers that range from small walk-in cold rooms to large scale commercial refrigerated warehouses. Small-scale cold rooms can be designed using traditional mechanical refrigeration systems, low cost CoolBot™ equipped air-conditioner based systems (see detail below), or as evaporative cool chambers. Food processors can choose from chillers, blast freezing, IQF, freeze drying and many other technologies. During transport, cold can be provided via the use of ice, trailer mounted refrigeration systems, evaporative coolers or via passive cooling technologies (insulated packages or pallets covers during transport).

The suitability of these options will depend upon the food products being handled and the level of sophistication of the value chain. Kitinoja and Thompson (2010) and Winrock International (2009) have reviewed the cooling practices utilized during pre-cooling and cold storage for horticultural crops. These documents provide basic recommendations on cooling options and information regarding capital costs and energy use for small-scale, medium scale and larger scale operations. In general, the highest cost will be for mechanical refrigeration systems using electricity or diesel fuel where temperatures are the hottest, but the benefits of using cold chain technologies can still outweigh costs, since it is in these regions where food losses due to lack of temperature management are the highest. Evaporative cooling systems work well only in dry regions or during the dry seasons when the relative humidity is low. Total construction and operating costs for refrigerated systems will vary widely depending on the costs of local materials, labor and electricity. Postharvest losses can be greatly reduced with the use of cold storage, but the ROI for any specific operation will always depend largely upon the market value of the food commodities being cooled and stored and the use efficiency of the facility (i.e. whether or not it is operated at full capacity).

Table 4: Examples of mechanical technologies available for refrigeration/freezing

Cold chain step	Small-scale	Large scale
Pre-cooling systems	Portable forced air cooling systems	Vacuum cooling Forced air cooling Hydro-cooling
Cold Storage	Walk-in cold rooms CoolBot™ equipped cold room	Refrigerated warehouses
Processing-chilling or freezing	"Direct expansion" chilling of bulk milk "instant" chilling of milk	Blast freezing IQF Vacuum cooling of packaged meats
Refrigerated transport	USDA Porta-cooler	Reefer vans Refrigerated marine containers Refrigerated intermodal containers (for road, rail and sea shipping)

A recent development on the small-scale mechanical cooling technology front is a CoolBot ™ equipped cold room for storage of chilled food products and fresh horticultural produce. A small cold room with a commercially installed refrigeration system costs about $7000 for 3.5 kW (1 ton) of refrigeration capacity (Winrock, 2009). A small-scale option is to use a modified room air conditioner, a method originally developed by Boyette and Rohrbach in 1993, to prevent ice build-up which restricts airflow and stops cooling. The control system of the window style air conditioner unit is modified to allow it to produce low air temperatures without building up ice on the evaporator coil. Recently a company has developed an easily installed digital controller that prevents ice build-up but does not require modifying the control system of the air conditioner (Cool-bot ™, Store It Cold, LLC, http://storeitcold.com). A room air conditioner and Cool-bot ™ control system currently costs about 90% less than a commercial refrigeration system. The control system is designed so that any moisture condensed on the refrigeration coils is returned to the cold room air and the system will therefore cause less product moisture loss than the commercial refrigeration system.

Figure 1: The CoolBot™ controller (Photo source: http://storeitcold.com)

For refrigerated transport, small-scale producers and marketers can use the USDA Porta-cooler. Two types of portable pre-coolers currently exist and both have been tested extensively (Boyette, no date; USDA 1993). They can be self-constructed at relatively low cost, and complete plans are available on the internet on the NCSU website http://www.bae.ncsu.edu/programs/extension/publicat/postharv/ag-414-7/index.html and the ATTRA website (http://www.attra.ncat.org). The USDA Porta-cooler can be carried on traditional small scale transport vehicles, either pulled as a trailer or set into a pick-up truck bed. The Porta-cooler consists of a small insulated box (3.5 m^3), holding approximately 700 kg of produce, fitted with a room sized air conditioner (2.9 to 3.5 kW) and diesel-powered generator (2 kW). These units can be operated successfully at temperatures of 10°C or above with good results, making them most useful for transporting tropical and sub-tropical horticultural crops. At temperatures below 10°C, however, ice will build up on the coils, and the air conditioner will not work as designed. The CoolBot™ control system described above could be utilized to overcome this limitation. A full set of plans for construction of an insulated trailer equipped with the CoolBot™ has recently been developed by scientists at North Carolina State University and is available online for free download (http://plantsforhumanhealth.ncsu.edu/2012/08/20/pack-n-cool/).

Non-mechanical cooling practices:
For horticultural crops, the cold chain can sometimes be a "**cool chain**" depending upon the commodity. For example, tropical fruit crops and tomatoes require handling temperatures of 12-18°C for longer shelf life. Colder temperatures during handling, storage or transport will result in chilling injury, reduced storage potential and reduced market value. Symptoms often appear only after the commodity is returned to warmer temperatures during marketing or home use. Non-mechanical cooling practices can often achieve these moderately cool temperatures at very low cost.

Evaporative cooling: Lowering temperature of fresh horticultural produce via systems utilizing the evaporation of water to 2-3°C above the ambient dew point temperature. Evaporative cool storage rooms are commonly used for bulk storage of tropical and sub-tropical crops (such as sweet potatoes) or as small-scale cool chambers for temporary storage of fruits and vegetables in tropical climates, and work best in dry climates or during the dry season. Evaporative coolers can be passive (zero energy) or assisted (using a solar powered or electric fan to move air through the storage chamber).

Table 5: Examples of Non-mechanical technologies available for cooling

Cold chain step	Small-scale	Large scale
Pre-cooling systems	Portable evaporative forced air cooling systems	Slurry ice
Cold Storage	Zero energy cool chambers (ZECC) Evaporatively cooled cool rooms (charcoal coolers) Underground storage (root cellars) Night air ventilation High altitude storage Radiant cooling Solar chillers	Evaporatively cooled warehouses Underground storage (caves) High altitude storage Radiant cooling
Processing-chilling and freezing	None available	None available
Refrigerated transport	Evaporatively cooled insulated transport boxes or trailers	Passive cooling (insulated pallet covers)

Figure 2: Large scale evaporatively cooled storage facility for cured sweet potatoes.
(Photo credit: Robert Kasmire)

A variety of designs for small-scale evaporatively cooled storage chambers have been developed for fresh tropical and sub-tropical produce. Kitinoja and Thompson (2009) provide a review of the many designs currently available in Southeast Asia, India and Africa, and most can be constructed locally using low cost materials. The low cost passive cooling chamber illustrated in figure 3is constructed from locally made clay bricks. The cavity between the walls is filled with clean sand and the bricks and sand are kept saturated with water. Fruits and vegetables are loaded inside, and the entire chamber is covered with a rush mat, which is also kept moist. During the hot summer months, this chamber can maintain an inside temperature of 15 and 18 °C lower than the ambient temperature and a relative humidity of about 95%.

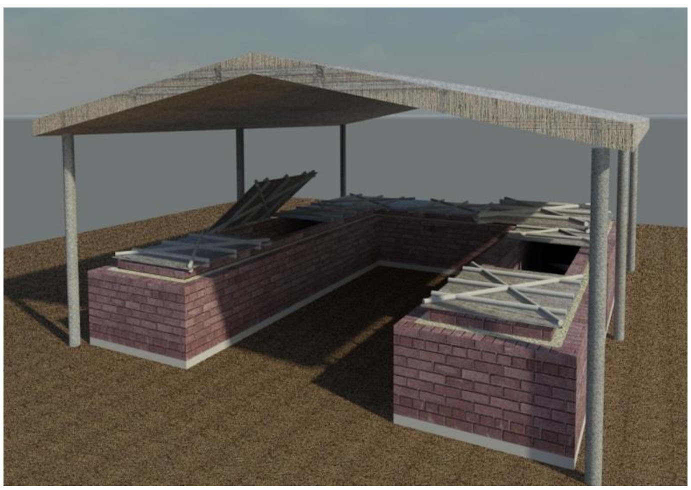

Figure 3: Design for a 1MT capacity ZECC (Kitinoja, 2010)
Digital illustration credit: Amity University, Uttar Pradesh, India

The original developers of this technology at IARI in India called it a "Zero-Energy Cool Chamber" (ZECC) because it uses no external energy. A larger version of this chamber was constructed in the design of a small cold room (6 to 8MT capacity), and needs only the addition of a small water pump and a ventilation fan at the roof line (similar to the vent fans used in greenhouses). Since a relatively large amount of materials are required to construct these cold storage chambers, they may be most practical when handling high value products.

The cost for construction of the small unit in India was $200 (200 kg capacity), the cost for the large walk-along unit was $1000 (1 MT capacity) and the cost of the commercial sized 6MT unit is estimated to be $8,000 (Kitinoja 2010). Results are best when the relative humidity conditions outside the ZECC are low, as during the dry season or in semi-arid regions.

In addition to these simple evaporative systems, other cooling systems are available for use when electricity is not available. Harvesting fresh produce early in the morning (with the exception of citrus crops because of fruit susceptibility to physical damage when turgid) will ensure produce is being handled at a lower temperature when compared to daytime ambient temperatures. The use of shade after harvesting will keep produce from warming in the sun while waiting for transport. Crushed or slurry ice can be used for rapid chilling or pre-cooling of fish or vegetables that can tolerate water. Slurry ice is a solution of about 40% water, 60% ice and 1% salt. Ice in large pieces or blocks can be used to cool water which can then be used in shower or immersion type hydro-cooling systems. The cost of ice production can be very high compared to its cooling capacity (Kitinoja and Thompson, 2010), and ice melt can cause safety and sanitation problems during handling, storage, transport and marketing.
Night air ventilation is the opening of vents in the basement of an insulated storage structure during the cooler night hours, then closing the facility during the daytime to keep the cool air inside. As a rule night ventilation effectively maintains a given product temperature when the outside air temperature is below the given product temperature for 5 to 7 hours per night (Kitinoja and Thompson 2010). Natural underground cooling can be used in caves or root cellars and high altitude cooling can be used where ambient air temperatures are lower than average.

Radiant cooling can be used in dry climates with clear night skies to lower the temperature of ambient air. By using a solar collector at night, air will cool as the collector surfaces radiate heat to the cold night sky. Temperatures inside the structure of 4°C less than night air temperature can be achieved (Thompson et al 2002).

Passive cooling (insulated packages or pallets covers) can be used during transport to keep pre-cooled or chilled foods cold. The insulation will act to prevent rapid rewarming, but has a limited range, and the distance or time that foods can be kept cool will depend on the outside air temperature and desired product temperature upon delivery. RefrigiWear is one of the companies that has developed and markets this kind of products, and claims they can maintain product temperatures for up to 12 hours when properly used with temperature changes of less than 1°C per hour. (http://www.refrigiwear.com/WeatherGuard/index.htm)

Solar powered cooling systems that function via ice bank or ice battery are in the development stage (www.solarchill.org), but currently available solar chilling systems are very expensive and too small for commercial food handling or storage. Prototypes of this ice-based cool box are available via a United Nations program for storage of pharmaceuticals and vaccines. They use a solar powered 3 x 60 W PV array and ice as the energy storage medium (rather than acid batteries which tend to have a short life in hot climates and create environmental hazards if not recycled properly). Cost is estimated at $1,500 for a unit that has a storage capacity of 50–100 L. These units would be best used for temporary storage of highly perishable high value foods such as fresh cut fruits or vegetables, strawberries, cheeses, milk, bean sprouts or mushrooms.

Freezing: A common method of freezing is simply indirect contact with a refrigerant that flows through shelves or belts that may touch the bottom or both top and bottom of the packages, commonly called convection freezing.

Blast freezing rapidly passes cold air over packages as they move through a tunnel or when they are stacked in rooms. This method is in most common use by refrigerated warehouses for freezing foods—either from the unfrozen state for a processor with limited freezer capacity or for bringing the temperature of still-frozen foods back to -18°C after they have been exposed to higher than optimal temperatures.

The freezing process can be sped up even further by using a free flow freezing process to achieve individually quick frozen (IQF) product pieces. The unpackaged food is frozen either on belt freezers where air at -40°C blows up through a mesh belt and through a thin layer of small food product pieces or in fluidized-bed freezers where the blast of upcoming air is of sufficient velocity to partially suspend the food. The frozen food pieces are then packaged and moved into cold storage.

Very rapid freezing methods, such as using liquid nitrogen for commercial freezing are available but the technologies are extremely expensive. Shrimp, for example, can be frozen by passing them under a liquid-nitrogen spray. The shrimp are conveyed first through a cooling area where nitrogen gas from the freezing part of the process is used to cool the product. The shrimp then come into direct contact with liquid nitrogen sprays at -195°C, for less than 2 minutes. The product then equilibrates to -29°C and is ready for cold storage. This technique, commonly called conduction freezing, can be used for high value vegetables, fruits, shellfish and other food products.

Methods that produce quick freezing (IQF, liquid nitrogen) result in better quality food products than do methods that provide slow freezing (traditional freezer room racking). Rapid freezing prevents undesirable large ice crystals from forming in the frozen food product because the molecules don't have time to form. Slow freezing creates large, disruptive ice crystals. During thawing, they damage the cells and break cell walls and membranes. This causes vegetables to have a mushy texture and meats to weep and lose juiciness. Quicker freezing methods, however, also can be more expensive.

Temperature fluctuations during storage and distribution are common in developing countries, allowing product to melt slightly and new, larger ice crystals to form when temperatures drop. Figure 4 is a photo taken during a cold chain assessment in Indonesia where frozen foods on pallets awaiting customs inspection were left out on an open loading dock in a seaport.

Figure 4: Melting symptoms in frozen chicken shipments in Indonesia during a break in the cold chain (Photo credit: Lisa Kitinoja)

Traditional blast freezing requires the use of a separate cold room with a door that can be sealed to prevent human entry while very low temperature air is blasted into the room. A recent innovation is the use of forced air blast freezing for packaged foods on individually shrouded pallet loads inside a racked cold room. Industry professionals claim that the slightly higher temperature of forced air blast freezing can be targeted to speed freezing, therefore saving time and energy while reducing labor costs (www.tippmanngroup.com).

Energy use efficiency: The energy use efficiency of any cold chain technologies will affect both feasibility and economic sustainability. Approximately 35% to 40% of the energy use for cold storage is used to keep product cool, while the remainder is used to remove the heat coming into the facility from solar radiation, warm air infiltration, fans, lights, people, and other equipment, so any measures to reduce heat load will help reduce energy use. A recent study done in the UK looked at chilled, frozen and mixed (chilled and frozen) stores and it was clear from the data that a large range in efficiencies exists. The worst cold store consumed over 8 times as much energy per storage unit when compared to the most efficient cold store (Evans, no date).

There are many excellent publications available on the selection of components of refrigeration systems, fans, doors, controls, defrost systems and other equipment (Thompson et al 2002; Winrock 2009). With assistance from the US Department of Energy's Inventions and Innovation Program, Advanced Refrigeration Technologies (ART) has commercialized an innovative control for walk-in cooler refrigeration systems. The ART Evaporator Fan Controller is inexpensive ($100 to $300), easy to install and reduces evaporator and compressor energy consumption by 30% to 50%.

The choice of construction materials and type and amount of insulation will influence the heat load on the cold storage structure. The design features of the facility, including its color, size, shape and internal layout, can influence heat load and refrigeration efficiency. For example, long, short, dark structures will incur more solar heat load than will square, tall, white structures of the same internal capacity. IACSC publishes a wide range of specifications for designs for cold storages and freezers (www.iacsc.org). The British Frozen Food Federation estimates that improved cold storage management would allow the raising of evaporator temperatures from -32°C to -28°C and would reduce energy use by 11% (BFFF 2009).

Impediments for adoption and use of cold chains

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. Social norms may decrease demand for chilled or frozen foods, as in some parts of India where "fresh" means food harvested the same day as it is consumed. 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.

Equally important is that there are mechanisms in place so that the increased value created by cold chain investments will accrue to those making the investments. Farmers can be very conservative and often limited in their ability to make investments. In order to invest in even the simplest and lowest cost cold chain elements the farmer, handler or trader must be confident that the market will reward the investment. This may not be the case if, for example, a farmer builds an evaporative cooler but then finds that refrigerated transport is not available. Any added value from using the pre-cooler on farm will be lost during open transport to market. Such breaks in the cold chain are often a major impediment to individual investments in needed cold chain elements. A comprehensive systems assessment is necessary to understand where investment is necessary in any given country to best facilitate the investments made elsewhere in the cold chain.

Training and capacity building for cold chain development

A recent review of cold chain development points out that "Even in many regions or sites where adequate infrastructure is available, overall knowledge of proper cold chain practices, maintenance (including availability of spare parts), and applications are weak in most of the developing world, and it is generally worst in facilities owned or operated by government than in facilities owned or operated privately" (Yahia, 2010). Yahia (2010) also reports, "There has been reasonable growth in cold chain infrastructure in Morocco, Egypt, and lately in Libya, but in all [developing countries] there is still major room for growth and much great efforts to improve capacity training to form better technicians and to improve applications."

Extension efforts and training needs differ by target group, and there are often difficulties in reaching smallholder farmers, women, youth, middlemen/traders and processors. Traders and middlemen have been generally ignored although they have a large impact on temperature management during handling and transport, and therefore upon the final quality of foods and their potential market value. Future extension efforts should seek to include this group of men and women in efforts aimed at adopting the use of the cold chain (Kitinoja et al 2011).

Training topics should include:

- Commodity systems assessment s (identifying the causes and sources of losses)
- Basic practices for reducing losses for perishable foods intended for cold storage
- Technical subjects along the cold chain (postharvest handling, refrigeration, cold storage, cold transport, food processing, etc.)
- Value chain development (processes and practices)
- Management topics (managing labor, equipment, finances, risk, marketing, etc.)
- Logistics (interactive complexities of managing a cold chain system)
- Engineering (including design, modifications, repairs, maintenance of cold technologies)
- Food safety issues (including the potential impact of poor food safety)
- Environmental issues
- Energy efficiency

Capacity-building efforts undertaken in cold chain technology must be made more comprehensive, and include technical knowledge on handling practices, research skills, access to tools and supplies, cost/benefit information, extension skill development (training needs assessment, teaching methods, advocacy), internet/web access, use of IT and cell phones for information sharing and provision of follow-up mentoring for young scientists and extension workers after formal training programs have been completed (Kitinoja et al 2011). And since training and capacity building needs will shift over time as changes occur in agricultural value chains and cold chains, continual formative evaluation to improve programs is needed to ensure capacity building efforts continue to meet the needs of target audiences.

Conclusions and Recommendations

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.

The term “cool chain” should be used when describing the agricultural value chain for handling and distribution of fresh tropical fruits and vegetables. Cool chain investments in simple, low cost technologies such as evaporative pre-cooling, zero energy cool chambers and night-time ventilated cool storage structures are cost effective and easy to manage, leading to increased profits.

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 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 educational levels in order 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.

The use of the cold chain is often avoided by food producers, handlers and marketers due to its perceived complexity and logistical challenges. There is a need to promote awareness and local, national, regional and international capacity building and training of trainers in the proper use of the cold chain. Once the cold chain is in operation, regular access to technical training on cold chain management and cold supply chain logistics will be needed by both the public and private sector.

Currently the lack of the use of the cold chain in developing countries leads to high food losses and loss of market value, leaving little profit for farmers, handlers, processors or marketers, while promoting the development of cold chains, could be a good source of new jobs. Producers would benefit as the agricultural value chains for their food products are fully developed, and **new jobs would be formed all along the cold chain** for those perishable foods for which pre-cooling, cold handling, freezing, cold storage and refrigerated distribution and marketing have been demonstrated to be cost effective.

Historically cold chains are often developed and utilized first for exports of higher value commodities and food products, but once in place are also used for domestic handling and marketing. Where cold chains exist for exported food products, they can be used as models for education, capacity building and skill development, and expanded to include cold storage and refrigerated distribution of perishable foods for domestic markets. Using the cold chain for improving domestic food supply chains will lead to improved nutrition and food safety while reducing food losses and lowering market prices for the local population.

Finally, we 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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