POTENTIAL FOR COLD STORAGE OF HORTICULTURAL COMMODITIES IN TROPICAL COUNTRIES

by

Liette Connolly-Boutin
Department of Bioresource Engineering
McGill University, Montreal

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ABSTRACT

An evaluation of the use of short-term cold storage of tomatoes to tide over the cyclical market glut of horticultural products was conducted in Coimbatore, Tamil Nadu, India. Farmers stored their harvest at a rental commercial cold-storage facility in the city and at an experimental cold store at the Tamil Nadu Agricultural University in Coimbatore. The goal was to study the storage characteristics of the produce as well as to assess the economic benefits of adopting such an intervention. The temperature and relative humidity conditions at both locations and the fate of the produce were monitored. The proportion of marketable produce diminished significantly as the storage period increased, with major losses occurring due to microbial damage. Differences in the air conditions at the locations did not have a significant effect on the storage-related losses of produce. Economic analysis showed that short-term cold storage would not aid farmers unless measures were taken to reduce the microbiological losses during postharvest handling.

RÉSUMÉ

Une évaluation d'entreposage de tomates à court terme a été effectuée à Coimbatore, dans l'état du Tamil Nadu en Inde, dans le but d'aider les fermiers à pallier la saturation cyclique du marché des fruits et légumes frais. Des fermiers ont entreposé leur récolte de tomates dans un entrepôt frigorifique commercial situé dans la ville, ainsi que dans un entrepôt frigorifique expérimental situé dans le Tamil Nadu Agricultural University dans la même ville indienne. Le but de l'expérience était d'étudier les caractéristiques d'entreposage du produit, ainsi que d'évaluer les bénéfices économiques liés à l'adoption d'une telle intervention. La température, l'humidité relative et le sort des produits horticoles ont été surveillés. Avec l'augmentation des temps d'entreposage, la proportion des fruits frais ayant une valeur marchande a baissé considérablement; la plupart des pertes était due à des infections microbiennes. Les différences dans les conditions ambiantes des deux entrepôts n'ont pas eu d'effet considérable sur les pertes de fruits frais dues à l'entreposage. Une analyse économique a démontré que l'entreposage à court terme n'aidera pas les fermiers à moins que des mesures supplémentaires soient adoptées afin de réduire les pertes microbiennes durant les manipulations post-récoltes.

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CHAPTER 1
INTRODUCTION

1.1 Situation

The eradication of poverty and hunger is the most important of the United Nations' Millennium Development Goals. Ensuring food security is a major, multidimensional challenge for developing countries, involving problems in food production, as well as in food availability and its quality and quantity. Food production is dependent on the seasonal availability of water coupled with high ambient heat. The variability of these factors plays a significant role in ensuring food security in tropical developing countries. Periods of growth are typically limited by water availability. As such, food crops, in particular horticultural produce, will usually be produced in fairly large quantities, followed by periods of low to no production. Lack of suitable postharvest handling and storage options has been observed to cause significant damage to produce output. For most farmers, this situation causes severe stress on marketing options, leading to distress sales and economic losses that affect the sustainability of their operations.

Postharvest storage solutions that could enable the deferred sale of horticultural produce would provide farmers with options to tide them over the crisis of low market prices during the harvest season. Long-term storage is used to spread product supply in the market over a wider period. Thus, it can be possible to obtain remunerative returns. This form of storage is commonly practiced in developed countries. However, opportunities to adopt similar strategies by farmers in developing countries are limited. Lack of capital and energy sources for controlled- and modified-atmosphere storage solutions are the major factors that limit such practices.

India is one of the major developing nations in a tropical region and has a large production of horticultural products. In 2003-04, India was the second largest producer of fruit and vegetables in the world, with 44 MT of fruit (10% of world production) and 87.5

MT of vegetables (14% of world production). Due to its significant population, most of the country's produce is consumed internally. It has been estimated that 60% of produce is sold in markets a few kilometres from the point of production, and 40% transported over longer distances for consumption in urban markets (Jairath, 2004). Nearly 50% of the produce is believed to be lost in post-production due to inefficiencies in storage, handling and market infrastructures. The bulk of the losses is borne by the farmers; economically this severely stunts the economic sustainability of farming.

One of the most commonly observed trends in India is the market glut during the harvest season, especially of common horticultural products such as tomato, onion and potato, which is then followed by a period of scarcity. Lack of suitable and appropriate storage options results in supply that exceeds the market demand during the glut. The resulting collapse in prices of commodities causes the farmer's remuneration to fall below the cost of production. In India, this phenomenon has had dramatic results. Farmers are often observed leaving the standing crops to rot in the field unharvested, or ploughing-over the standing crop to prepare the field for the next season. Such losses often have severe consequences on the fate of farmers and their families.

Figure 1.1: Woman collecting the remaining tomatoes of a ploughed-over field. Farmers typically plough over their fields when the price that the produce fetches on the market is lower than the price it costs to grow and harvest.

Southwest monsoon winds sustain India's annual growing season, which is known as the *kharif*. It usually lasts from June to September. The city of Coimbatore (10^{o}10' N – 11^{o}30' N; 76^{o}40' E – 77^{o}30' E) has a population of 1.44 million (2001 census) over an area of 105.5 km^2 in western Tamil Nadu. It is surrounded by small villages where a variety of crops are grown. The region is bounded by the Western Ghat mountains in the west and lies in the rain shadow during the southwest monsoon rains; major rainfall occurs during the northeast monsoons in October. However, the water supply to the region is from watersheds that are fed by the SW monsoons. Hence, the amount of rainfall during the *kharif* season is important for local agriculture.

Tomato is a common product in the region, and is marketed in several small wholesale markets around the city. During the *kharif* season of 2006, a similar situation to the one described above was observed in the Coimbatore district of the state of Tamil Nadu, India.

1.2 Hypothesis and Objectives

In 2006, the market price of tomatoes in Coimbatore reached particularly low levels following the monsoon rains, making even the harvesting of their crop economically unsustainable. A survey of market arrival volumes and the corresponding weekly price data for the years 2002-2006 showed seasonal fluctuations in volumes and prices. It was hypothesized that the adoption of short-term cold storage for tomatoes could enable farmers to gain profit from the produce at the end of the growing season. To test this hypothesis, the current study was undertaken during such a period in 2006. The study examines the feasibility of short-term cold storage of tomatoes and evaluates its risks and benefits. The study also gauges the state of cold-storage facilities and technological interventions available to Indian farmers.

CHAPTER 2
LITERATURE REVIEW

2.1 Postharvest Storage of Horticultural Crops

Depending on market conditions and their characteristics, agricultural produce can be stored for varying periods after harvesting. Such storage usually involves some degree of processing prior to storage.

2.1.1 Pre-cooling

Pre-cooling is the removal of field heat from the product before it is shipped, processed or stored. It is generally performed within minutes or hours of the harvest, in a separate area from the storage facility (ASHRAE, 2003). Pre-cooling is carried out to reduce the temperature and thereby the rate of various metabolic reactions that take place in the produce after harvest.

When produce is harvested at a high temperature, there is significant moisture loss during the temperature pull-down in storage. To reduce the amount of moisture lost due to high initial temperature, produce can be harvested at times when it will have a lower field heat, such as early morning or at night. The produce should also be cooled immediately after harvest (ASHRAE, 2003).

2.1.2 Selecting a Cooling Method

The choice of a cooling method is usually based on the size of the operation, the product to be cooled and market demand. The decision could also be influenced by whether or not the produce is packaged on the field, and on the price of packaging materials. In the case of some produce, only one method can be used; for example, the air cooling of apples. However, when more than one method can be used, as is the case with sweet corn, which can either be hydrocooled or vacuum cooled, cost becomes a major factor in the choice of a method (ASHRAE, 2003).

2.1.3 Storage

According to the United States Department of Agriculture (USDA), the purpose of postharvest storage is to “lengthen the time the plant material can be consumed or utilized” (Gross, 2004). The most important aspect of postharvest storage is temperature control. Keeping produce at the lowest temperature it can withstand without experiencing chilling injury increases its shelf-life by lowering its respiration rate, decreasing its sensitivity to ethylene gas and reducing water loss. On the other hand, keeping produce below its optimal chilling temperature will result in chilling injuries, which can manifest as a failure to ripen (as in the case of bananas or tomatoes), the development of sunken areas (cucumbers), brown discolouration (avocados and eggplant), an increased susceptibility of decay (cucumbers and beans) and the development of off-flavours (tomatoes) (Kitinoja and Kader, 2004).

2.1.4 Cold Storage

2.1.4.1 Refrigeration Loads

Cooling is the removal of heat from a product in order to inhibit pathogen growth and spoilage, and to reduce the rate of quality and flavour loss (ASHRAE, 2003). In order to properly design a cold store, the designer must estimate the sensible and latent heat loads caused by the stored product (Becker *et al.*, 1996a, b and c). In its 2002 Refrigeration Handbook, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has published a series of equations to calculate the refrigeration load of a cold store.

The overall equation for refrigeration load is:

$$Total\ Refrigeration\ Load = Transmission\ Load + Product\ Load + Respiration\ Load + Internal\ Load + Infiltration\ Load + Equipment\ Load$$

Equation 1

2.1.4.1.1 Product Load

The heat removed from a product with an initial temperature and final temperature above freezing is calculated using:

$$Q = mc_p(t_f - t_i)$$

Equation 2

where m is the total initial mass of the product, c_p is the specific heat of the product, and t_f and t_i are the final and initial temperatures, respectively.

2.1.4.1.2 Respiration Load

The respiration load is the amount of heat produced by the product during its respiration.

2.1.4.2 Respiration

As living entities, harvested fruits and vegetables continue to respire during storage. Respiration is the process during which O_2 is combined with sugars to produce energy, CO_2 and water. The process is in reality a series of reactions, which can be condensed into the following equation using glucose as a base sugar:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2667kJ$$

Equation 3

Approximately 42% of the energy produced in this reaction is used by cells during their metabolic processes in order to maintain the commodity's health (Kader, 1987). The rest of the energy is lost in the form of heat and is termed "vital heat". This heat contributes to the refrigeration load (Saltveit, 2004). In the case of most fruits and vegetables during the postharvest stage, the majority of the energy produced is released as vital heat since there is little cell development (ASHRAE, 2003).

Table 2. 1: Respiration rates of perishable commodities

Class	**Range at 5°C ($mg\ CO_2\ kg^{-1}\ h^{-1}$)**	**Commodities**
Very low	<5	Nuts, dates
Low	5 to 10	Apple, citrus, grape, kiwifruit, onion, potato
Moderate	10 to 20	Apricot, banana, cherry, peach, nectarine, pear, plum, fig, cabbage, carrot, lettuce, pepper, tomato
High	20 to 40	Strawberry, blackberry, raspberry, cauliflower, lima bean, avocado
Very High	40 to 60	Artichoke, snap bean, Brussels sprouts, cut flowers
Extremely High	>60	Asparagus, broccoli, mushroom, pea, spinach, sweet corn

Source: ASHRAE (2003)

To determine a fruit's or vegetable's rate of respiration, the following equation, developed by Becker and Fricke (1996b) can be used:

$$W - \frac{10.7f}{3600}\left(\frac{9t}{5} + 32\right)^{g}$$

Equation 4

where:

- W is the rate of heat generation due to respiration in W/kg as a function of temperature, t, in ^{o}C;
- f and g are respiration coefficients that vary with the commodity as given in Table 2.2.

Table 2. 2: Commodity Respiration Coefficients

Commodity	**f**	**g**
Apple	5.6871×10^{-4}	2.5977
Carrot	0.050018	1.7926
Grape	7.056×10^{-5}	3.033
Lemon	0.011192	1.7740
Potato	0.01709	1.769
Strawberry	3.6683×10^{-4}	3.0330
Tomato	2.0074×10^{-4}	2.8350

Source: Becker and Fricke (1996b)

2.1.4.3 Factors Affecting Postharvest Respiration Rate

The rate of respiration is affected by:

1. Stage of development

The rate of respiration (and hence the heat of respiration) varies with the age of the commodity. Young shoots and actively growing tissues such as asparagus, spinach and broccoli, as well as fast-developing fruits such as strawberries, raspberries and blackberries, have a higher rate of respiration than slow-developing fruit such as apples, grapes and citrus (ASHRAE, 2003).

The fruits that ripen after harvest are called climacteric fruit, and include apple, apricot, avocado, banana, kiwifruit, mango, muskmelon, nectarine, papaya, peach, pear, plum, sapote, tomato and watermelon. Those that do not ripen are called non-climacteric fruit, and include blueberry, cacao, cherry, citrus fruit, cucumber, grape, olive, pepper, pineapple and strawberry (Saltveit, 2004).

After harvesting, climacteric fruit will experience a raise in respiration rates, unless they are stored at low temperatures (around $0^{o}C$), which inhibit ripening. This rise in respiration rates will peak, followed by a rapid decline. Non-climacteric fruit, on the other hand, experience a slow decline in respiration rates following harvest (Saltveit, 2004). Vegetables (except for root crops, which have low rates of respiration), for their part, experience a high rate of respiration for the first one or two days of storage. This is followed by a decrease in the respiration rate until the equilibrium rate is reached (ASHRAE, 2003).

2. Temperature

Temperature has a remarkable effect on postharvest respiration rates. Increasing the temperature causes an exponential increase in respiration rates. The Van't Hoff rule states that for every $10^{o}C$ rise in temperature, the respiration rate increases two- to three-fold (Kader, 1987). Produce held at temperatures above 35 ^{o}C will deteriorate rapidly (Wills *et al.*, 1989).

3. Atmospheric conditions

In order to maintain aerobic respiration of the produce, a minimum O_2 concentration of 2% to 3% must be maintained in storage. Failing this, the produce would begin anaerobic respiration (fermentation), thus spoiling and emitting foul odours. It is possible to store certain crops at lower O_2 concentrations, but temperatures must be kept at optimal levels for that particular crop (Saltveit, 2004).

One common practice to lengthen storage life of some commodities is to increase the CO_2 content in the storage area. This reduces the rate of respiration, as well as delays the growth of pathogens. N_2 can also be increased with the same results for some commodities. However, care must be taken to ensure that O_2 concentrations do not fall below aerobic respiration levels (Saltveit, 2004).

4. Physical stress

Damaged produce experiences an increase in the production of ethylene gas and higher respiration rates. Such increases often last no more than a few hours or days. However the increase in ethylene production and respiration can promote ripening, in effect shortening the shelf-life of the produce (Saltveit, 2004).

Bruising can occur by impact, vibration, abrasion, or compression (Crisosto *et al.*, 1993). In addition to accelerating the ripening of the fruit, bruising and skin breaks leave it susceptible to pathogens (FAO, 1989).

2.1.4.4 Ethylene

Exposing climacteric fruit in their preclimacteric stage to ethylene (C_2H_4) kick-starts the ripening process, causing a climacteric rise in respiration rates. Once the ripening process has begun, adding more ethylene will not affect it (Kader, 1987).

When non-climacteric fruit are exposed to ethylene, they also experience an increase in respiration rates that resembles the climacteric rise. However, unlike climacteric fruit, their respiration rates decline when the ethylene is removed (Kader, 1987).

2.1.4.5 Transpiration

Transpiration is the process through which water contained in the commodity is transported through its skin and evaporated to the surroundings. The rate at which this occurs has an effect on produce quality; if too much moisture is lost, the product will shrivel. This has a direct effect on product appearance, texture, flavour and saleable mass (ASHRAE, 2003).

Moisture loss is driven by a difference in water vapour pressure between the surface of the commodity and its surroundings (Becker and Fricke, 1996b). In its simplest form, it is represented by the following model:

$$\dot{m} = k_t(P_s - P_a)$$

Equation 5

where:

- $\dot{m}$ is the transpiration rate expressed as the mass of moisture transpired per unit surface area;
- k_t is the transpiration coefficient, a constant for a given commodity;
- P_s is the surface water pressure and P_a is the vapour pressure in the surrounding air.

The relative humidity of the air in cold storage is usually maintained at higher levels, close to saturation. Not only does high relative humidity reduce the water pressure deficit between the product and its surroundings, that humidity is then absorbed by the packaging material, which thereby absorbs less moisture from the product itself (ASHRAE, 2003).

2.1.5 Alternate Cold Storage Methods

There are many different ways to store produce. Storage methods are chosen according to product requirements, storage length and available facilities. The most common refrigeration method used throughout the world is based on vapour-compression refrigeration systems. The technology is well developed and widely available; however, the need for electrical energy to operate these systems is a shortcoming for their adoption in developing, tropical countries where the heat load is high and the availability of electrical energy is limited or highly irregular. Because of this, such places are better served with technologies based on alternate sources of energy.

2.1.5.1 Evaporative-cooling

Evaporative-cooling is a low-cost cooling method that is used by some farmers in developing countries (Kitinoja and Kader, 2004). In direct evaporative-cooling, water evaporates using the heat supplied by the air into which it evaporates. This lowers the dry-bulb temperature of the air (ASHRAE, 2003). This method works best in dry regions, as the lowest cooling temperature is a few degrees above the wet-bulb temperature (Kitinoja and Kader, 2004). The cooling chambers are made from locally available materials, and are meant as short-term storage at the farm level (Gaikwad *et al.*, 2004 and Kitinoja and Kader, 2004).

One study by the Central Food Technological Research Institute (CFTRI), Mysore, India, demonstrated that an evaporative cooler could store produce at temperatures 10^{o}C to 15^{o}C cooler than the ambient, and around 90% R.H. At temperatures around 22 ^{o}C to 24^{o}C and 95% R.H., the evaporative cooler stored the fruits and vegetables for periods significantly longer than ambient conditions.

Most evaporative coolers can be made with local materials and require little to no energy input. One such model is made from burlap and bamboo. The water input is made by gravity flow through a bamboo tube connected to a pot.

Another design, developed in the Philippines, consists of galvanised iron wire mesh. This design has two variants. Variant a) consists of a galvanised iron wire mesh box whose top and bottom rest in galvanised iron pans of water. A jute sack covers the box and is dipped in the top and bottom pans, ensuring that it remains wet. Variant b)'s inner walls are made of galvanised iron sheets with small holes every 5 x 5 cm. The outer walls are galvanised iron thin wire mesh (0.32 cm). The walls are spaced 1.5 cm apart. This space is filled with rice hulls. A pan of water rests on the top of the box. A cloth is soaked in the pan and its edges are in contact with the rice hulls, keeping them wet. The produce in these boxes keeps longer than at ambient temperatures, at lengths comparable to refrigerated storage. However, due to the high humidity contained in the box, decay caused by microorganisms can be a problem. This problem can be reduced by dipping the produce in a chlorinated water solution before storage (Kitinoja and Kader, 2004).

The Indian Agricultural Research Institute (IARI) in New Delhi, India has developed an evaporative cooling chamber that it has called the zero energy cooling chamber (Ganesan *et al.*, 2004). The walls of the zero energy cooling chamber are constructed by sandwiching a layer of sand between two layers of bricks. The chamber is covered with a rush mat. The brick-and-sand walls and the rush mat are kept moist with water. Ganesan *et al.* (2004) conducted a study to determine the ideal quantity of water to be fed by drip irrigation to the walls of the zero energy cooling chamber and reported that the shelf-life of the stored produce increased with increasing water volume. The shelf-life increased from three to nine days with the addition of 100 litres of water per day.

Dash and Chandra (2003) developed a computer model to simulate the room temperature and relative humidity inside an evaporative cold room. The variables considered in the model are: variations in ambient temperature and R.H.; wind velocity; solar radiation; the size, shape and construction materials of the evaporative storage room; the rate of evaporative cooling and ventilation/infiltration through the structure; as well as the produce to be cooled.

The model was tested using a zero energy evaporative cooling chamber, and two structures made from wood walls padded with wool, brick floors and gunny cloth covers. The structures were tested using potatoes. The model proved successful; the maximum temperature difference between the predicted and recorded values was 3.7^{o}C. The mean deviation between the predicted and observed inside air temperatures for the brick structure was between 0.6^{o}C and 0.8^{o}C, well within the acceptable limit.

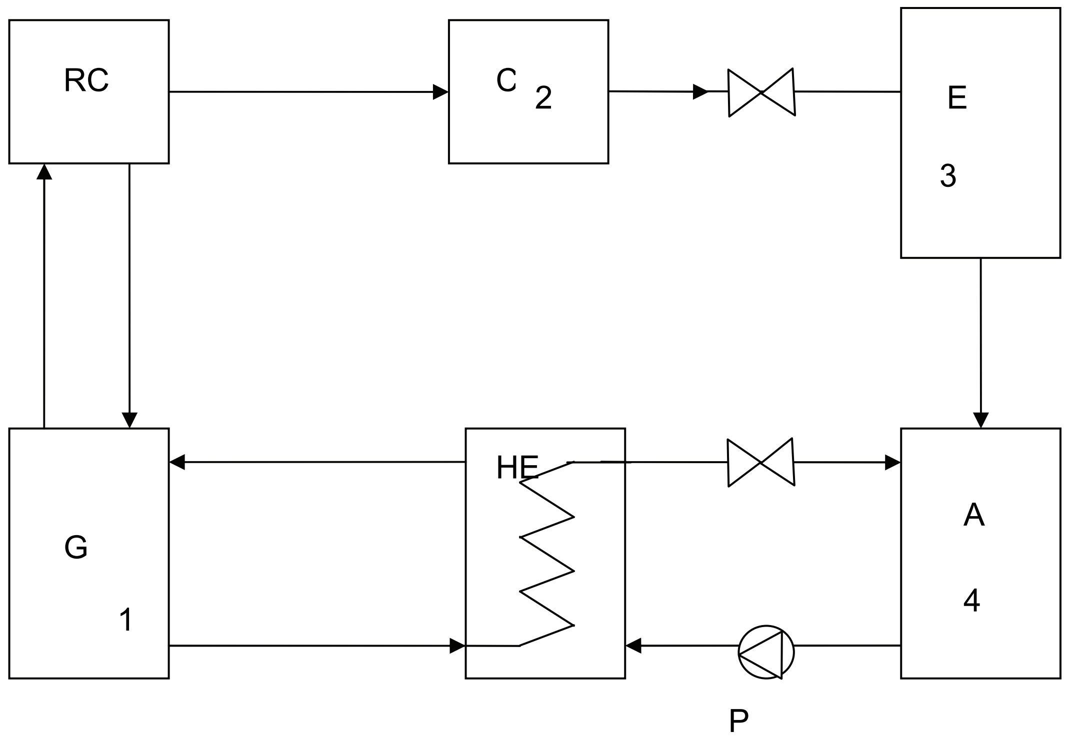
2.1.5.2 Absorption Refrigeration

Absorption refrigeration is an interesting alternative-energy refrigeration system, as it requires heat as an energy source to produce cooling (Wang, 2001). It can be outfitted to use alternative energy sources, such as waste heat, solar power or biogas (Borde and Jelinek, 1987).

Most absorption refrigeration systems work with either a lithium bromide-water solution, where lithium bromide acts as the absorbent and water as the refrigerant, or an ammonia-water solution, where ammonia acts as the refrigerant and water as the absorbent. Ammonia has a lower evaporation point than water and consequently, when used as the refrigerant, can cool the inner chamber of the refrigeration system below $0^{o}C$ (Borde and Jelinek, 1987).

In the absorption refrigeration system (Figure 2.1), heat is applied to the refrigerant-absorbent mixture in the generator (1). The refrigerant, which has a lower boiling point than the absorbent, travels to the condenser (2) in gaseous form. In a continuous cycle, the liquid refrigerant then enters an expansion valve into the evaporator (3), where it evaporates and cools the refrigerated space. The refrigerant is then re-absorbed into the absorbent in the absorber (4) and the cycle continues (Chinnappa, 1992).

The intermittent absorption refrigeration system consists of two vessels: the generator-absorber, which contains the refrigerant-absorbent, and the condenser-evaporator, which is initially empty. At the beginning of the cycle, heat is applied to the generator-absorber. The refrigerant evaporates and travels to the condenser-evaporator, where it condenses. The generator-absorber is then cooled, and the pressure drops in the system, causing the refrigerant in the condenser-evaporator to boil. This cools the cooling chamber. The cycle ends when the refrigerant has left the condenser-evaporator and has been reabsorbed into the absorbent. The cycle must then be repeated for further cooling (Chinnappa, 1992).



Source: Chinnappa (1992)

Figure 2. 1: Schematic of an absorption refrigeration system
P: pump; HE: heat exchanger; G: generator; RC: rectifier; C: condenser; E: evaporator; A: absorber

For absorption refrigeration systems, the coefficient of performance (COP) is the ratio of the cooling effect (Q_e) to the heat supplied (Q_G), where Wp is the work performed by the pump:

$$COP = \frac{Q_e}{Q_G + W_P}$$

Equation 6

The COP for an absorption system is usually around 0.5. This may seem low compared to other refrigeration systems, as the COP of compression refrigeration systems is usually in the range of 2.3 to 2.6. However this definition of efficiency may not be the best measure of evaluation of absorption systems fuelled by low-cost energy, as is the case with biogas or solar-powered absorption refrigeration systems (Klein and Reindl, 2005).

Borde and Jelinek (1987) studied a variety of absorbent-refrigerant combinations to determine which would be best suited to meet the requirements of cooling agricultural produce using low-grade heat such as waste heat, solar-plate collectors or solar ponds. They modelled the thermodynamic processes of R22 (a hydrochlorofluorocarbon) as a refrigerant with various organic solvents as absorbents. They then tested the combinations on a 15-tonne absorption refrigeration cold-storage room kept at 5^{o}C. The best combination was a mixture of R22 and the organic solvent DMF (dimethyl formamide).

2.1.5.2.1 Solar Energy

Many alternative-energy absorption refrigeration systems use solar radiation as an energy source. This source of energy, though widely available, presents some interesting challenges, as it is intermittent and variable.

Solar radiation is collected as heat through solar collectors. The best suited collectors for this task are the high-performance flat-plate collector and the evacuated-tube collector. The most economical choice is the flat-plate collector (Chinnappa, 1992).

2.1.5.2.2 Biogas

Biogas is the product of the anaerobic digestion of organic wastes. The resulting gas, a mixture of methane, carbon dioxide, hydrogen sulphide and ammonia, can be used as a fuel for cooking, lighting, internal-combustion engines that operate irrigation pumps, or vehicles (Mital, 1996).

2.1.5.2.3 Properties of Biogas

Biogas consists mainly of methane, at 60% to 70%. Carbon dioxide is the secondary gas, and comprises of 30% to 40% of biogas. Hydrogen sulphide and ammonia are largely undesirable trace gases that can be removed through scrubbing (Mital, 1996).

Table 2. 3: Properties of Biogas after Purification

Properties	**Value**
Density	0.72 g/L
Energy content	37.75 MJ/m^3
Octane rating	130
Ignition temperature	651^oC
Volumetric Air:CH_4 for complete combustion	10:1
Explosion limits in air	5-14%
Wobbe index (heating value / sq root specific gravity)	732
Flame speed factor	11.1

Source: Mital (1996)

Siddiqui *et al.* (1986) analyzed the economics of running a pumpless LiBr-H_2O absorption refrigeration system using biogas. They found that the cost of biogas used in the system increased by 1.3% for every 10 mm Hg rise in the generator pressure. They also found that for every 10% dip in the effectiveness of the heat exchangers, the optimal cost of biogas increased by 2%. Furthermore, if the refrigeration system were built without a pre-cooler, the cost of biogas would increase by 1.5% to 2%.

Siddiqui (1987) evaluated the use of biogas to power four single-stage absorption refrigeration systems using the following absorbent-refrigerant pairs: ammonia-water, ammonia-sodium thiocyanate, ammonia-lithium nitrate and lithium bromide-water vapour. He optimized the four systems with the goal of comparing their efficiencies at various evaporator and generator temperatures. He found that for evaporator temperatures above 0^oC, the $LiBr-H_2O$ is the most efficient. He also found that the NH_3-H_2O system is 8% to 16% more expensive to operate than the $LiBr-H_2O$ system, as it has a lower performance.

Siddiqui and Riaz (1991) optimized the generator temperatures of two-stage dual-fluid absorption refrigerator cycles in order to minimize the amount of biogas used by the systems. The temperatures were optimized for three different absorbent-refrigerant combinations: NH_3-H_2O, NH_3-NaSCN and NH_3-LiNO_3. The condenser and evaporator temperatures were kept constant. They found that reducing the absorber temperatures results in lower temperatures in the generator, hence improving the second-stage performance of the systems. They concluded that the use of $LiBr-H_2O$ at the first stage and any of the three ammonia combinations at the second stage would build a system capable of using low-grade energy as a source of heat.

2.2 Market Dynamics in India

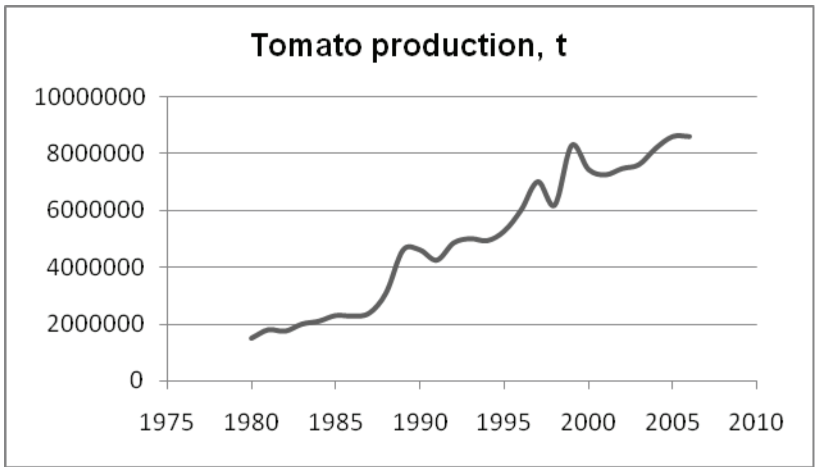
2.2.1 Horticultural Growth Dynamics

Subramanian *et al.* (2000) analysed the production, area and yield trends of potato, tapioca, onion, cabbage, cauliflower, eggplant, okra, tomato, beans, chilli, garlic and ginger in India. They found that the area of vegetable production for the time period 1980-1993 increased by 3.2% annually, whereas yield and production increased in the early years of the data, but stagnated in later years.

2.2.2 Supply and Demand

India is the second-largest fruit producer in the world after Brazil, and the second-largest vegetable producer in the world after China. In comparison, India’s share of the global agricultural commodity trade is of only 2-3% (Gaikwad *et al.*, 2004).

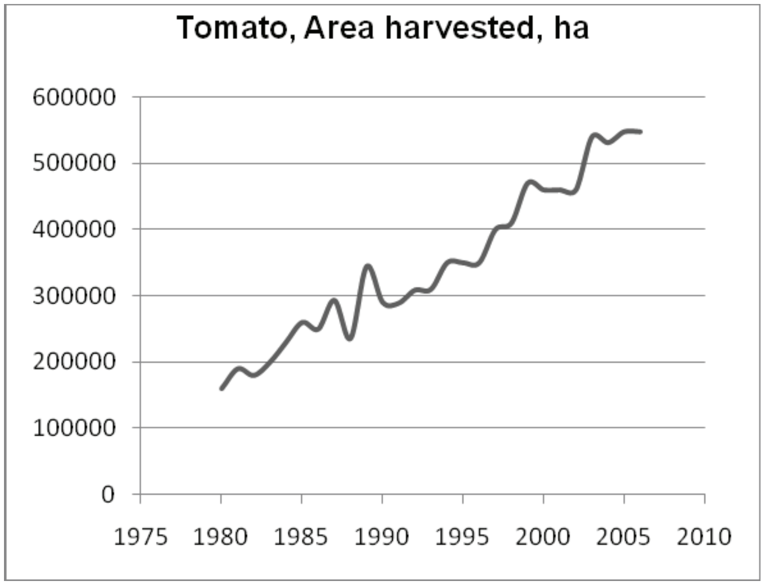
Between 1980 and 2006, vegetable production increased from 19.7-million tonnes to 35-million tonnes. Most of this increase occurred after 1997, when vegetable production increased sharply. Tomato production has increased steadily since 1980, from 1.5-million tonnes to 8.585-million tonnes. Similarly, fruit production has also steadily increased in the same time period (FAOSTAT, 2007).



Source: Subramanian et al. (2000)

Figure 2. 2: Indian tomato production over time (1980-2005)

The vegetable harvest area has increased over that same time period, but did experience a decline between 1987 and 2001. It has since increased over its 1980 levels. In the case of tomato, the area harvested has grown steadily throughout that period.



Source: Subramanian et al (2000)

Figure 2. 3: Area of tomato harvested in India over time

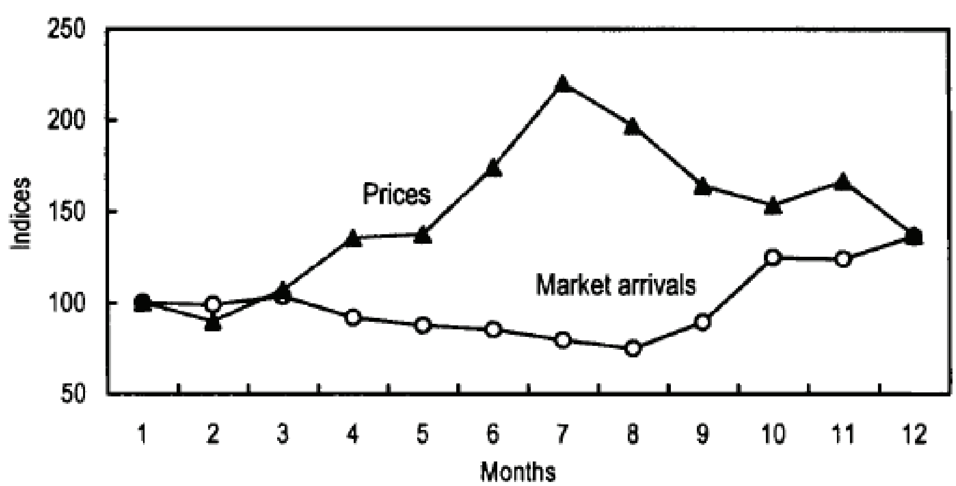
Ali (2000) reports that the increase in production of vegetables does not match the increase in demand. In India, between 1980 and 1993, there was a 4.92% per annum increase in total vegetable demand. The supply, on the other hand, increased by 4% per annum. There was hence a demand-supply gap of 0.92%. However, as seen in the above graphs, vegetable production rose dramatically following 1998. There is no data on vegetable demand post 1993; it is therefore not possible to know whether this increase in production satisfied the demand, or was further surpassed by demand.

Whereas the demand for vegetables is inelastic, some vegetables are highly income elastic. As such, cauliflower, peas and beans are preferred by higher-income families. On the other hand, potato, onion, cabbage, eggplant, okra, tomato and other vegetables are income inelastic, meaning that they are purchased through all income scales. This is especially true in rural areas, where an increase in income does not translate into the purchase of different vegetables (Subramanian, 2000). This also hints that with increasing urbanisation, the demand for vegetables, and more specifically certain types of vegetables, will increase (Ali, 2000).

2.2.3 Seasonality

The price of vegetables in India has risen faster at the retail level than at the farmgate or wholesale level. Subramanian *et al.* (2000) studied the Indian seasonality of vegetable prices for the years 1990-91 to 1993-94. They found that at the national level, the weighted average monthly market-price index of all vegetables was highest during the rainy months of June to August, and lowest during the cool months of January to March. The rainy months can drive the price of produce up because the combination of high temperatures, excessive humidity, frequent and intensive flooding and poor field drainage leaves the produce susceptible to pest infestation and pathogens (Ali, 2000). These conditions can also make it very difficult to harvest the produce, which will consequently deteriorate on the field.

Subramanian *et al.* (2000) also found that the vegetable arrival index (the indexed measure of the quantity of vegetables that arrive at the market each month) for 34 markets in India was inversely proportional to the price index. In fact, the price of vegetables during the low supply period was 120% of the price during the high supply period. Furthermore, the supply of vegetables at the low supply time period was approximately 55% of that of the high period.



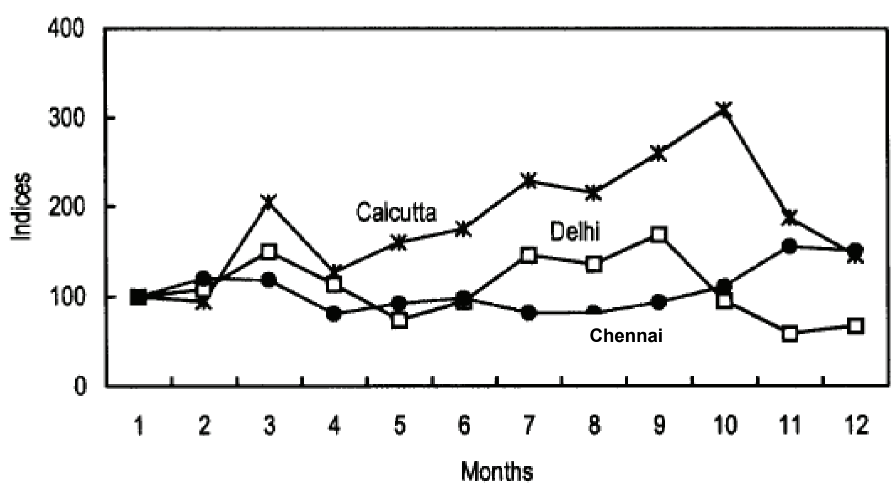
Source: Subramanian et al. (2000)

Figure 2. 4: Seasonality in vegetable prices and market arrivals (monthly average 1990-1993)

They also reported that markets around the country are not well integrated, therefore the prices of commodities any given day will vary depending on which state the market is in. For instance, when eggplant prices peak in October in Calcutta, the prices are low in Delhi and Chennai. They suggested better price and market arrival communication between markets as a solution to this problem (Subramanian *et al.*, 2000).

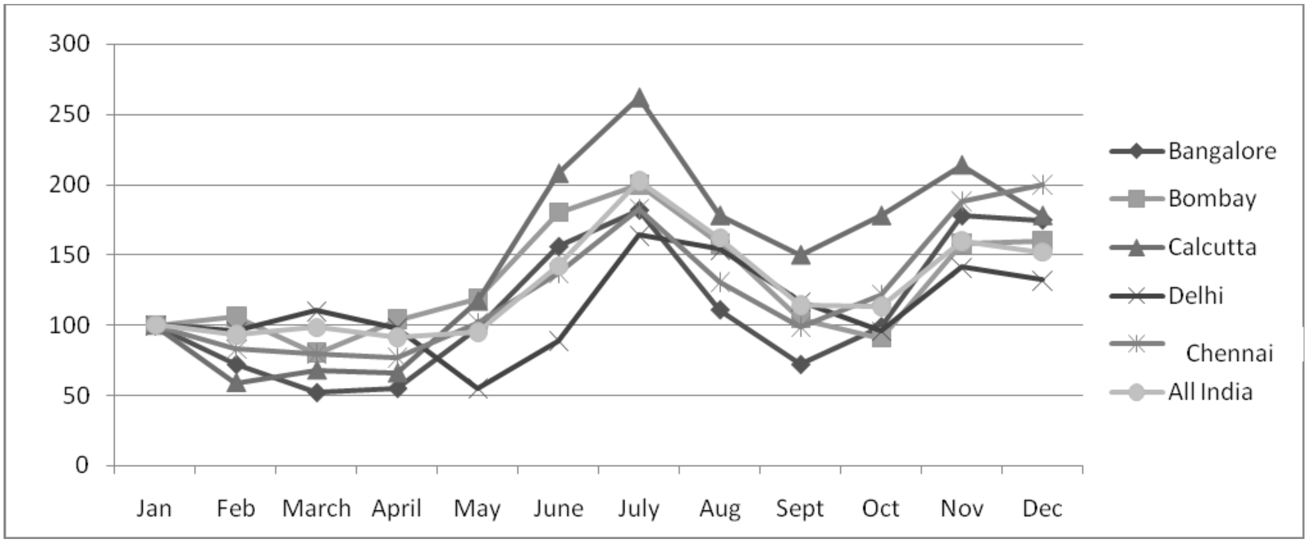
Ali (2000) remarked that the price variation observed by Subramanian *et al.* (2000) is also present at a larger scale throughout Asia. Peaks and low periods in price vary between countries. He suggests that seasonality could be reduced by strengthening regional and cross-country trade.

Furthermore, Ali (2000) challenges the perception that seasonality in one vegetable can be counterbalanced with other vegetables. He demonstrates that this is not the case, since vegetables as a group show seasonality throughout the year. The same is true when comparing the seasonalities of fruits and vegetables. They follow similar trends.



Source: Subramanian et al. (2000)

Figure 2. 5: Regional monthly price indices of eggplant prices (average 1990-93)



Source: Subramanian et al. (2000)

Figure 2. 6: Price index of tomatoes for various cities in India

2.2.4 Marketing Channels

There are seven market channels that vegetables can travel through to get from the producer to the consumer (Subramanian *et al.,* 2000). They are the following:

1. Producer → Commission Agent → Shipper → Secondary Wholesale Trader → Retailer → Consumer
2. Producer → Commission Agent → Primary Wholesale Trader → Retailer → Consumer
3. Producer → Commission Agent → Retailer → Consumer
4. Producer → Primary Wholesale Trader → Retailer → Consumer
5. Producer → Cooperative (or regulated market) → Primary Wholesale Trader → Retailer → Consumer
6. Producer → Cooperative (or regulated market) → Retailer → Consumer
7. Producer → Cooperative (or regulated market) → Consumer

The role of commission agents is very important in India. Subramanian *et al.* (2000) identify channels 1, 2, 3 and 5 as the most important (of which channels 1, 2 and 3 include a commission agent). Market studies conducted by the Indian Institute of Horticulture Research in Karnataka, Andhra Pradesh and Tamil Nadu showed that 92% of Karnataka farmers and 62% of Tamil Nadu and Andhra Pradesh farmers use commission agents to sell their vegetables (IIHR, 1989). The situation has not changed significantly over the years and a majority of farmers continue with this arrangement to the present day (Subramanian *et al.*, 2000).

In India, highly perishable products such as vegetables are mostly grown in peri-urban areas, as the marketing infrastructure is not developed enough to allow producers to ship their produce great distances. Instead, the produce is cultivated near the consumption centres so as to sell quickly and avoid losses in quality and value.

Subramanian *et al.* (2000) have also studied the farmer's share of the price paid by the consumer for produce. They found that for certain vegetables, such as tapioca, cabbage, cauliflower, pea, chilli, garlic and ginger, the farmer's share was quite high (from 40% to 67%). In the case of the other crops that they studied, the farmer's share fell to 30%. Furthermore, in the case of potato, tapioca, onion, tomato, eggplant and chilli, the producer's share of the consumer's rupee fell over the period of the study (1980-81 to 1991-92).

2.2.5 Marketing Cost

The cost of marketing produce includes transportation, labour, commissions, packing, taxes, and other incidental costs. The following table is an excerpt from a table devised by Subramanian *et al.* (2000) that specifies the various marketing costs by state for a few commodities.

Table 2. 4: Marketing Costs of Specified Produce by State, in Rs. per tonne

Item	Crops				Average of all vegetables[1]	
	Tomato	Eggplant	Cabbage	Carrot	Rs	Percent
			Karnataka			
Transport Cost	68.7	75.4	86.3	92.1	68.6	38.3
Loading/Unloading	15.2	9.2	14.2	15.5	14.2	6.7
Commission Charges	117.1	102.3	107.1	88.2	106.1	49.9
Packing Charges	13.3	6.6	5.9	6.1	7.7	3.6
Tax and other costs	3.2	4.4	1.1	1.7	3.2	1.5
Total	217.5	197.9	214.6	203.6	212.5	
			Tamil Nadu			
Transport Cost	28.0	25.4	45.7	76.0	30.7	34.0
Loading/Unloading	6.2	5.1	8.7	3.2	6.2	6.9
Commission Charges	47.7	18.8	42.0	101.4	35.8	39.7
Packing Charges	1.6	1.0	48.3	2.4	10.8	12.0
Tax and other costs	-	6.8	-	-	6.8	7.5
Total	83.5	57.1	144.7	183.0	90.3	

Source: Subramanian et al. (2000)

[1] Average of all vegetables in the country

2.2.6 Price instability

Subramanian *et al.* (2000) studied the variation in vegetable prices, yield, cultivated area, and production. They found that there is great variation in vegetable production, and that the variation in yields for vegetables is generally higher than the production variation. They explained this by the fact that agriculture in India is very vulnerable to climatic conditions. These variations in yield can and often do lead to an instability in produce price. The authors divided price coefficients of variability between the farmgate, wholesale and retail. They discovered that for potato, onion, cabbage, cauliflower, okra, peas and the average of all vegetables, price variability was greater at the wholesale and retail level. This indicates that the wholesalers and retailers bear the brunt of price fluctuations. In the case of tapioca, tomato, chilli, garlic and ginger, the greater price variability is seen at the farmgate, indicating that farmers face a higher price fluctuation.

2.2.7 Postharvest Losses

India produces approximately 110-million tonnes of fruit and vegetables yearly (Gaikwad *et al.*, 2004), of which 7.1 million tonnes are tomatoes (CARDS, 2007). There is very little refrigeration along the supply chain, from the harvesting stage to the consumption stage. As such, postharvest losses of fruit and vegetables are high (Gaikwad *et al.*, 2004).

Table 2. 5: Postharvest Losses of Specific Fruit and Vegetables in India

Produce	Loss (%)
Apple	14
Banana	20-80
Lemon	20-95
Orange	20-90
Grape	27
Papaya	40-100
Cabbage	37
Cauliflower	49
Onion	16-35
Potato	5-40
Tomato	5-40

Source: Gaikwad et al. (2004)

2.2.8 Planning for Storage

Ideally, storage planning should be based on future prices. However, predicting the fate of an agricultural commodity is difficult in a market supplied by numerous fragmented sources growing horticultural products that are highly dependent on varying climate and other factors. The decision to store is made with the assumption that commodity prices will increase by the time the produce is ready to be released to the market and hence involves significant risk (Ostendorf, 1973).

The success of planning for storage depends on a variety of factors, some of which are beyond the planner's control. The technical aspects of planning can be controlled to a certain degree; they depend on available technologies (as in the decision to refrigerate versus the decision to store in controlled-atmosphere chambers) and on the commodity's requirements. Storage must also be hedged against the risk that the market price of the commodity upon release to the market is not high enough to cover storing expenses. Furthermore, hazard costs must be taken into account. The produce could shrink, deteriorate or otherwise experience a loss in quality. Therefore, the decision as to whether or not to store produce must be made with the full realisation that it will not provide unconditional protection against risks. Instead, risks must be fully taken into account in order to be profitable in the long-run (Ostendorf, 1973).

2.3 State of Agricultural Production and Management Practices in India

2.3.1 Tomato Production in Tamil Nadu

Annually, approximately 10,800 tonnes wet weight of tomatoes are exported from India, mostly to Bangladesh, Nepal, Pakistan and the United Arab Emirates. In the southern state of Tamil Nadu, there are two tomato-growing seasons: May to June and November to December. In India, Tamil Nadu is the seventh-largest producer of tomatoes. The 25,000 hectares of tomato fields in India produce approximately 300,000 tonnes per year (CARDS, 2007). Tomato is produced mainly in the districts of Dharmapuri, Coimbatore, Salem, Krishnagiri, Theni Dindigul and Vellore.

Coimbatore is the second-largest tomato-producing district in the state. As the city of Coimbatore is a major transportation hub, the district's market supply is affected both by its own tomato production and by the transportation of tomatoes from the neighbouring states of Karnataka and Kerala.

The major tomato markets of the district of Coimbatore are Saibaba Kovil, Kinnathakadavu, Nachipalayam and Velandhavalam. From August to January, these markets are supplied by local farmers. From February to July, they are supplied by farmers from the neighbouring state of Karnataka. Tomato production in Karnataka lasts throughout the year, however it cannot compete with the local supply during the Tamil

Nadu growing season. Traders therefore import tomatoes into Tamil Nadu only during the off-season, when the local supply of tomatoes is low (CARDS, 2007).

2.3.2 Postharvest Management

2.3.2.1 Handling, Grading Facilities and Packaging

In India, few cleaning, grading and packaging facilities exist at the farm level, although these facilities are key to reducing qualitative and quantitative losses, especially with regards to perishable commodities. Losses due to excessive moisture and heat, insect, pest and rodent infestation, careless handling, and poor packaging are therefore common and avoidable (Acharya, 2004).

Grading and packaging are very important in fruit and vegetable marketing. Proper grading results in substantially higher prices for farmers at the market. Furthermore, proper packaging reduces transportation losses, produce damage and waste, and adds to the product's value. It allows for perishable and fragile produce to be shipped longer distances to urban and peri-urban areas, and even for export. The demand for packaging and grading services and facilities is on the rise in India. However, the education of farmers by agricultural extension workers has been insufficient, resulting in a lack of motivation for farmers. Compounding the problem is a lack of available grading and packaging facilities both at the village or farm and at the market levels. Projects show that when the proper efforts are made to educate farmers and to provide the required facilities, postharvest handling of the commodity in question is greatly improved and farmers showed the willingness and motivation to undertake proper postharvest handling (Acharya, 2004).

2.3.2.2 Transportation

Transportation is integral to any market. In fact, trade and transportation reinforce each other. The state of transportation in India has improved since the 1950s, however only 48.4% of villages in the country are connected by a road (Acharya, 2004). As of 31st of March 1995, villages smaller than 1,000 in population have an average road connectivity of 37.45%. This proportion increases to 75.88% for villages with a population between 1,000 and 1,500, and to 91.73% for villages with more than 1,500 people. Southern states, as well as Haryana and Punjab, fared better than northern and eastern states in road connectivity. But the mere fact of being connected by a road does not mean that the road is easy to travel. Only 57% of India's total road length is surfaced. Furthermore, of the 43% of unsurfaced road length, a good proportion is unmotorable (Thorat and Sirohi, 2004).

In order to facilitate postharvest transportation, specialised roads, rail transportation and refrigerated transportation are needed (Acharya, 2004). There is an important need for reefer (refrigerated) vans. Presently, there are only 400 such vans in the country. At least 3,000 eight-ton capacity vans are needed for the transport of perishable commodities. These vans would allow producers and shippers to transport perishable commodities to distant markets (Acharya, 2004).

2.3.2.3 Storage

There is a large amount of waste of perishable commodities in India, in particular fruits, vegetables and spices. This is in part due to the fact that there is a lack of proper, "scientific" storage facilities. The lack of adequate storage facilities also aggravates seasonal price fluctuations (Acharya, 2004).

There are currently 4,199 cold stores with a capacity of 15.38-million tonnes of produce in the country. These numbers represent approximately 10% of the total production of fruits and vegetables in India. The majority (89%) of these cold stores are found in the private sector. These private cold storage rooms account for 95% of the total storage capacity available in the country (Acharya, 2004).

There is a large opportunity for expansion in the cold-storage business. Demand for cold storage is set to increase, as vegetable and fruit production is predicted to grow. Furthermore, many of the existing cold-storage rooms require upgrades, as they are often unscientifically designed. The Government of India predicts that 15,000 new cold storage units will be needed by 2011; these cold storage units should account for an additional 4.5 million tonnes of produce (Acharya, 2004).

Table 2. 6: Sector-Wise Distribution of Cold Storage Facilities in India

Sector	Number of Cold Storages	Capacity (million tonnes)
Private	3,739	14.613
Cooperative	310	0.680
Public	150	0.091
Total	4,199	15.385

Source: Acharya (2004)

2.3.2.4 Processing and Value Addition

Processing is another crucial postharvest operation. It reduces losses, expands markets, adds value to products and creates employment opportunities. Currently, approximately 98% of fruits and vegetables is traded as fresh commodities. Processing accounts for only 1.8% of the fruits and vegetables market. Clearly, there is room to grow (Acharya, 2004).

Fruit and vegetable productivity is much lower in India than in many other countries. Consequently, the price of produce destined for processing is three to four times higher than elsewhere in the world. Furthermore, the varieties grown in the country are not the best suited for processing. Processing is currently restricted to a select few types of fruits and vegetables (Gaikwad *et al.*, 2004).

CHAPTER 3
MATERIAL AND METHODS

3.1 Collection and Transportation of Tomatoes

Studies were conducted on a pilot scale, working with selected farmers of the Madampatti and Kuppanoor villages, which are located at a distance of 20 km from Coimbatore city. The selected farms were of average size, producing about 100 to 125 kg of tomatoes per day. The average yield of tomato production in India is 14 tonnes per hectare. There are two growing seasons in Tamil Nadu: May-June and November-December. Traditionally, the produce is harvested during the morning, packed in cane baskets and sent to the local market early in the evening for sale.

Figure 3. 1: Tomatoes stored the traditional way, in cane baskets. Traditional packing methods often result in bruised produce. Such packing methods are also inappropriate for stacking.

Farmers were provided with orientation on the concepts of proper harvesting, the physiological maturity of the fruit, sorting and grading, packing for transportation and cold storage. The farm labourers were trained to harvest the tomatoes at the breaker stage followed by sorting for removal of diseased fruits. The produce was then graded to obtain a uniform product of similar size and maturity stage. The fruits were packed in plastic crates with openings for aeration, as well as provisions to stack without damaging contents. The produce was weighed, tagged and loaded onto vehicles for transportation to the cold store in Coimbatore city. One set of crates was placed in a walk-in cold store available at the Postharvest Technology Centre of the Tamil Nadu Agricultural University. The time required for transportation between the farms and the cold stores varied from 45 to 60 minutes. At the cold store, the crates were unloaded, weighed again, and stacked in the cold storage at 15°C. There was no pre-cooling of the produce; the fruits were sorted, graded and packed in shade at ambient temperature (28°C to 29°C).

Figure 3. 2: Farmhand sorting tomatoes prior to storage.

Figure 3. 3: Loading the truck for transportation to the cold storage. Traditional baskets are often stacked, resulting in larger losses caused by bruising and compression.

Figure 3. 4: Tagged crates on the truck en route to the cold storage. These crates are specially designed for produce.

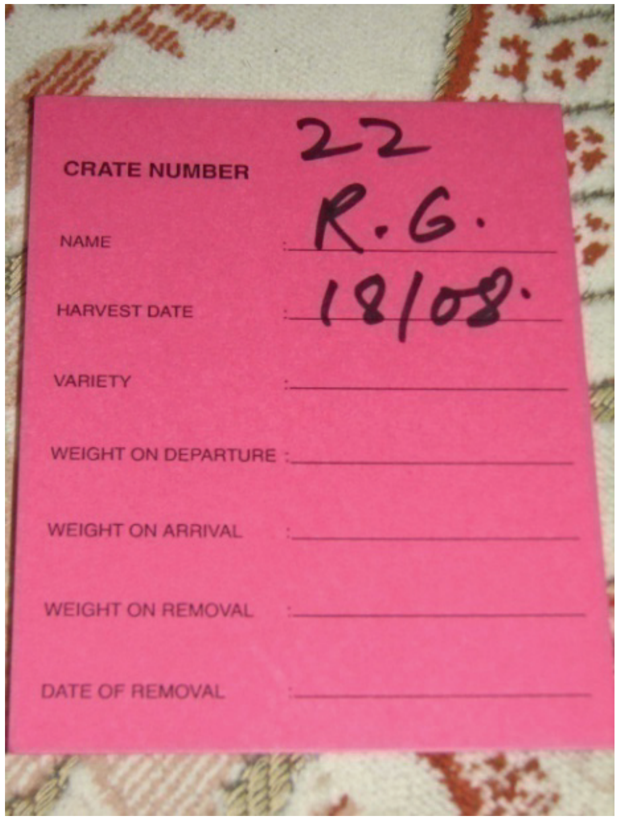


Figure 3. 5: Tag used to identify the crates and shipments.

Figure 3. 6: Crate being weighed at the farm prior to transportation.

3.2 Cold Storage

The city of Coimbatore only has one commercial cold-storage facility that is commonly used for cash crops, such as chillies and turmeric. Prior to this study, no fruits or vegetables had ever been stored at the cold store, which has been operating for more than three decades. The cold-storage facility consisted of multiple chambers with independent evaporators run by a set of three compressors. There was no equipment available to control the relative humidity in the chambers. The temperature of the air in the selected chamber was indicated by dial thermometers located on the door. The set temperature was controlled manually by the operator, who constantly monitored the temperature and cut the refrigerant supply to the evaporator in the chamber when it attained the set point temperature. Based on the loading/unloading schedule, the frequency of this operation varied from five to six times a day. In order to maintain a high relative humidity in the chamber, five flat, wide, open trays, each of 2.5-litre capacity, were filled with water and placed at the corners of the stacked produce. Apart from these trays, a large pan below the evaporator, originally meant to collect the water from the coils during defrosting, was kept filled with water by the operator. The tomato baskets (used on the first day) and crates were carried into the chamber and stacked manually; this operation took 10 to 15 minutes for each shipment.

Figure 3. 7: The commercial cold store in the city of Coimbatore. An ammonia evaporator sits at the back of the room, and cool air is circulated through a large duct at the top of the room.

Figure 3. 8: Storing tomatoes in the commercial cold store.

Figure 3. 9: Bringing tomatoes into the commercial cold store. The commercial cold store in Coimbatore was on the fifth floor; the produce had to be loaded into an elevator.

Figure 3. 10: Crates loaded into the elevator.

Figure 3. 11: Crates waiting at the farm to be transported to the commercial cold store.

Figure 3. 12: Crates stacked in the commercial cold store.

A walk-in cold store available at the Tamil Nadu Agricultural University campus, located about 3 km from the commercial cold storage facility, was also used in the study. This cubic chamber with 2-m sides was equipped with a PID Controller to maintain the temperature and relative humidity. Relative humidity was maintained by injection of steam into the air in the chamber. The produce maintained at this experimental cold storage was moved in one shipment.

Figure 3. 13: Crates in the experimental cold store at the Post-Harvest Technology Centre.

Figure 3. 14: Crates in the experimental cold store at the Post-Harvest Technology Centre.

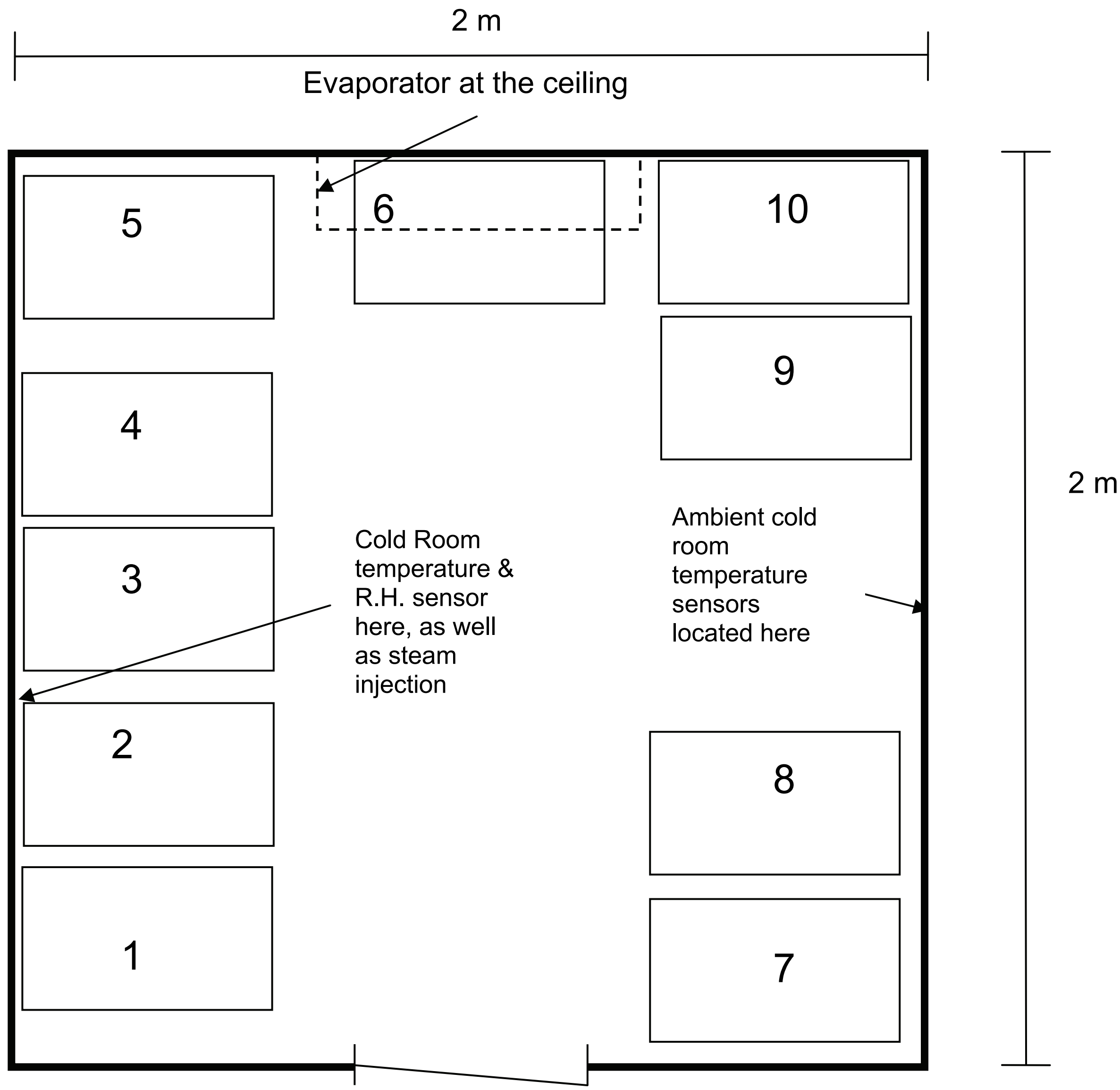


Figure 3. 15: Schematic of the experimental cold store at the Post-Harvest Technology Centre, Coimbatore. Numbers 1 to 10 are crate stacks.

A stack of 10 crates was maintained in the building outside the walk-in cold store at ambient conditions and considered as the control.

Crates were removed randomly from the stacks at regular intervals to evaluate the effect of storage. The crates were weighed and the fruits were individually inspected for changes. Fruits affected by microbiological attack were separated and considered spoiled. Those with visible shrinkage, shrivelling or softening were identified as fruits with storage-related changes. Good, firm and clean fruits were separated and identified as marketable. Each category was weighed and the marketable fruits were subsequently returned to the farmers to be sold at the market.

Figure 3. 16: Farmers sorting tomatoes after storage at the commercial cold store.

Figure 3. 17: Sorting tomatoes at the experimental cold store.

Figure 3. 18: Unsorted crate of tomatoes at the end of storage at the experimental cold store.

Figure 3. 19: Sorted, marketable tomatoes at the experimental cold store.

Figure 3. 20: Spoiled tomatoes from the experimental cold store.

3.3 Instrumentation

Data loggers (OMEGA Nomad-43, OMEGA Engineering Inc., USA) were used to record the temperature and relative humidity of the produce and the air in the cold stores. The mobile data loggers were programmed to record the inputs at varying intervals and placed in the middle of the crates to measure temperature and relative humidity around fruit. Two data loggers, one in the commercial and the other in the experimental cold store, were mounted on the wall to record air temperature and humidity. An electrical power meter directly recorded the power consumption in kWh (cumulative). This was recorded at regular intervals. There was no separate power meter available for the chamber at the commercial cold store.

Figure 3. 21: Wall-mounted data logger recording ambient conditions in the experimental cold store.

Theoretical power consumption was calculated based on the recorded temperature of the fruit, the weight and the specific heat obtained from literature. Respiratory heat generation values for tomato were also obtained from the literature (ASHRAE, 2003).

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Arrivals and Price Relationship

The quantities of weekly tomato arrivals in the Coimbatore market for the years 2002 to 2006 (data for the last quarter of 2006 were collected after the study and are included in the analysis) are shown in Figure 4.1. This information was collected and analyzed to identify any possible trends that could be used to design an intervention to assist farmers. As is clearly seen in the figure, the tomato supply to the market was higher during 2005 and 2006. This was probably due to the prevalent drought in the region between 2002 and 2004. During these years the country received low rainfall during both the southwest and the northeast monsoons. Normal to higher rainfall events during 2005 and 2006 could be the reason for higher supplies during those years.

The weekly modal price was compared with the quantity of market arrivals (Figures 4.2 to 4.6). There was no clear correlation between the two parameters, as would be the case in an ideal free market. An increase in market influx did not correlate well with a reduction in the price of the commodity.

A regression analysis of the weekly arrival data showed a fairly distinct sinusoidal function for the years 2002-2005, as can be seen in Figures 4.7 to 4.10. This function did not fit well for the data from the year 2006 (Figure 4.11 and Table 4.1).

Table 4. 1: Function Coefficients and Correlation Coefficients for the Sinusoidal Function [y = a + b.cos (cx + d)] Fitted to the Weekly Arrival Data of Tomatoes at Coimbatore Market during the Years 2002-2006

	Year				
	2002	**2003**	**2004**	**2005**	**2006**
a	41.02411	45.168687	43.452475	79.478303	-400.73438
b	15.170274	15.657363	10.190535	34.30648	505.5051
c	0.19281174	0.1997743	0.1497048	0.22070584	0.00797016
d	-4.1757824	1.6225769	-2.7553833	0.75665499	-0.1113751
r	0.7146	0.7072	0.5986	0.6188	0.3503

Interestingly, the fluctuation of the weekly price had a sinusoidal relationship with the week of the year as shown in Figure 4.12 using the combined week-price data for five years (2002-2006).

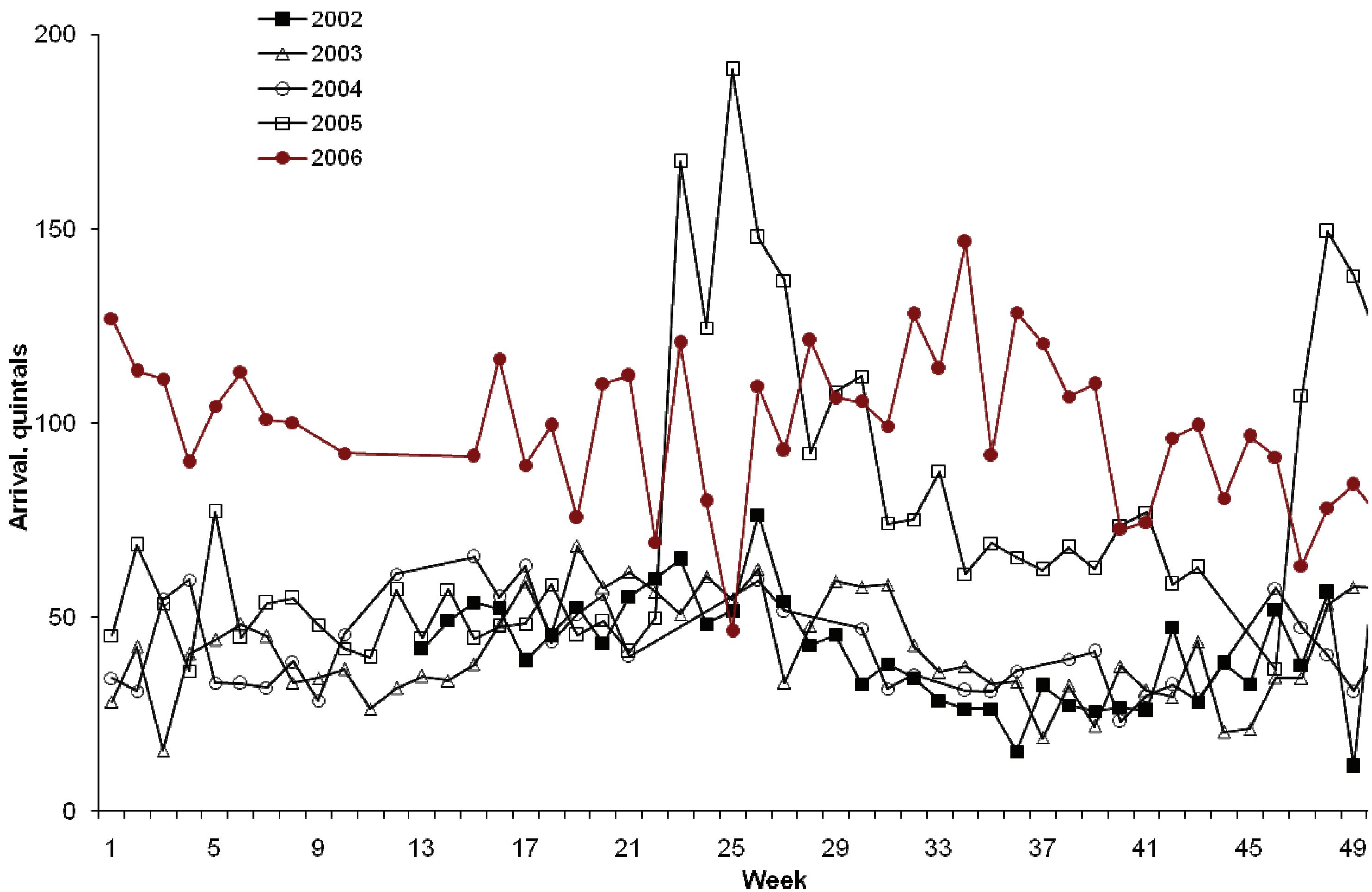


Figure 4. 1: Five-year (2002-2006) comparison of the weekly arrivals of tomatoes at the Coimbatore market

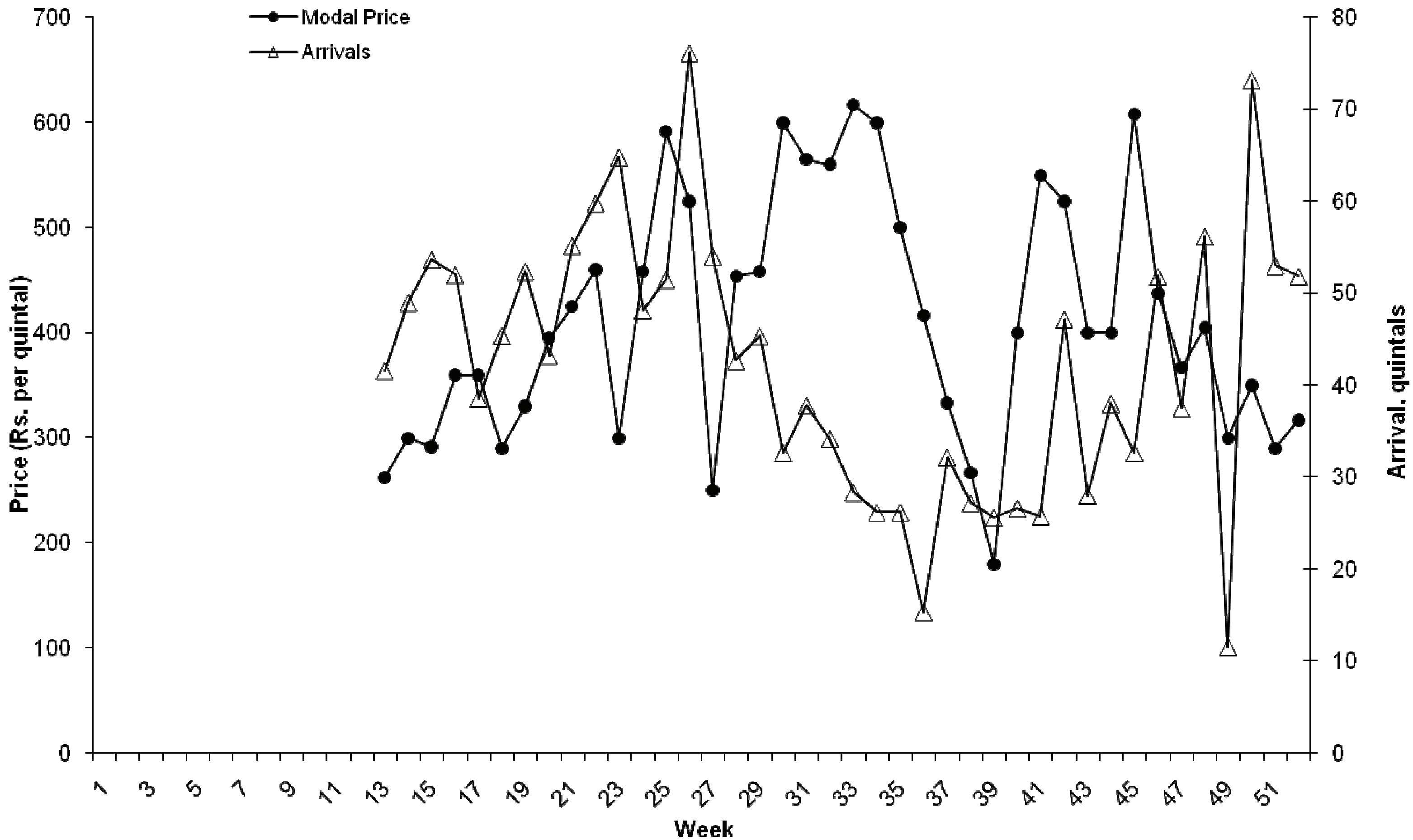


Figure 4. 2: 2002 weekly arrivals and prices of tomatoes at the Coimbatore market

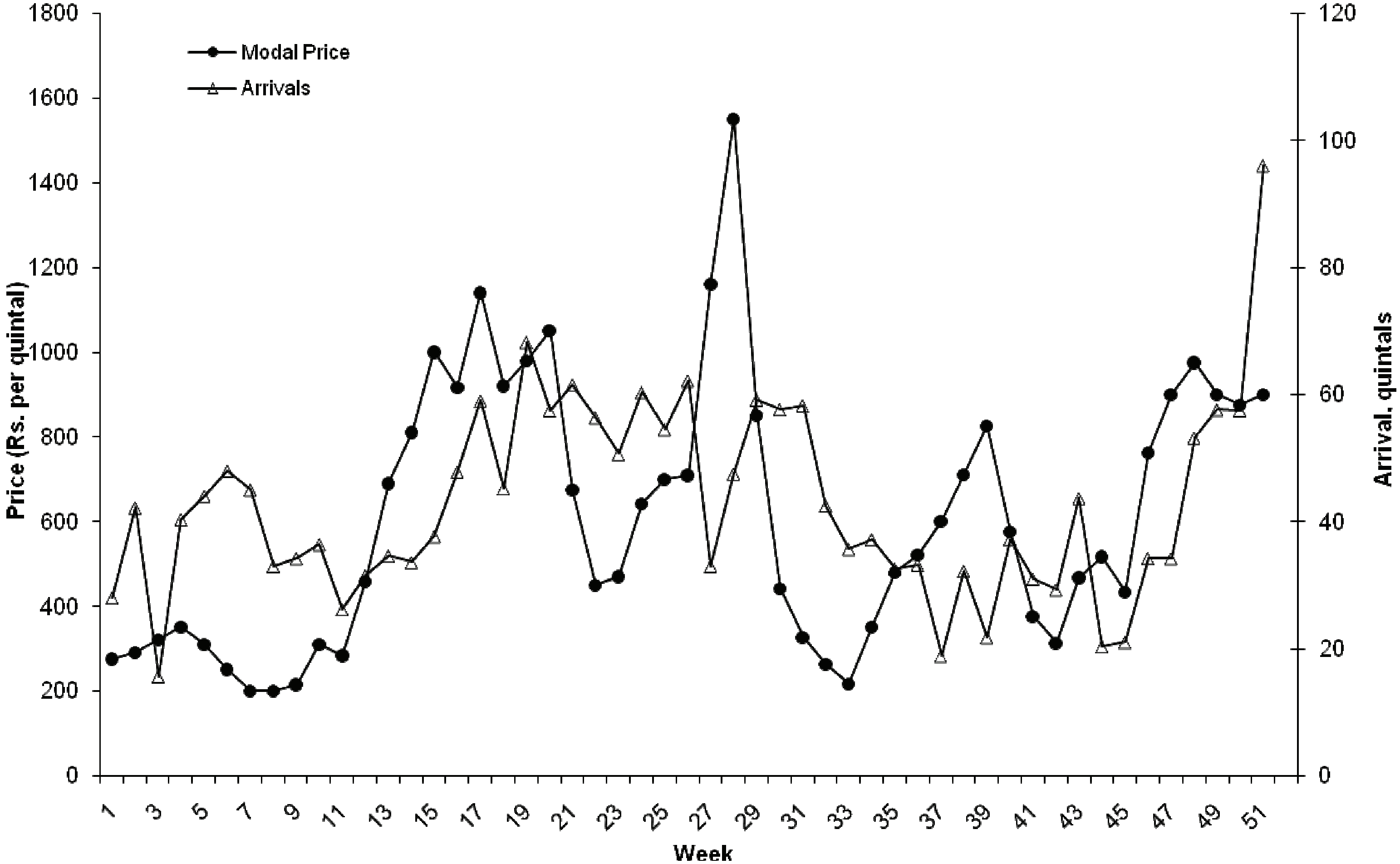


Figure 4. 3: 2003 weekly arrivals and prices of tomatoes at the Coimbatore market

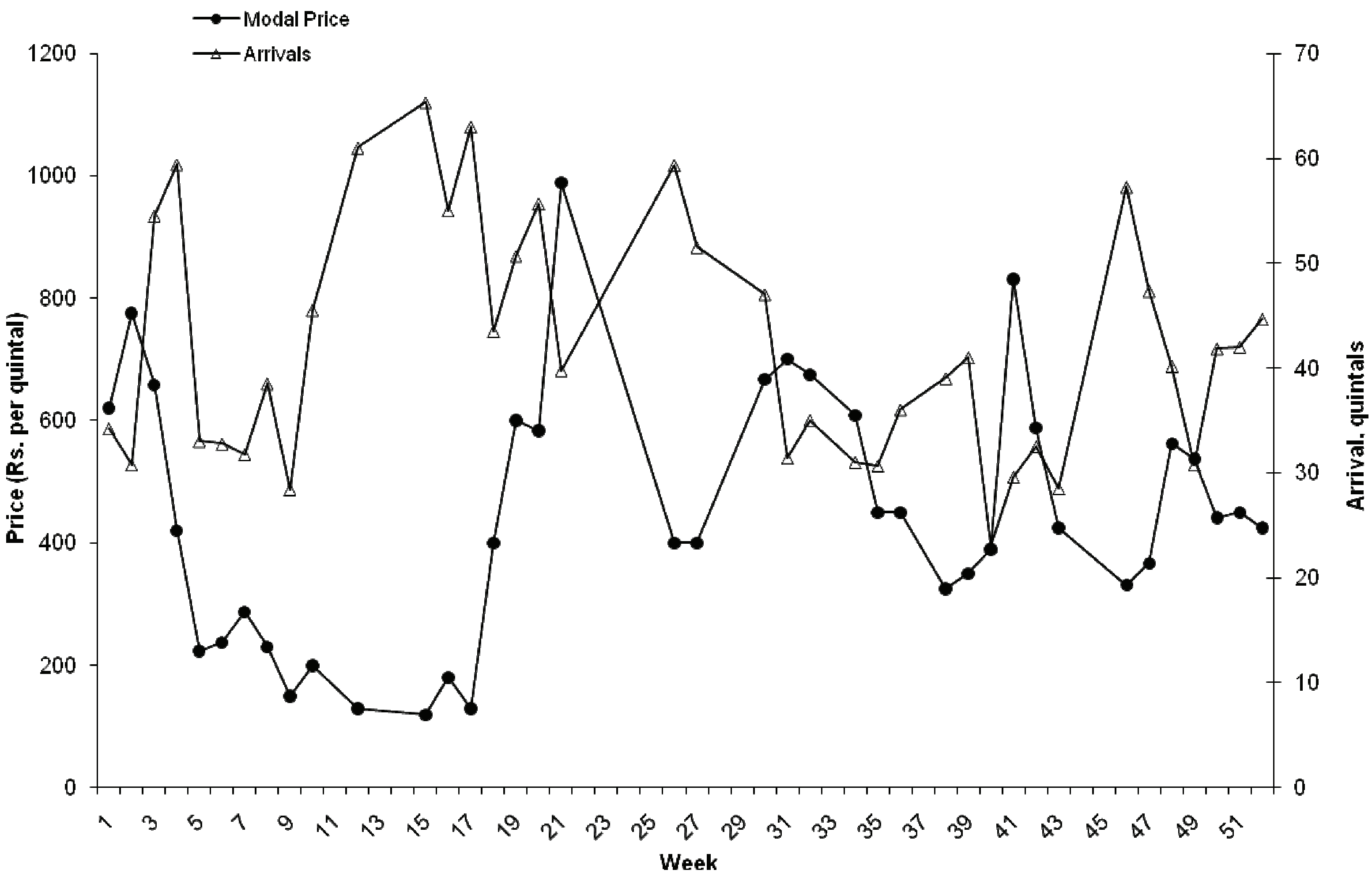


Figure 4. 4: 2004 weekly arrivals and prices of tomatoes at the Coimbatore market

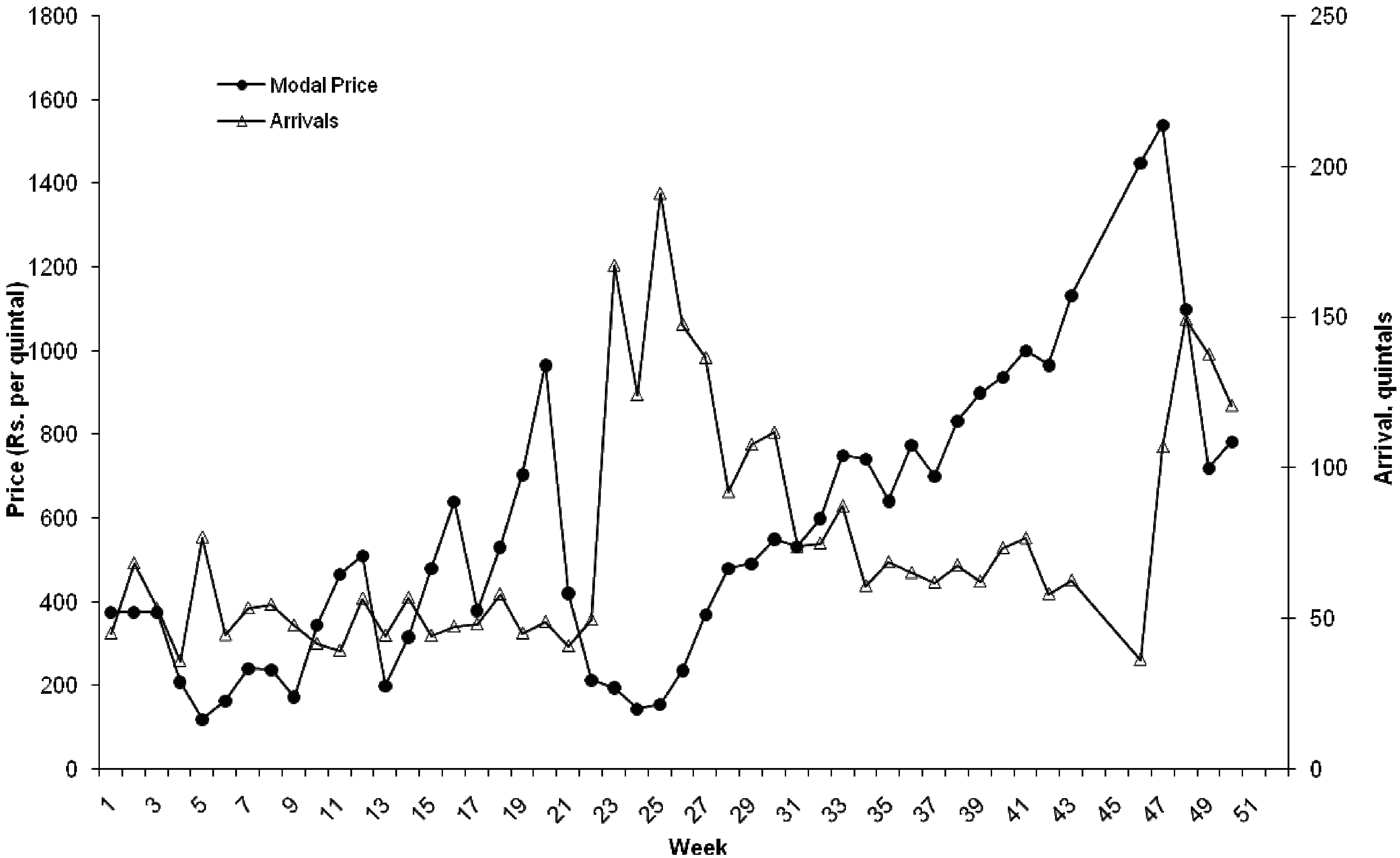


Figure 4. 5: 2005 weekly arrivals and prices of tomatoes at the Coimbatore market

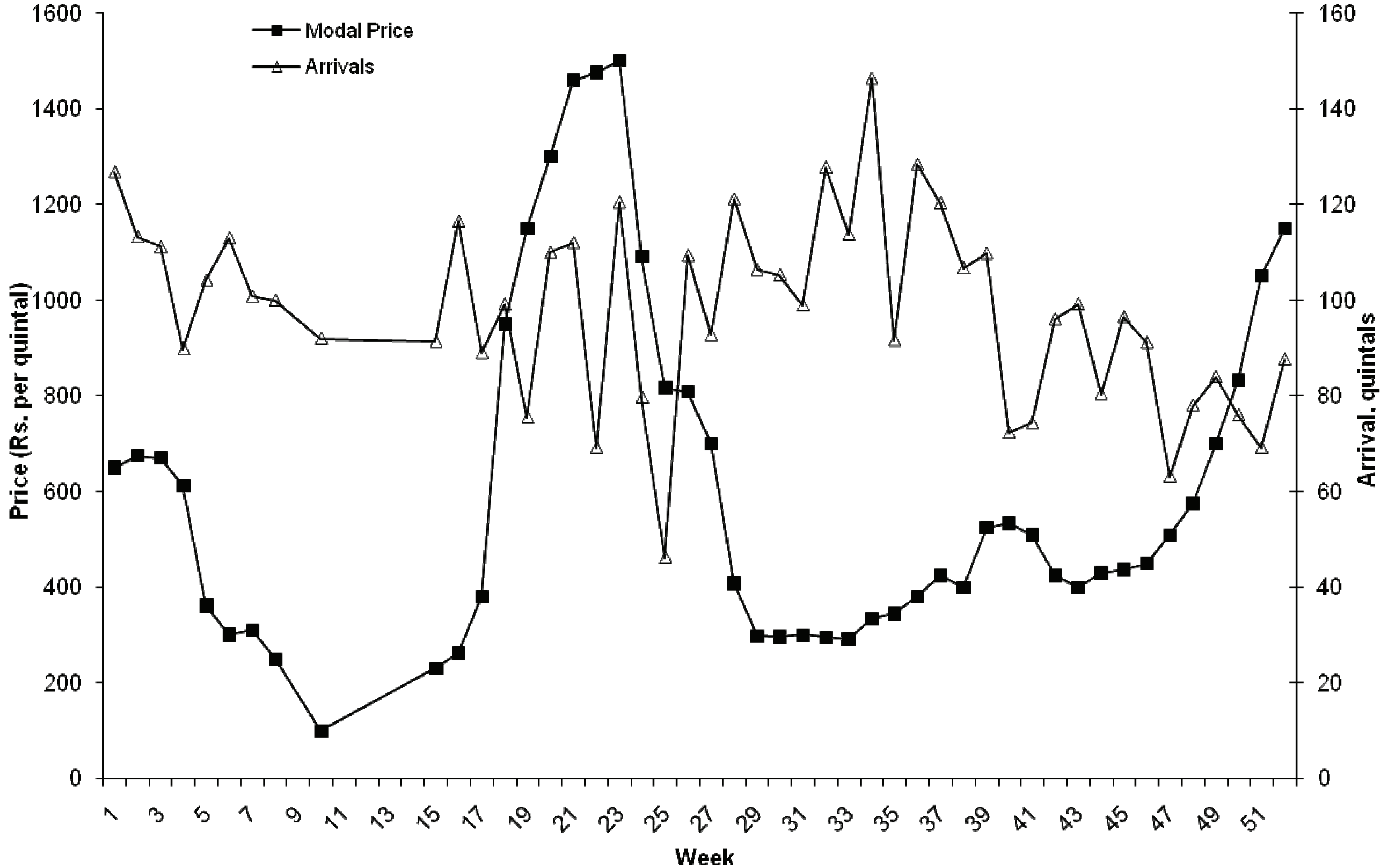


Figure 4. 6: 2006 weekly arrivals and prices of tomatoes at the Coimbatore market

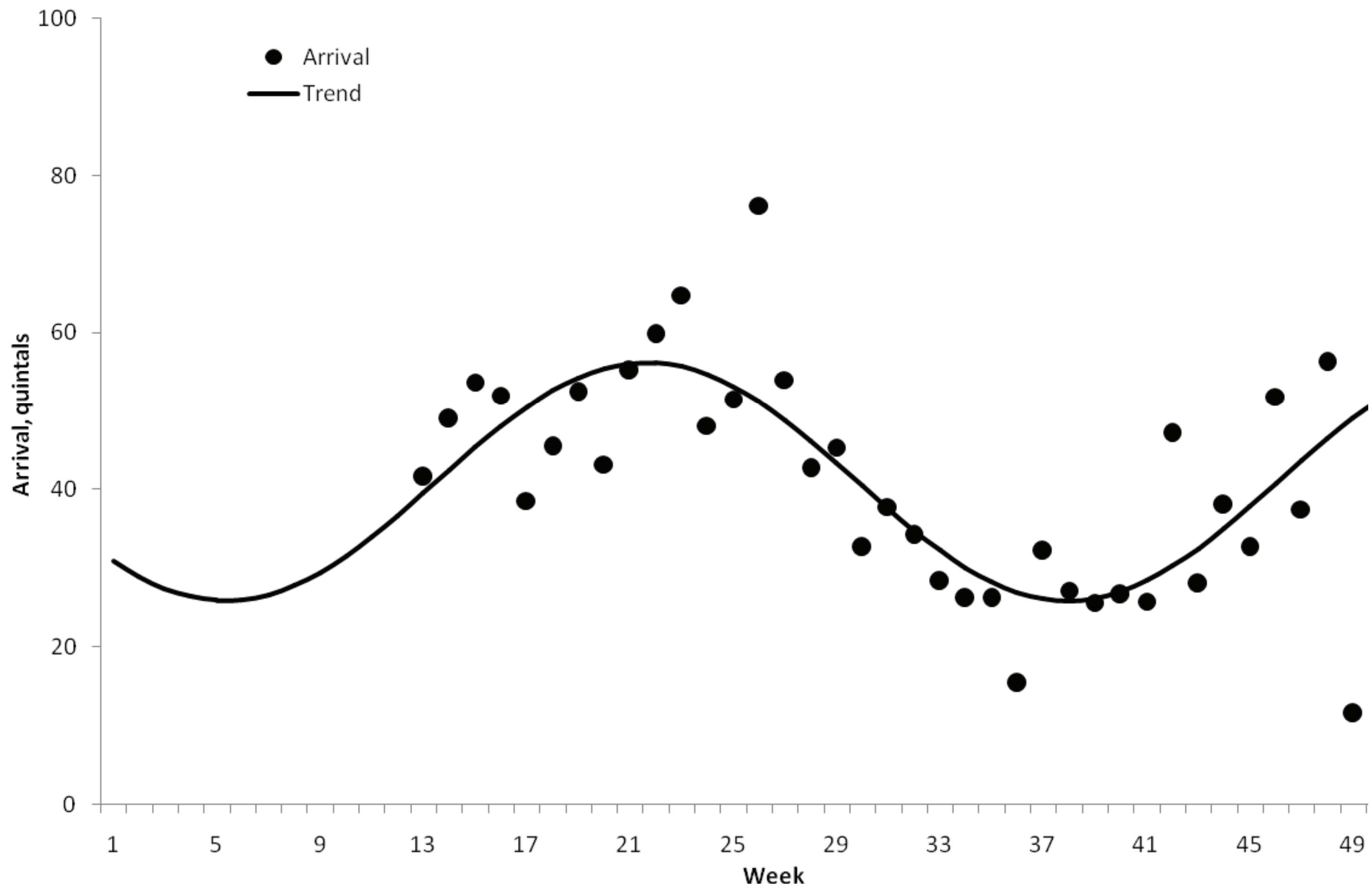


Figure 4. 7: Trend of 2002 weekly arrivals of tomatoes at the Coimbatore market

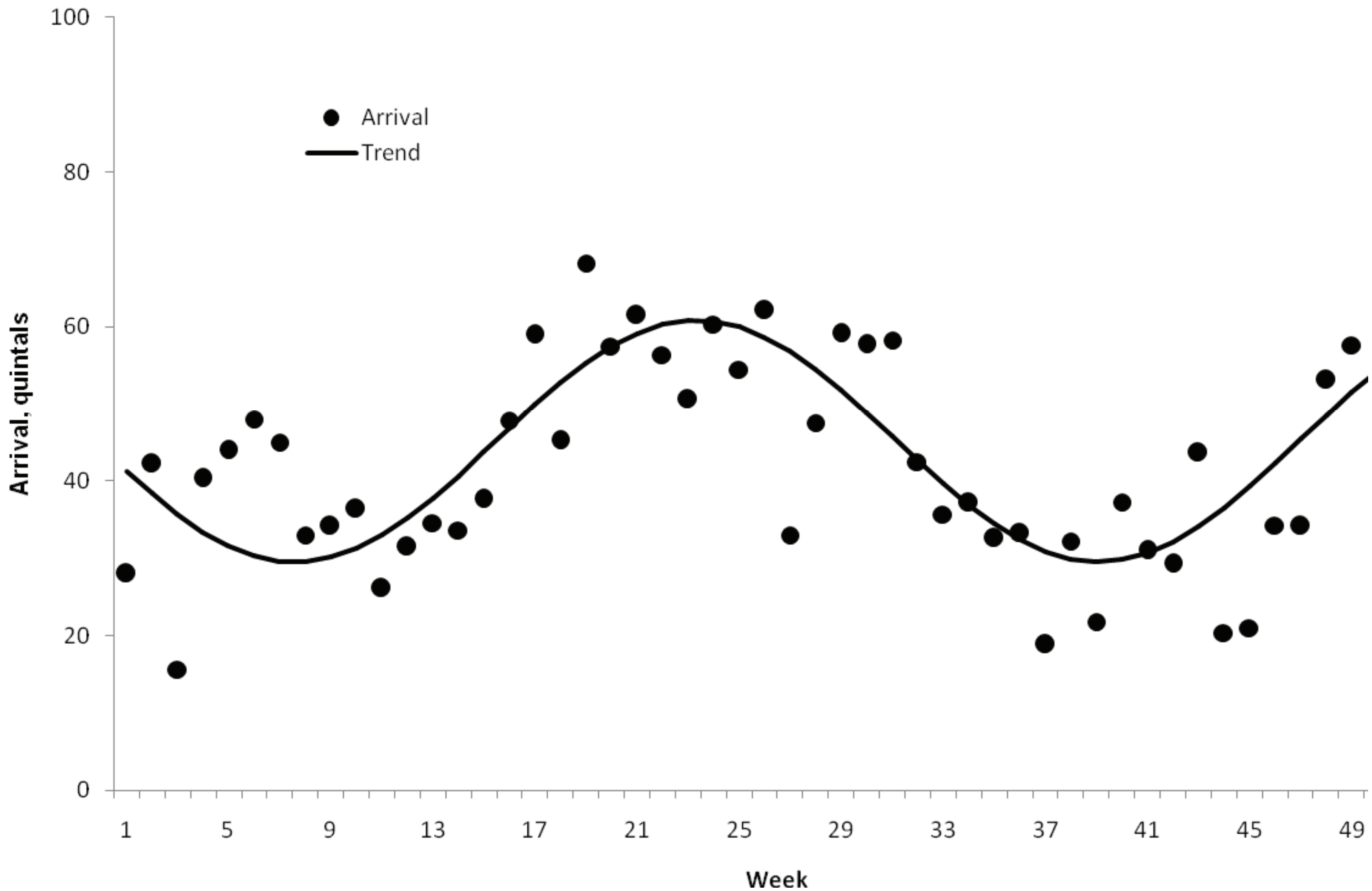


Figure 4. 8: Trend of 2003 weekly arrivals of tomatoes at the Coimbatore market

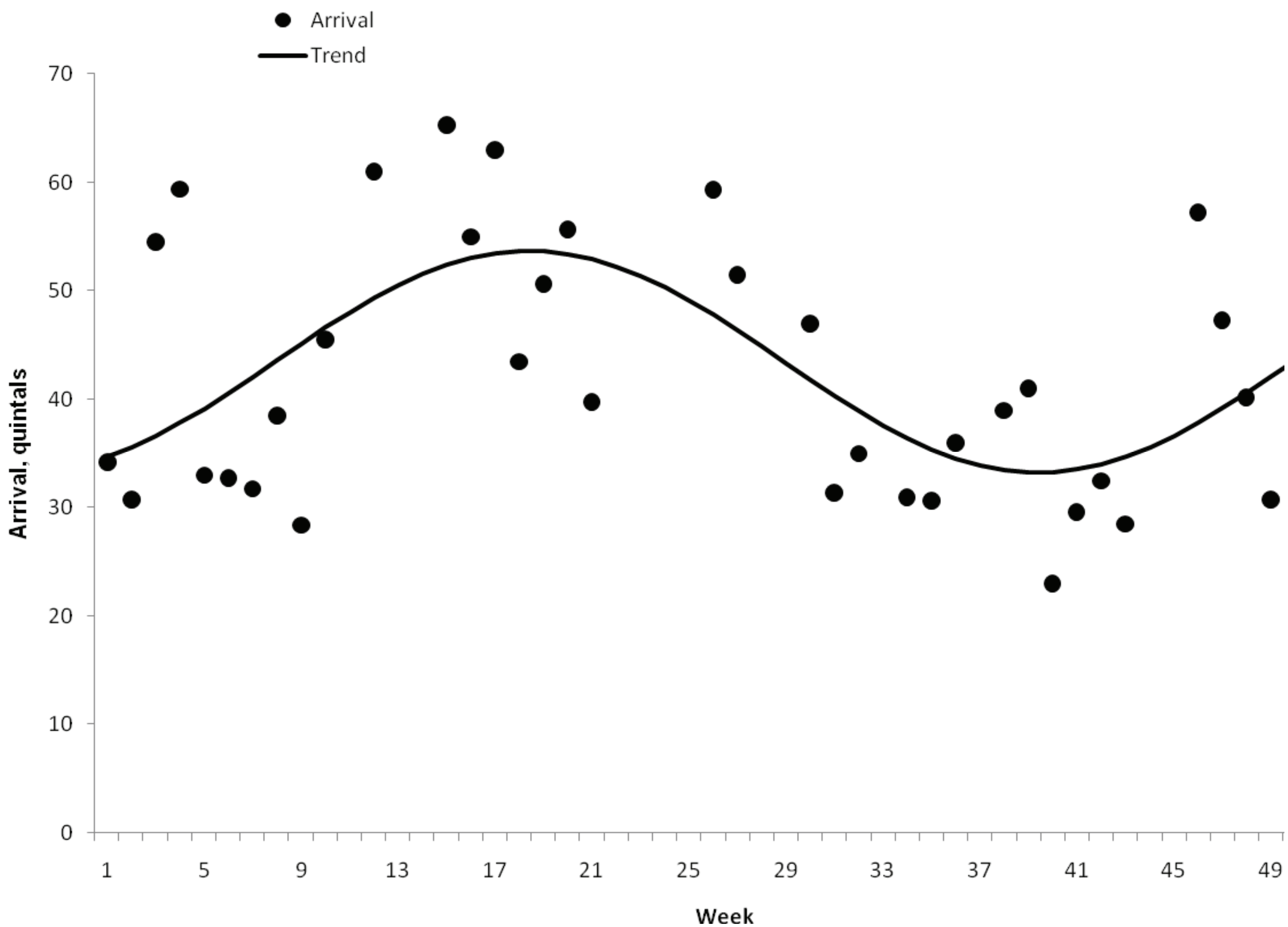


Figure 4. 9: Trend of 2004 weekly arrivals of tomatoes at the Coimbatore market

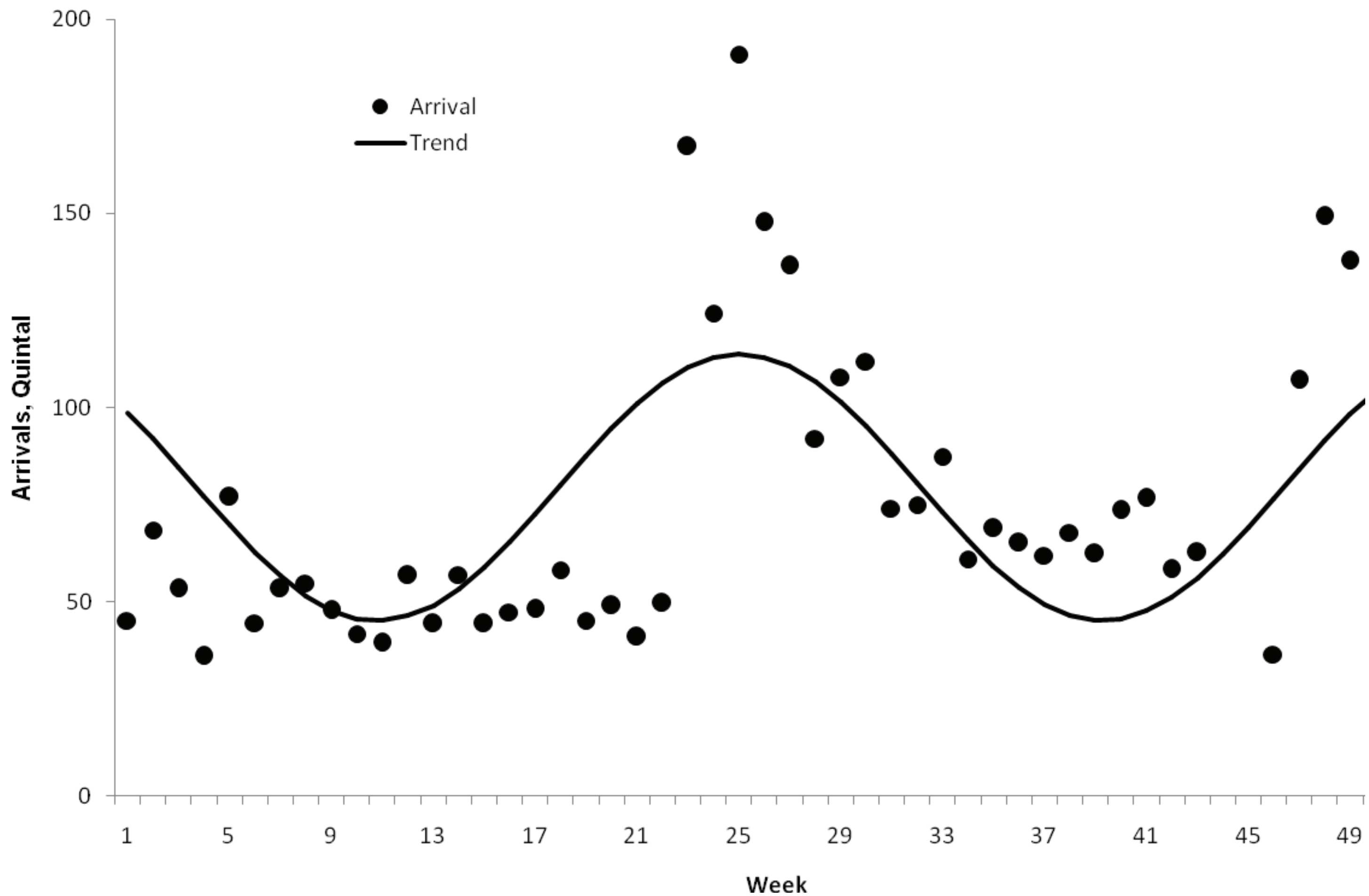


Figure 4. 10: Trend of 2005 weekly arrivals of tomatoes at the Coimbatore market

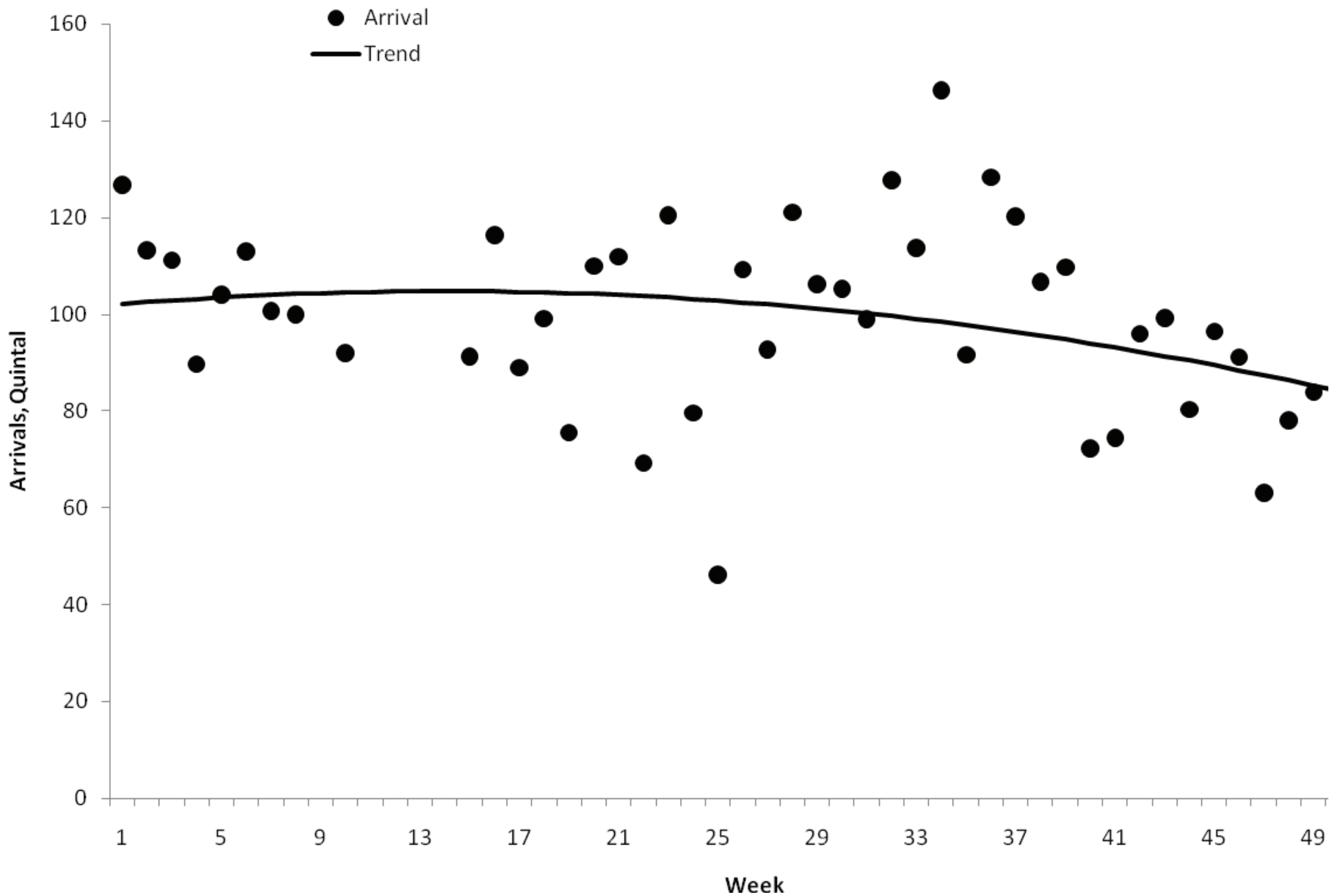


Figure 4. 11: Trend of 2006 weekly arrivals of tomatoes at the Coimbatore market

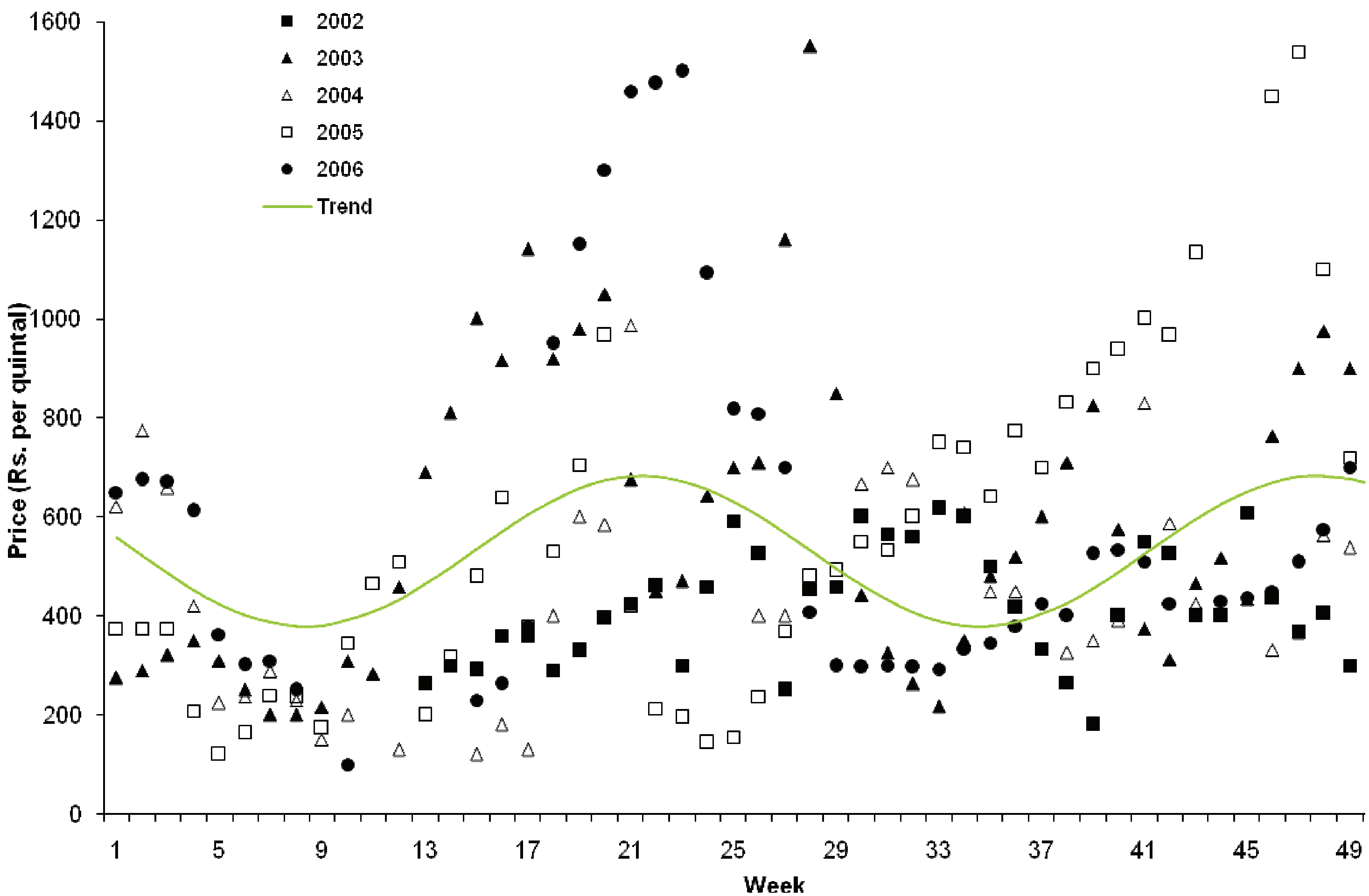


Figure 4. 12: Trend by regression of five years of prices (2002-2006)

Clearly, the pricing of tomatoes was governed by factors that were not limited to the quantity of arrivals of the commodity in the market. Discussions with local farmers, vendors, wholesale dealers, economists and leaders yielded various reasons for this behaviour. The control exercised over the wholesale markets by the dealers (called commission agents in India) was cited as the main reason. The majority of opinions concurred that the price was set by these buyers, who base it on various logical reasons (such as the quantity available at nearby markets, the consumption pattern of the consumers caused by festivals or other special events, bulk orders, etc.) as well as purposes that defied any perceivable economic logic.

However, the observed sinusoidal function that fits the price and arrival data hints at a possible regularity in these transactions. It is not appropriate to arrive at a definite relationship and use the coefficients listed in Table 4.1 for any predictive analysis. But with the use of more extensive market data and introduction of meteorological parameters into the analysis, it would be possible to describe a reliable relationship between the time of the year, and the arrival and pricing of commodities in an agricultural situation governed by seasonal rains and cultural factors.

The empirical function derived from the market data suggests the possibility of a technological intervention. It is certain that a sinusoidal function increases after a dip; this provides an opportunity to benefit economically by deferring the release of the commodity to the market. By intervening at the suitable time (when the price function slides down from the crest and rises again), it would be possible to derive economic benefits.

This hypothesis is also supported by the following observations:

- Most of the farms that supply small markets are small- or medium-sized units whose individual outputs do not significantly alter the volume of arrivals. Hence, a few farmers with the ability to maintain their inventory can withhold their produce without causing any noticeable impact on the market. This consideration is important not in free-market dynamics, but in decision-making of local wholesale buyers.

- During the glut, wholesale buyers rarely offer an economic incentive for a higher quality produce. A premium, if extended, is usually marginal; a rapid transaction without long waiting periods is the only benefit enjoyed by the holders of higher-than-average quality produce. Medium-sized farmers could store their higher-quality produce whilst immediately selling their lower-quality produce on the market. As such, they could sell their high-quality produce when the market prices rise while cushioning their risk with the money made by the sales of lower-quality produce.
- The period between the crests of the price function varies from 10 to 25 weeks (Figures 4.2 to 4.6, 4.12). However, it was observed that the period during which the market price falls below this minimum remuneration is spread over only a few weeks.

Based on these observations, a short-term cold-storage study was suggested to the participating farmers. A portion of the produce harvested during the period was sorted and graded for quality and uniformity, and was placed in a rental cold storage for a period of three weeks. The aim of the study was to test the economic feasibility of a short-term storage strategy for tomatoes. The strategy was also meant to identify the requirements of a cold-storage system that would be appropriate for this purpose.

This study is necessary for several reasons. In India, the prediction of future prices is extremely difficult in the case of common vegetables such as tomatoes, potatoes and onions. The scattered farm base, limited transportation infrastructure, strong external factors that control the markets, and the vital dependence on climatic factors complicate predictions, causing them to be fraught with uncertainties. Under such circumstances, the prospects for high capital-based, long-term postharvest storage strategies are limited among the small- and marginal-farmers who make up a large majority of the supply sources.

The use of cold storage for common horticultural products is almost non-existent in India. Though the country has numerous cold-storage facilities, these are mostly used for high-value, low moisture-content commodities. Potato occupies a majority of the cold stores in the country; its cold storage is usually limited for seed. In the case of onion, traditional storage structures are used in some parts of the country. In warm, dry regions, such structures make use of evaporative cooling and are effective in providing an economical and useful solution for storage. Tomatoes are rarely stored; they are usually sold by the farmers within 24 hours of harvest.

While reports are available on lab-scale experiments to determine the safe temperature for cold storage (to avoid chilling injury to the fruit), there is hardly any market-level information available on the economic feasibility of short-term cold storage of tomato in India. Due to the lack of such data, it is not known if the available commercial cold storages in the country are suited for the adoption of the concept by small farmers.

Economic profitability is the most important factor that influences the decision to adopt a new technology by most farmers. In the case of cold storage of agricultural commodities to defray the market glut, returns and risks involved are controlled both by the uncertainty of the market price and by the perishable nature of the produce. This study was able to demonstrate some of the benefits and limitations that could assist the farmers in deciding whether or not to store the produce, as well as deciding on the period of storage under different conditions.

4.2 Cold-Store conditions

Maintaining a constant storage temperature and relative humidity is considered very important for the cold storage of fruits and vegetables. Air conditions recorded at the commercial cold store during the storage period are graphed in Figure 4.13. It is clear that the manual handling of the refrigeration system, as well as the attempt to maintain the relative humidity by placing water trays, resulted in wide fluctuations. The spread of the conditions is shown in Table 4.2 and in Figures 4.14 and 4.15.

Table 4. 2: Conditions of Storage at the Commercial Cold Store

	Air conditions		**Produce conditions**	
	Temperature °C	R.H. %	Temperature °C	R.H. %
Average	15.77	66.81	15.48	78.27
Standard Deviation	1.11	13.64	0.81	15.71
Maximum	18.66	87.1	17.52	98.6
Minimum	11.77	26.3	13.32	30.75

The effects of such conditions on the stored produce are illustrated in Figures 4.16 to 4.19 (as well as Table 4.2). These values were obtained from the data loggers placed in the centre of tomato crates during the storage period.

The produce crates were transported to the cold store at ambient conditions (28°C to 33°C) without any pre-cooling. The initial period of cooling (pull-down) is therefore believed to be significant for storage. It took 28 hours for the produce to reach the set storage temperature. The values for the conditions in the commercial cold store that are shown in Table 4.2 correspond to those experienced after the initial cooling period.

Similarly, the air and produce conditions at the experimental cold store are shown in Figures 4.20 to 4.26, and compared in Table 4.3.

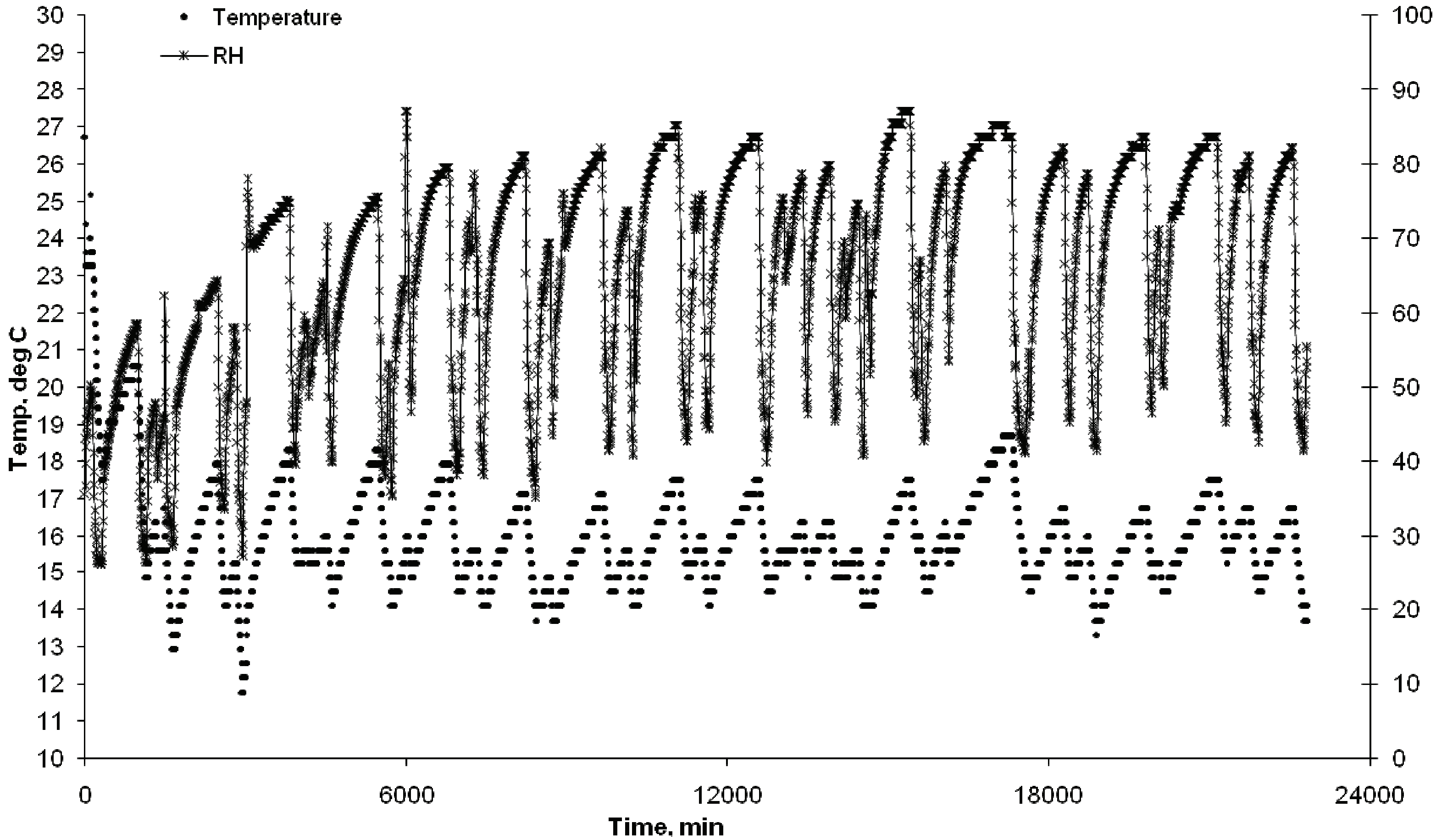


Figure 4. 13 Cold room conditions (temperature and relative humidity) in the commercial cold store

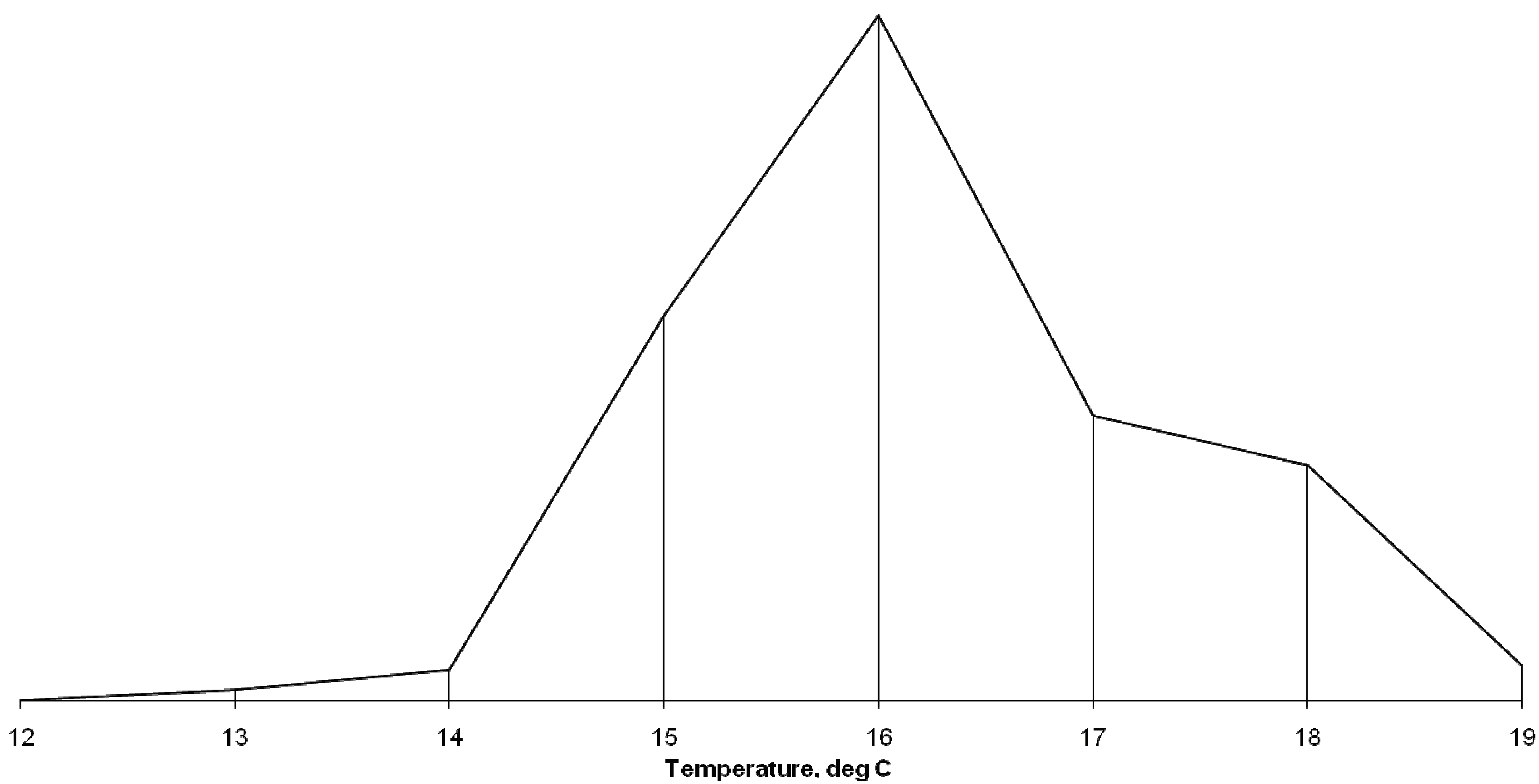


Figure 4. 14: Variation of air temperature at the commercial cold store

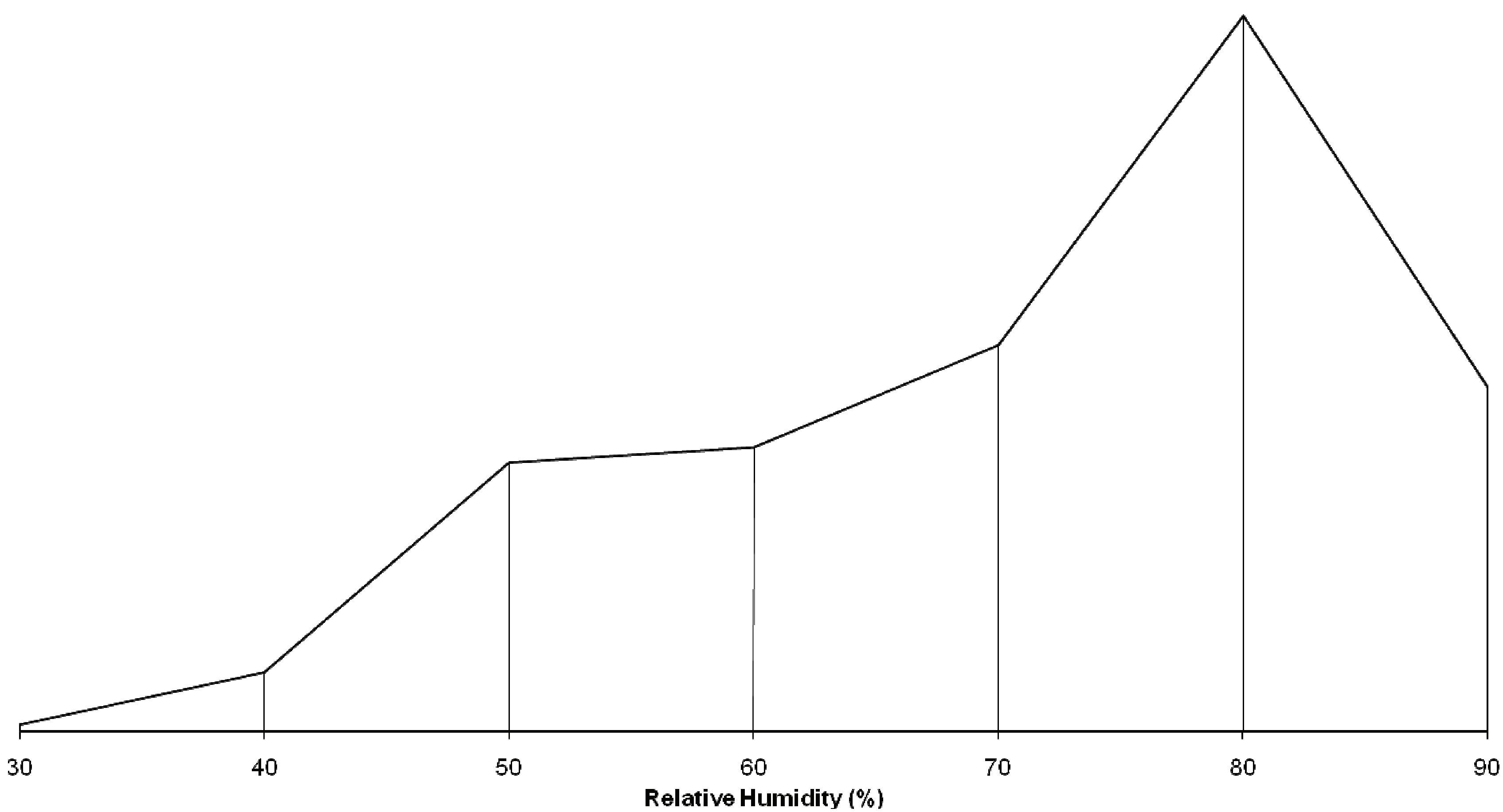


Figure 4. 15: Variation of the air relative humidity at the commercial cold store

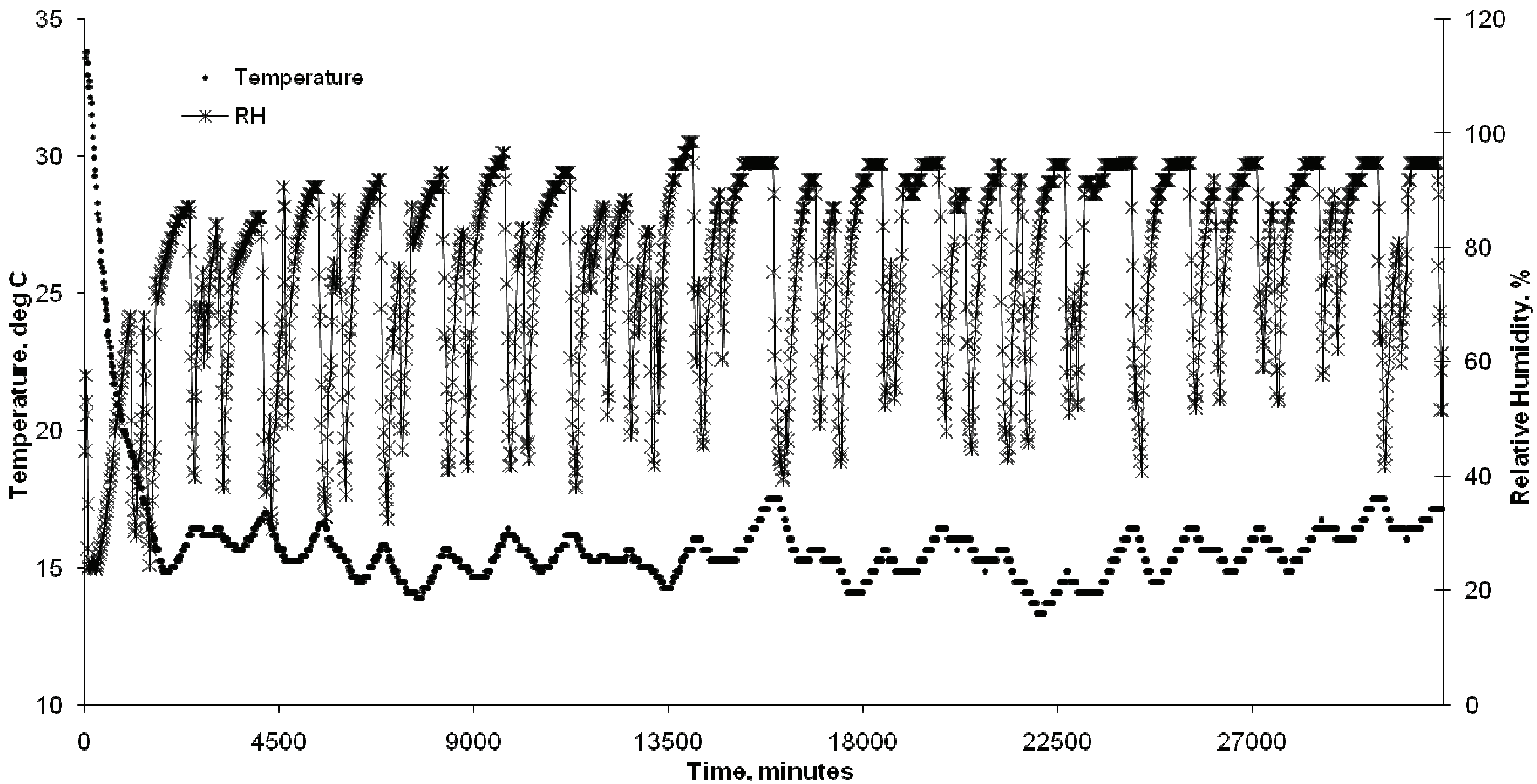


Figure 4. 16 Produce conditions (temperature and humidity) at the commercial cold store

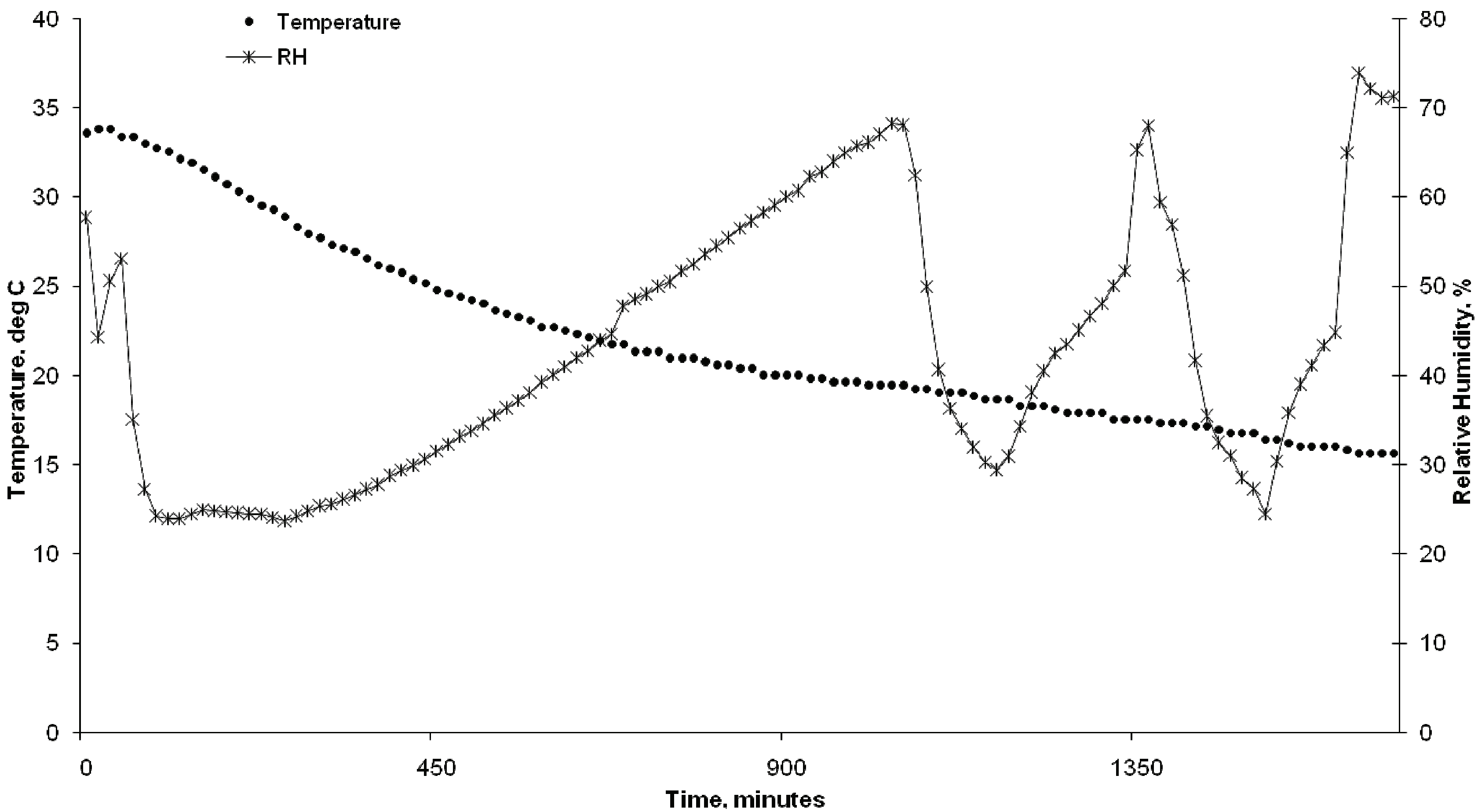


Figure 4. 17: Produce temperature and relative humidity during pull-down at the commercial cold store

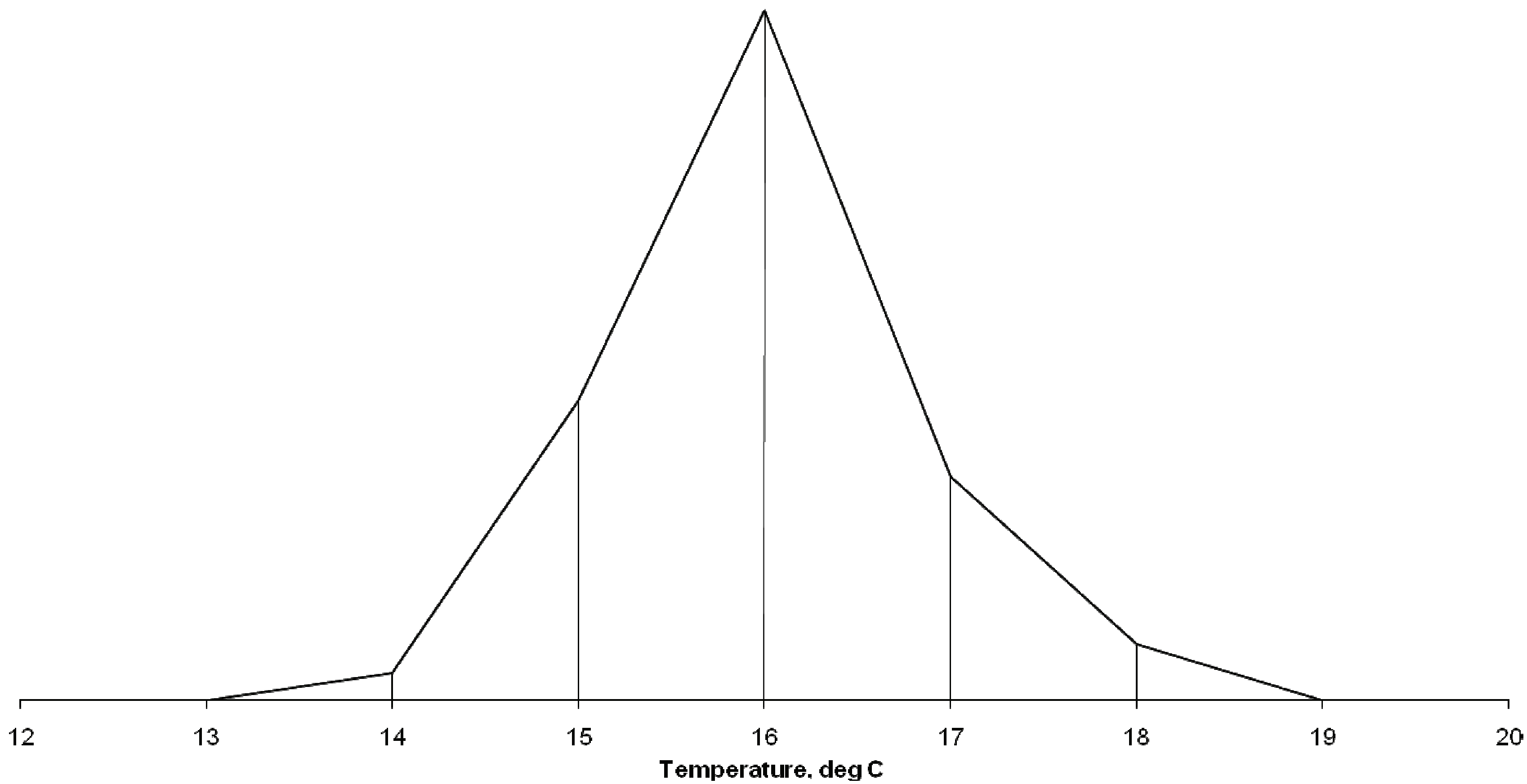


Figure 4. 18: Variation of produce temperature at the commercial cold store

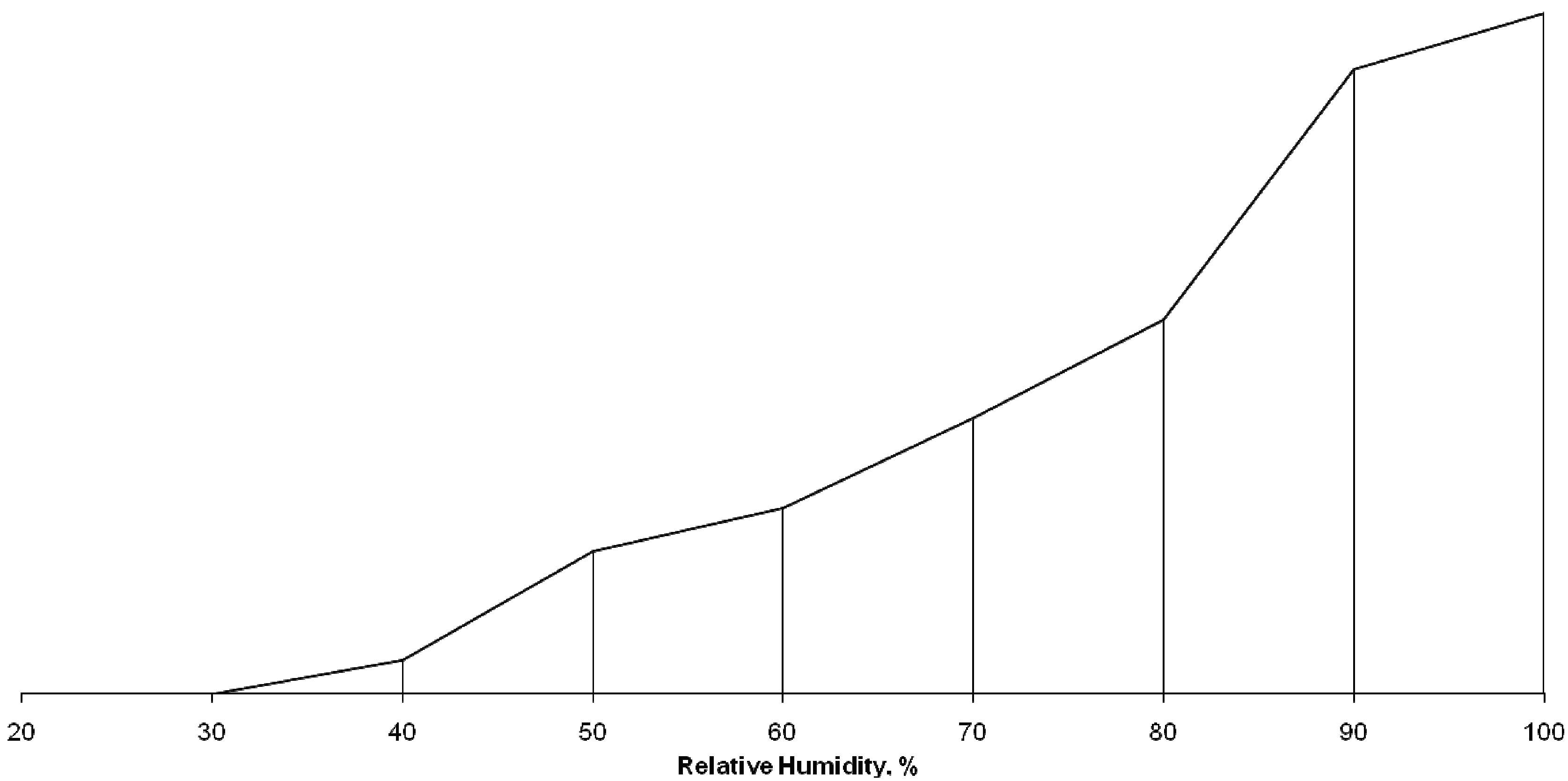


Figure 4. 19: Variation of produce relative humidity at the commercial cold store

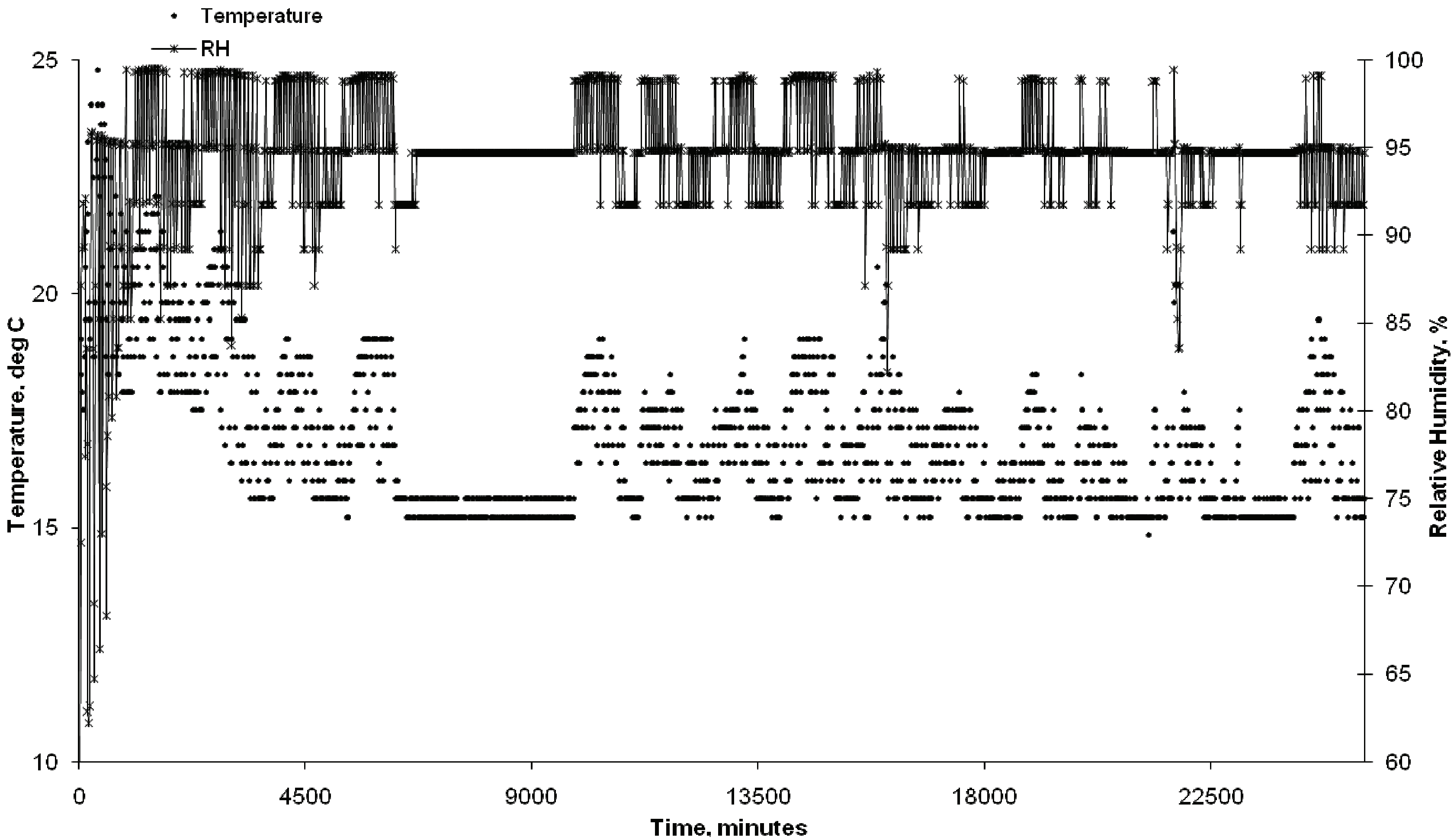


Figure 4. 20: Air conditions (temperature and relative humidity) at the experimental cold store

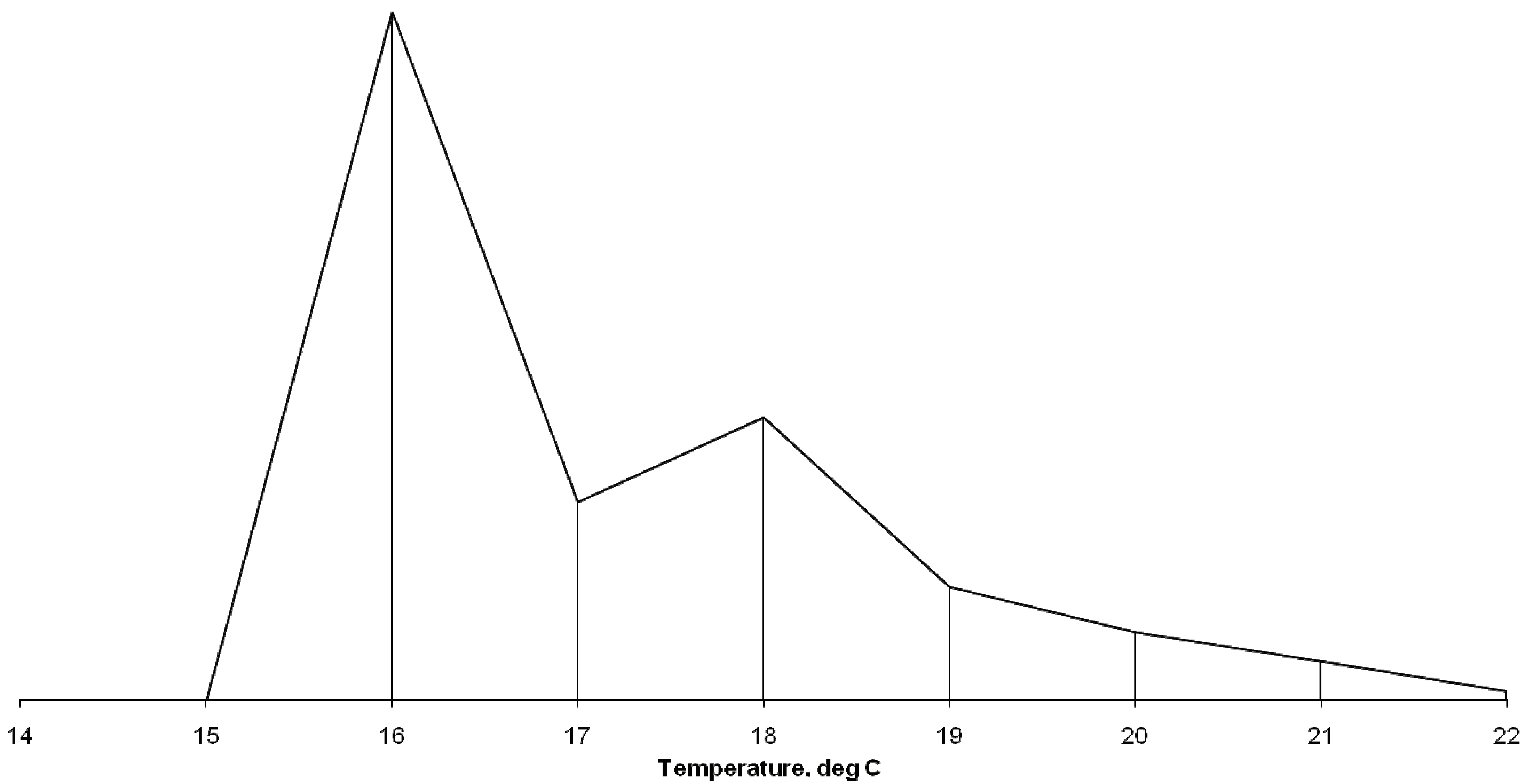


Figure 4. 21: Variation of air temperature at the experimental cold store

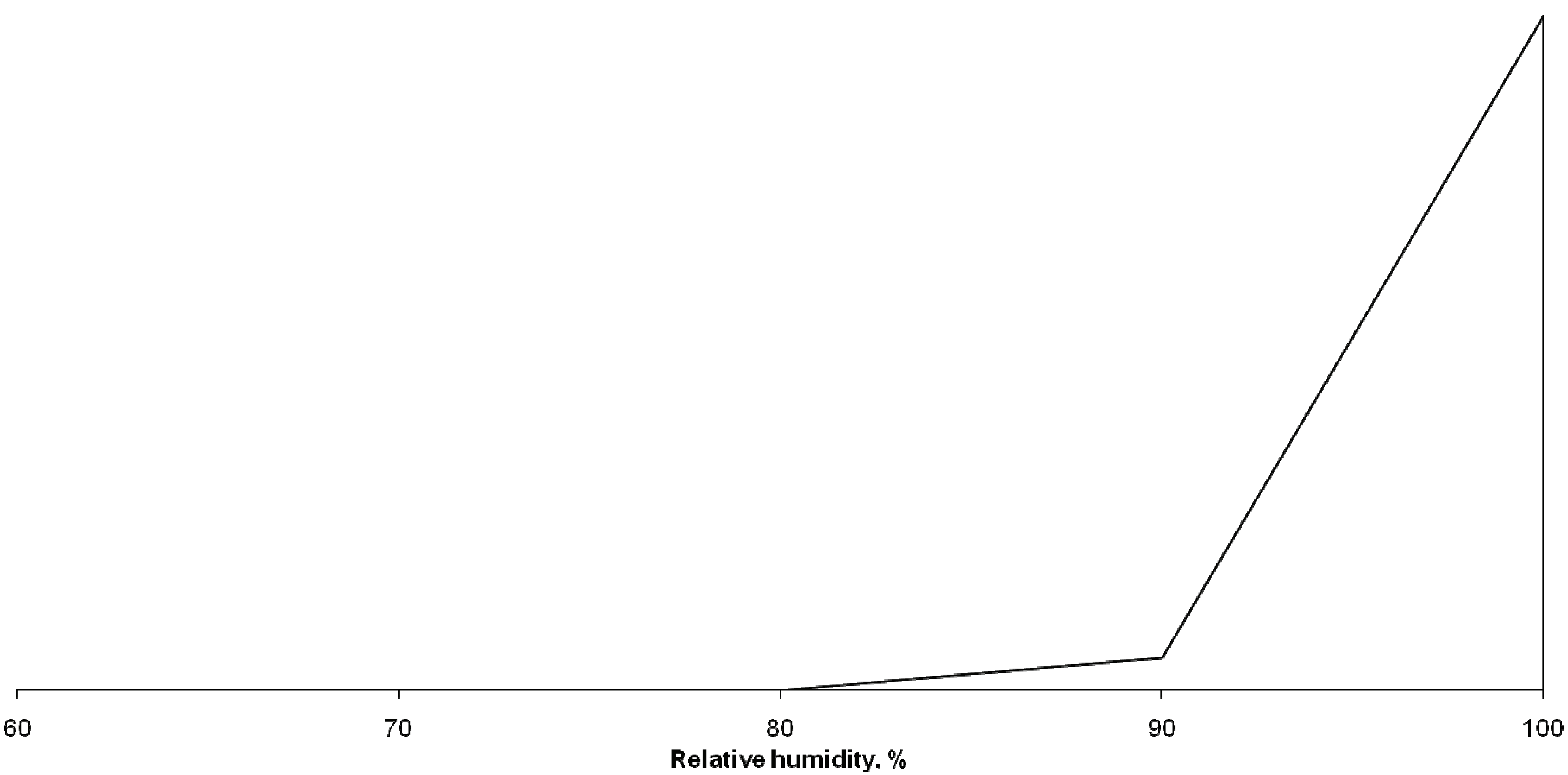


Figure 4. 22: Variation of relative humidity at the experimental cold store

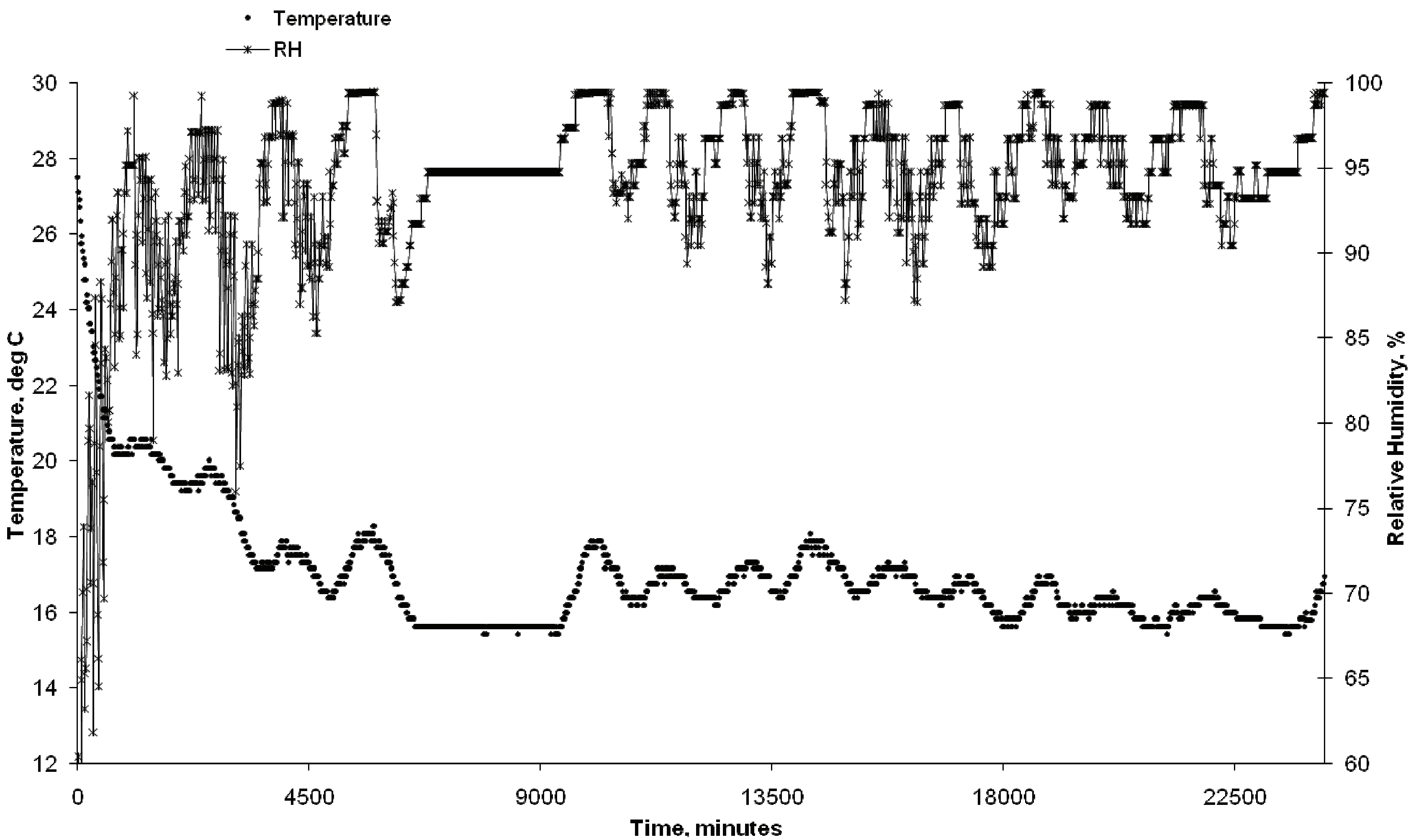


Figure 4. 23: Produce conditions (temperature and relative humidity) at the experimental cold store

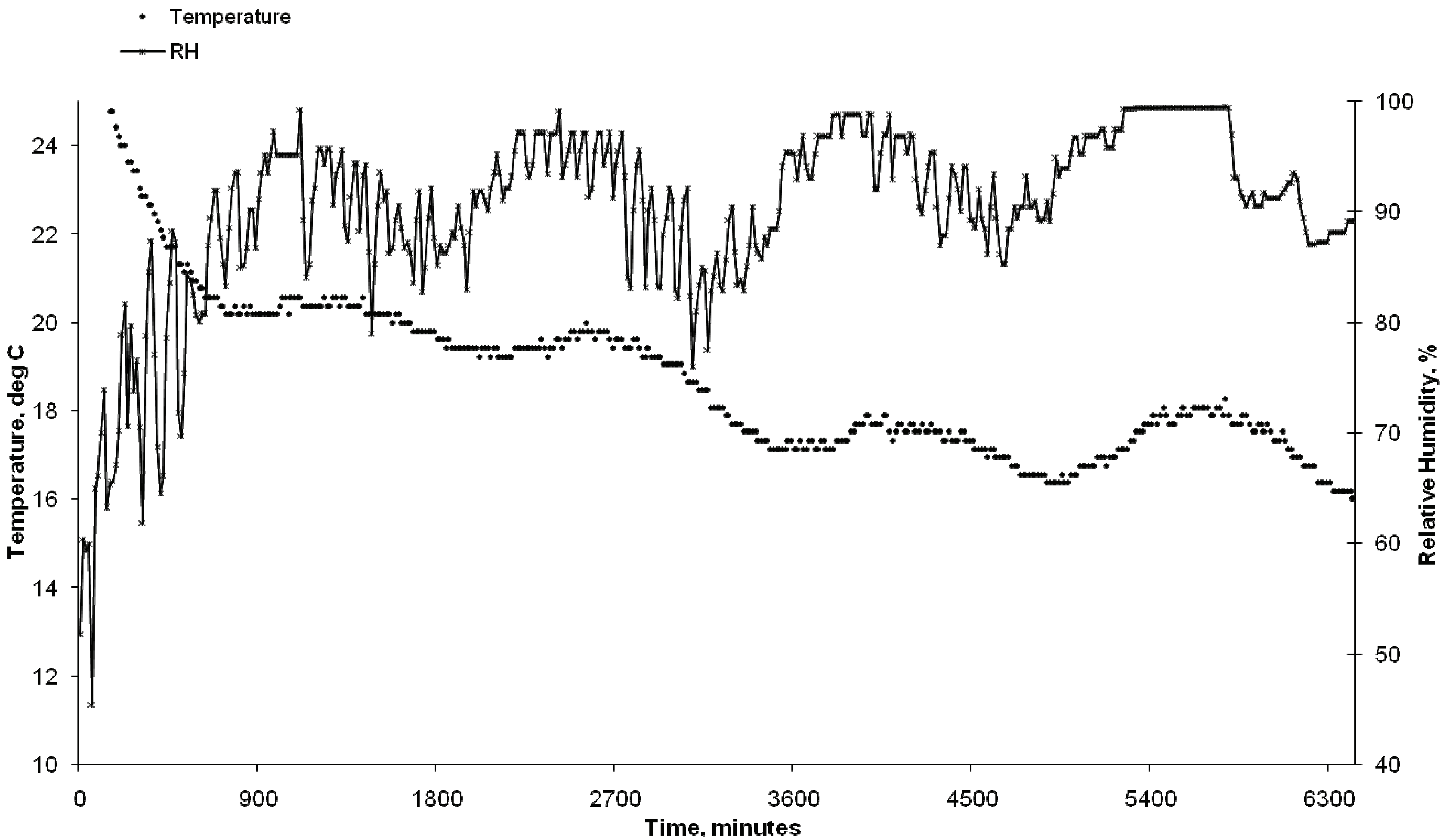


Figure 4. 24: Produce temperature and relative humidity during pull-down at the experimental cold store

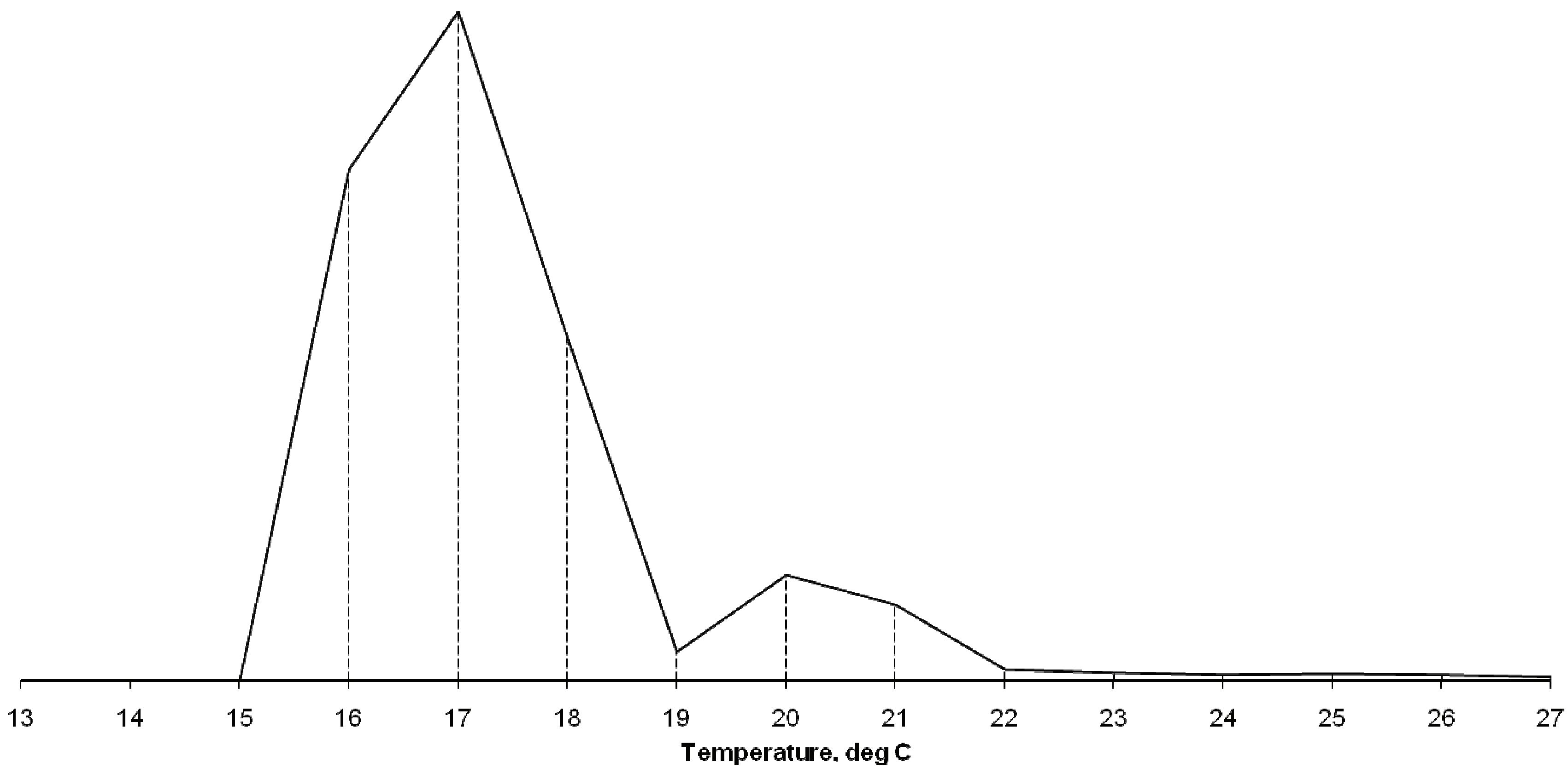


Figure 4. 25: Variation in produce temperature at the experimental cold store

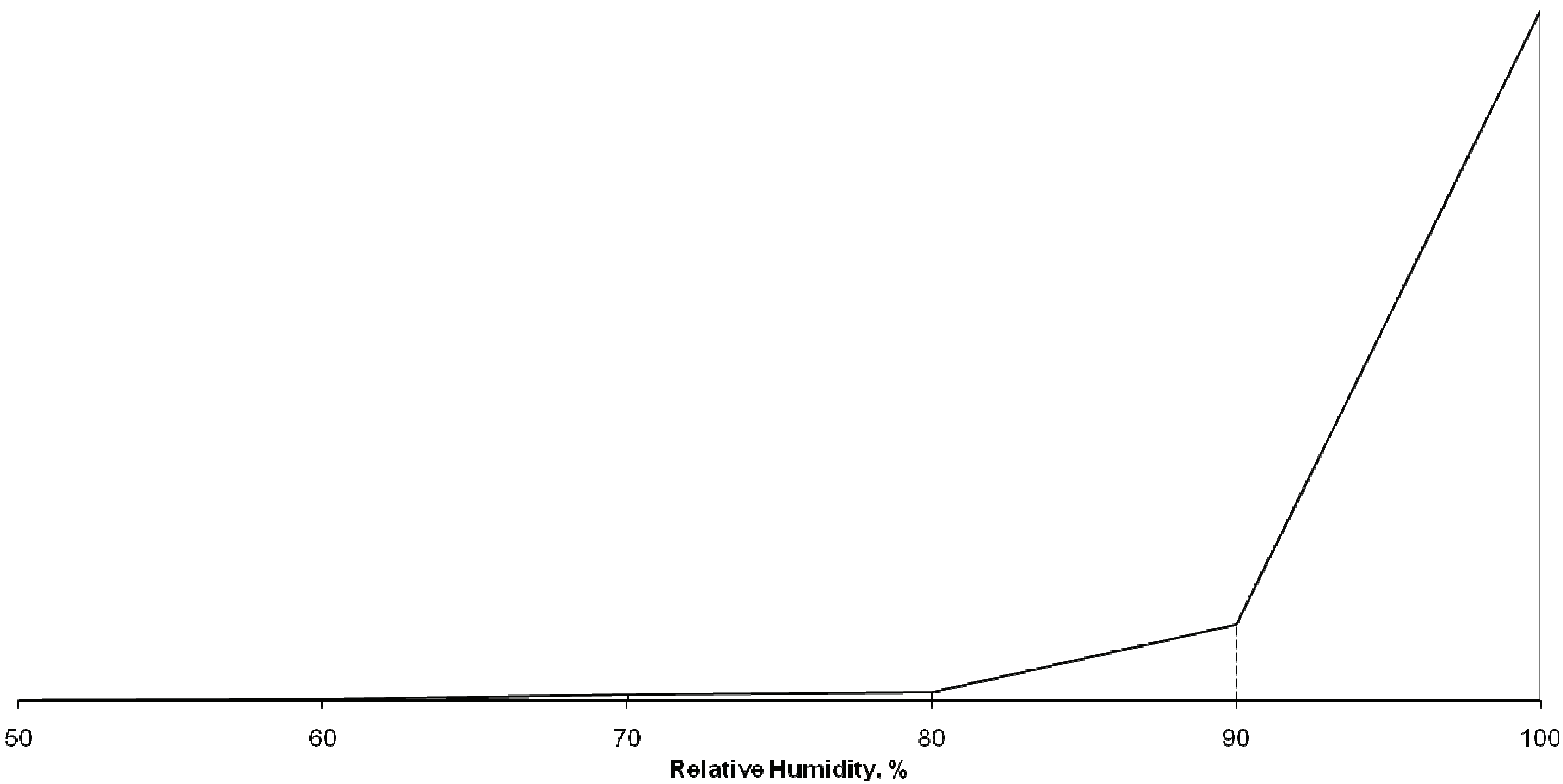


Figure 4. 26: Variation in produce relative humidity at the experimental cold store

Table 4. 3: Conditions of storage at the experimental cold store

	Air conditions		Produce conditions	
	Temperature °C	R.H. %	Temperature °C	R.H. %
Average	16.66	94.74	17.02	94.03
Standard Deviation	1.43	2.66	1.63	5.22
Maximum	22.09	99.5	27.52	99.5
Minimum	14.85	82.2	15.425	45.4

As expected, the experimental cold store was able to maintain the relative humidity at the desired high levels. However, this control was exercised by injecting steam into the chamber. This had serious consequences. The steam not only increased the cooling load on the refrigeration system, but it also led to extensive condensation in the storage chamber.

4.3 Fate of Stored Produce

All the produce maintained at room temperature (control) were spoilt and rendered unmarketable within 72 hours. The damage to the produce was varied; microbiological damage was the major cause, followed by softened and leaky fruits.

The fate of the stored product at the commercial cold store during the period of storage is illustrated in Figures 4.27 and 4.28. The produce was divided into three groups for analysis: marketable produce, spoilage losses and storage losses. Physiological weight loss was also investigated. The physiological weight loss corresponds to the overall reduction in weight due to the loss of moisture during produce metabolism. The storage loss refers to a lower quality produce resulting from various transportation, handling and storage-related changes. These changes include shrinkage, skin shrivelling and softening of the fruit. Farmers sorted the storage losses from the spoiled and marketable fruit; the resulting fruit represented a grade of produce that would never be sold at the market during the seasonal glut. The spoilage losses represent the total loss of the produce due to microbiological infestations.

The change in marketable produce and spoilage losses was statistically significant over the storage period. On the other hand, the change in storage losses was not statistically significant over the storage period. The differences in the physiological weight loss were also not statistically significant over the storage period.

Figure 4.29 illustrates the fate of the produce stored at the experimental cold store. The stored produce was emptied out during two consecutive days at the end of the study. The performances of the stored tomatoes after 18 days of storage at the commercial and experimental cold stores are compared in Figure 4.30. None of the differences between the two locations are statistically significant.

It is interesting to note the lack of significant difference in the losses observed between the two cold storage locations, as well as the differences during the period of storage at the commercial cold storage. The changes in the physiological weight loss appear to occur very early during the storage period. In hindsight, it would have been interesting to measure the physiological weight loss of the same set of samples more frequently during the first three days of storage. As seen in Figure 4.17, the produce reached the desired storage temperature after 28 hours in the cold store. This initial pull-down period represents the removal of field heat from the produce. It could also result in a loss of moisture from the surface, as the relative humidity surrounding the fruit is not well established at the set point. If this assumption is valid, then it is also implied that the subsequent storage conditions, in particular the variations in relative humidity, did not result in any significant loss of moisture from the produce. This implication is reinforced by the comparison of the results obtained at the experimental cold store, where a high relative humidity was successfully maintained during the storage period. The differences in the physiological weight loss between the two locations (Figure 4.30) are not statistically significant.

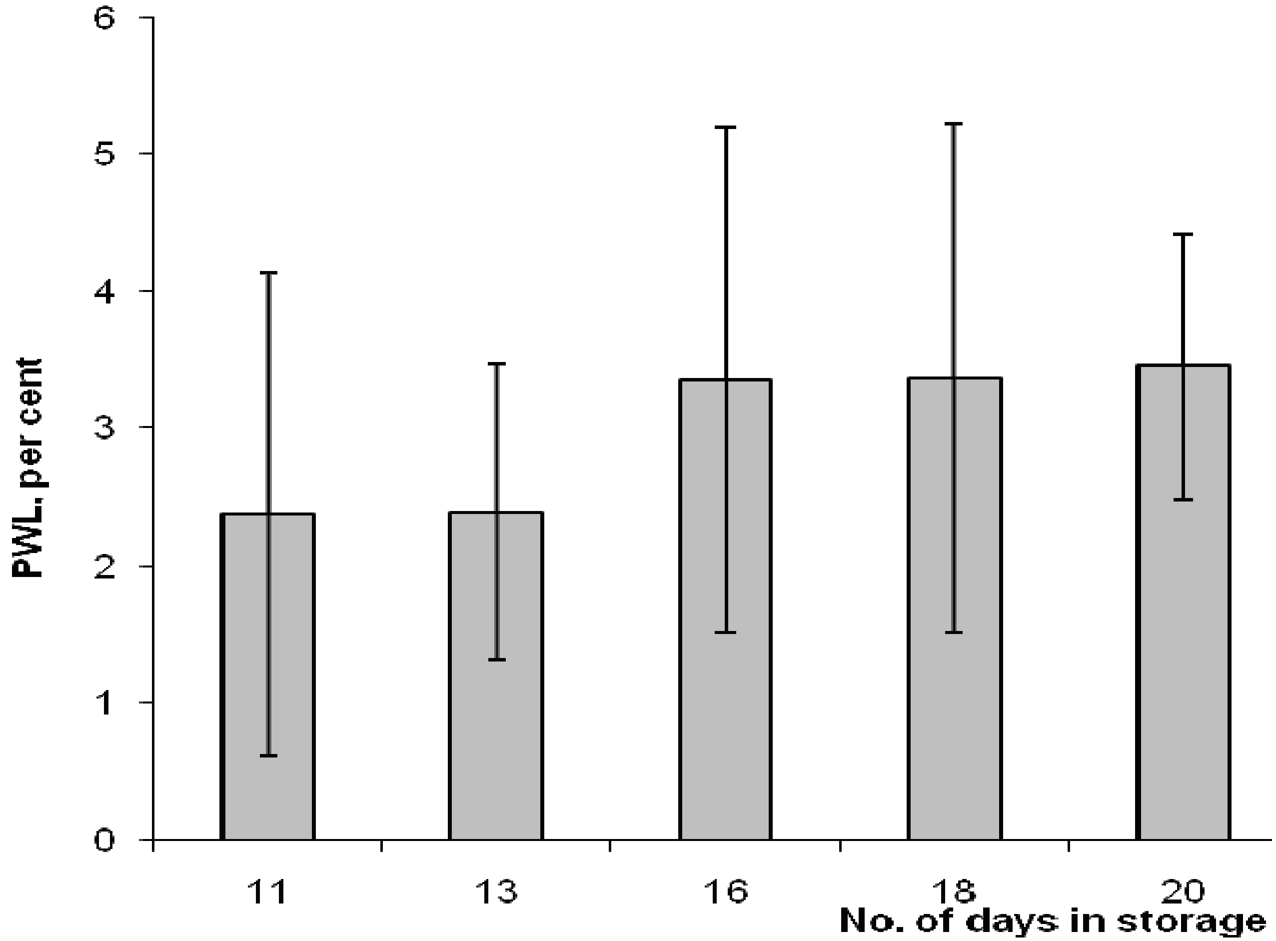


Figure 4. 27: Physiological weight loss at the commercial cold store

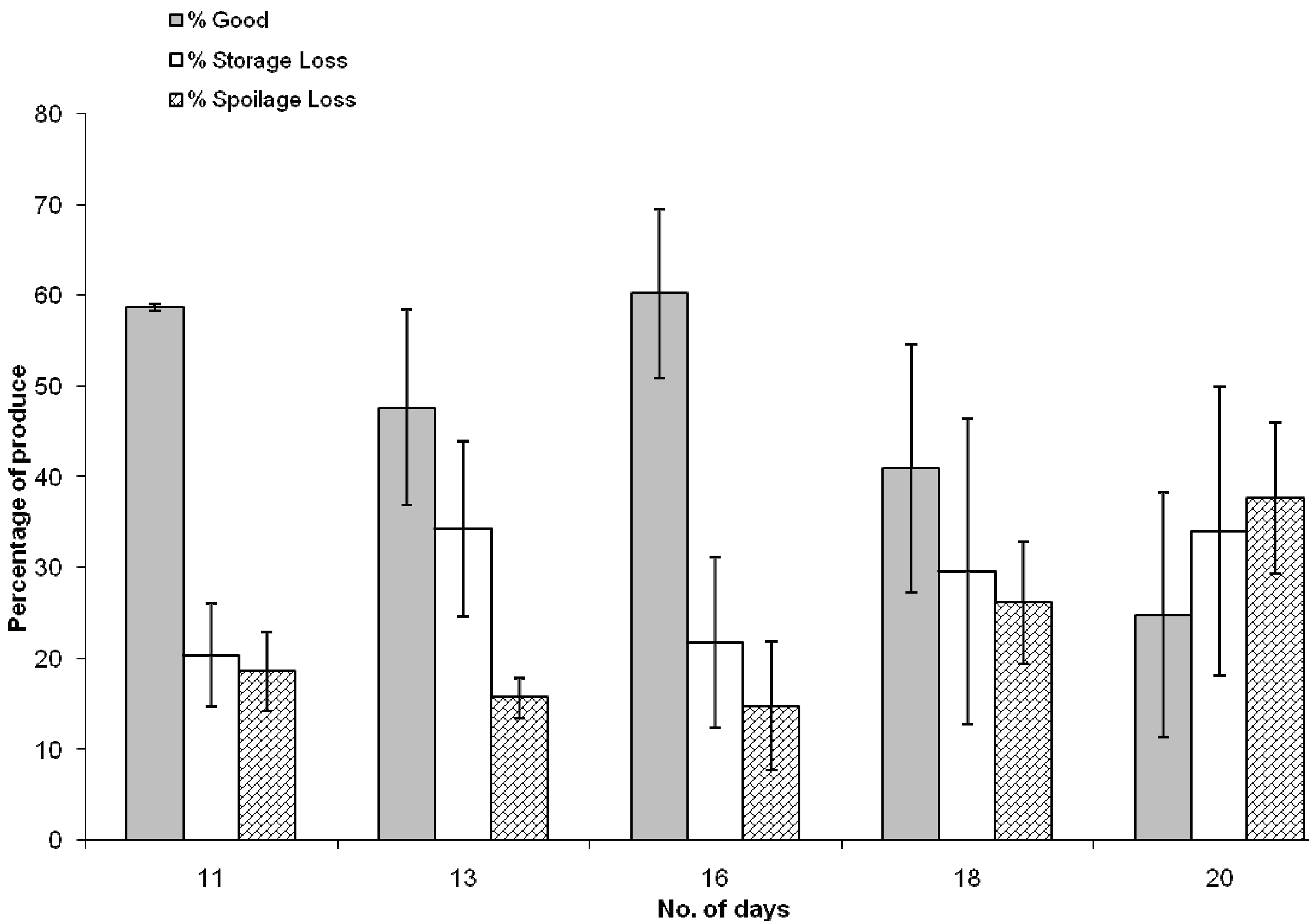


Figure 4. 28: Fate of the stored produce (per cent storage loss, per cent marketable, per cent spoilage loss) at the commercial cold store

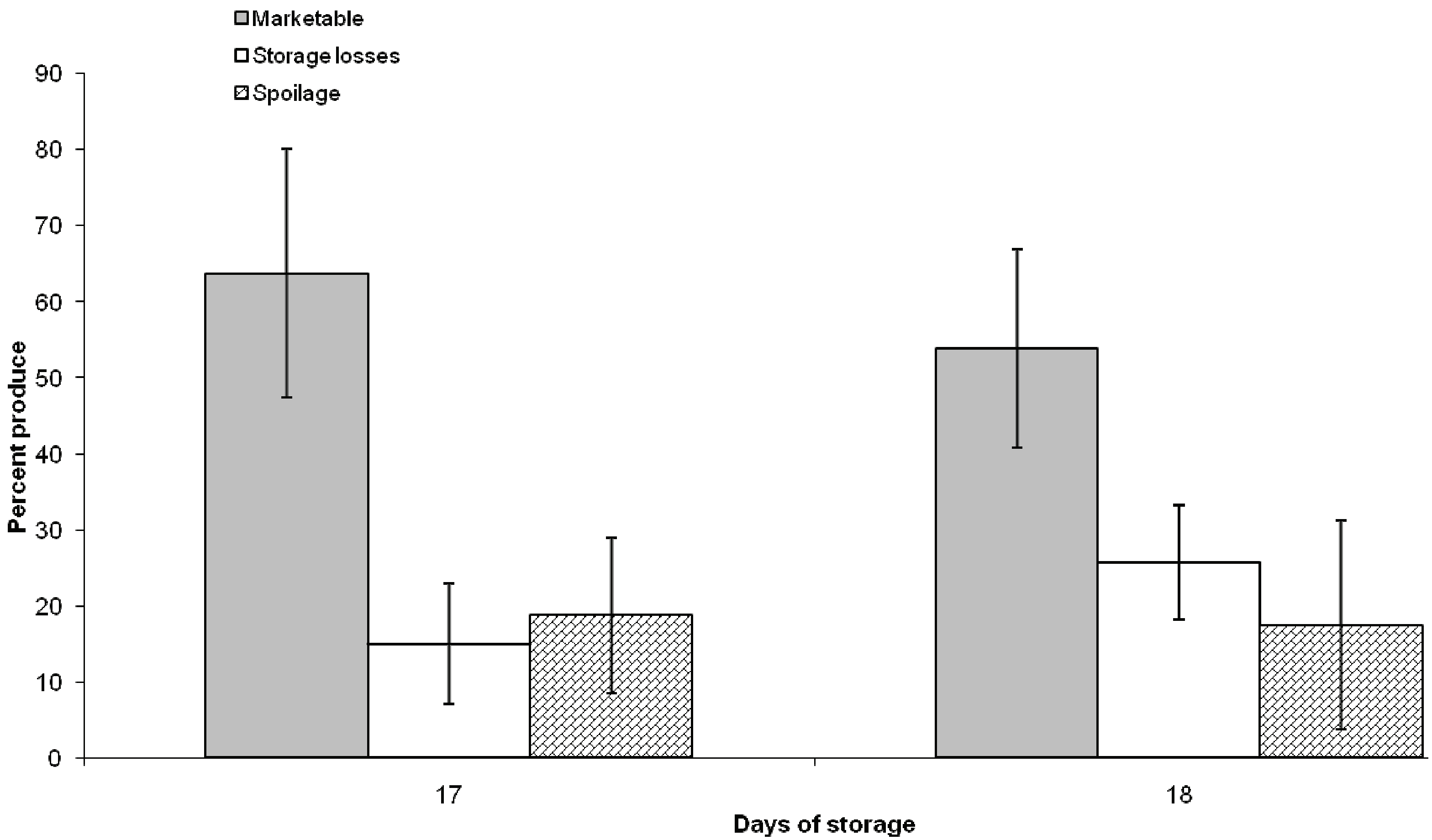


Figure 4. 29: Fate of the stored produce (per cent storage loss, per cent marketable, per cent spoilage loss) at the experimental cold store

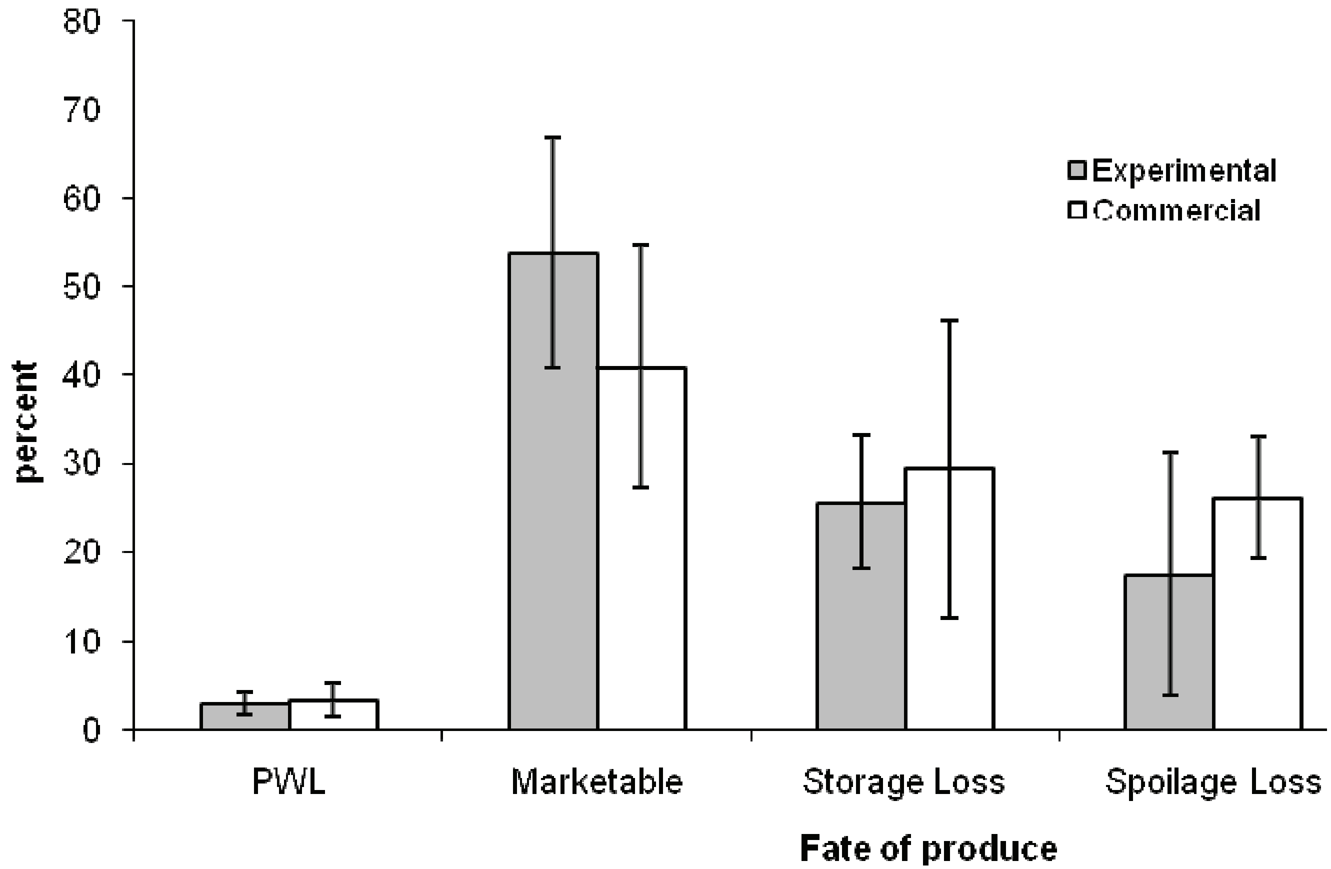


Figure 4. 30: Comparison of the fates of the produce (per cent weight loss, per cent marketable, per cent storage loss, per cent spoilage loss) between the experimental and commercial cold stores

The lack of differences in physiological weight loss between the two storage locations is an important factor in designing of cold-storage structures for short-term storage. The mechanical control of the relative humidity is expensive and complicated. The economic benefits derived from the long-term cold storage of commodities justify the use of sophisticated systems to maintain the desired R.H. in such facilities. However, a small, short-term cold-storage facility meant to assist a small or marginal farmer needs to be simple and cost-effective. A passive system can be effectively used under such conditions, provided the water is clean and sufficient time is provided for the equilibration.

The proportion of storage-induced losses was higher at the commercial cold store, but the differences were not significant compared with similar losses at the experimental cold store. The fluctuations in the temperature and relative humidity at the two locations had a similar effect on the produce. This observation is once again an encouraging factor for the development of cold-storage structures with inexpensive controls that can maintain the conditions within an acceptable bandwidth around the set point.

The spoilage losses at the commercial cold store were higher compared to those at the experimental cold store. However, this difference was not significant. The spoilage losses are the most important factors in controlling the economic feasibility of a short-term cold-storage intervention. It should be noted that the produce was sorted and graded before being moved into the cold store; it did not exhibit any visible signs of damage at the time of harvest. However, every crate of tomatoes had diseased or spoilt samples within a few days of storage. In the farmers' conventional marketing practices, this damage is not important, as the produce sold at the market the day it is harvested, and is usually purchased by the consumer within 48 hours. The manifestation of the damage occurs after this period; the risk is therefore transferred either to the retailer (who procures the produce from a wholesaler) or to the consumer. By opting for cold storage, the farmer takes on this risk, which needs to be minimized by adopting suitable production and management practices.

4.4 Energy Requirements

The energy required for cooling the produce was calculated based on the weight, the observed temperature profile and values for specific heat and respiration heat obtained from the literature. The estimated energy requirement during the temperature pull-down was compared with the actual energy consumption as recorded at the experimental cold store and shown in Figure 4.31. The energy consumption was found to be almost twice the theoretical requirements. During a 17-day storage period (more than 400 hours), the energy consumption of the experimental cold store was recorded as 745.29 kWh. The estimated energy requirement was 56.88% of the actual electrical energy used in the study. This observation could be used for estimating the actual energy requirements for designing a cold store. However, the excess energy that was introduced into the experimental cold chamber by injection of steam (to maintain the relative humidity) needs to be discounted.

One of the major hurdles to the use of cold stores in India is the availability of electrical power. As a net energy importer with insufficient electrical power-generation facilities (total generation capacity of 0.13 million MW with energy shortage of 7.1% and peaking shortage of 11.2%: *Ministry of Power, Government of India*), the challenge of providing sufficient power to match all the industrial requirements in the country is enormous. The bulk of the electrical power consumption in agriculture is for operating irrigation pumps. The agricultural sector is responsible for about 23% of the national energy consumption, and does so at a highly subsidized price. Commercial cold storages are levied the highest tariffs in the country (about 9 times the price of subsidized agricultural price). But more than the cost, it's the availability of a reliable power supply that hinders the development of this sector. Clearly, the technological options in such conditions will have to be based on alternate energy sources. Solar power and biomass-based energy are two promising options.

The average insolation in most parts of India ranges between 4.44 to 6.29 kWh per m^2 per day (NASA, 2007). In the South Indian state of Tamil Nadu, the value is about 5.5 kWh per m^2 per day. The theoretical potential of the country is estimated to be 5,000 TWh *per annum* (capacity of 600GW). Photovoltaic conversion of the incident energy into electrical energy is the most common means of harnessing this resource. The use of photovoltaic power generation to operate vapour-compression cooling systems has been attempted (Rudischer *et al.*, 2005). However, solar energy can be used for direct heating in absorption refrigeration systems (Stürzebecher *et al.*, 2004; Kimura, 1992). Stürzebecher *et al.* (2004) discuss the operation of two units, one of which is a small 1kW system. The finding was that it was possible to operate decentralized, small cold-storage depots by solar cooling.

One of the main requirements of sorption systems has been a high-temperature power input. In the case of solar sorption systems, this leads to a major drawback: high initial investment on equipment, in particular high-performance solar collectors. The other factor that keeps the cost of sorption refrigeration equipment high is that most of it is exclusively made-to-order (Stürzebecher *et al.*, 2004). However, this is a factor that could change favourably as the technology becomes more widely adopted.

A much simpler approach to adopting sorption refrigeration systems with high temperature inputs would be of using biomass-based energy. The annual production of herbaceous biomass in India is about 1,130 to 1,400-million tonnes, and the energy value of agri-residues and other waste is estimated to be about 5.14 EJ. The projected total biomass energy potential in 2010 is 8.76 EJ (Ravindranath *et al.*, 2005). With a large population of cattle in the country, there is also an enormous potential for the production of biogas that could fuel such applications (an estimated power of 17,000 MW).

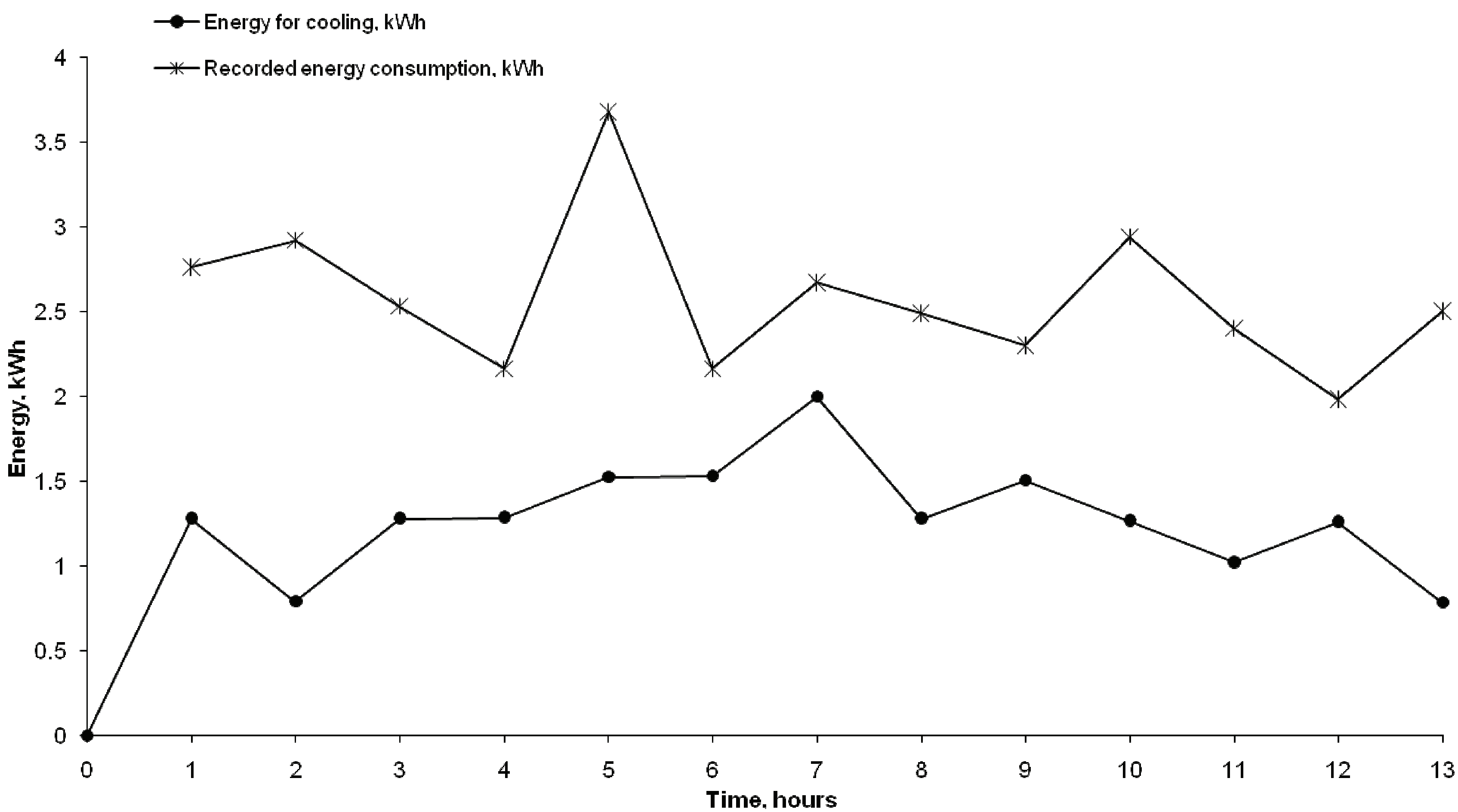


Figure 4. 31: Comparison of energy consumption and refrigeration load

By using these alternative sources to provide heat input, on-farm sorption systems could be envisioned for cooling and storage applications. These could be used for a wide range of products, thus spreading the initial investment over several income-generating activities. This is important in the establishment of a cold chain (the refrigerated continuum of pre-cooling, handling, storage and transportation) in the country, since one end of the chain needs to be anchored near the point of production, easily manageable and sustainable. Sorption systems based on alternative energy sources appear to possess the required characteristics to suit this role. The use of simple evaporative cooling structures on smaller farms to achieve the initial cooling or very short-term, temporary storage could also add to this initiative.

4.5 Economic Benefits

Based on the data obtained from the fate of the produce in the commercial cold store, an attempt was made to assess the economic feasibility of the exercise by the farmers. The availability of the marketable portion of the stored produce at different periods during storage was obtained by a linear relationship fitted to the observed data points. Based on the predicted availability of marketable produce and the storage-related costs (Table 4.4), the market price for the commodity that would be necessary to break even was calculated for each day during a 25-day period (Figure 4.32). The actual market prices for tomato on the days corresponding to the storage are also shown.

Table 4. 4: Parameters used for predicting the marketable produce during storage and the corresponding break-even market price required

Parameter	Value
Initial weight of the produce placed in the cold store (kg)	100
Production cost of tomato (Rupees per kg)	3.50
Added transportation cost to the cold store from the farm (Rupees per kg)	0.15
Added labour cost for movement of the produce into and out of cold storage (Rupees per kg)	0.05
Rental cost for cold storage (Rupees per kg per day)	0.05
Coefficients of the linear equation used for prediction of marketable produce ($y=mx+c$) where y is the percent produce available on day x	m = -3.1122 c = 95.14

Clearly, the cold storage option does not promise any economical benefits without a rapid rise in the market price of the commodity, coinciding with the storage period. The main factor that influences the economic feasibility of the exercise appears to be the large proportion of produce lost during the period. As discussed earlier, the microbial damage occurring in the produce during storage is not a factor that seems to be influenced much by cold store conditions. However, it increases significantly during storage and directly reduces the amount of marketable produce as the period increases. By controlling this factor, the exercise could be made beneficial, as shown in Figure 4.33. The slope of the predictive curve was reduced by different levels to illustrate less damage and loss. The corresponding changes in the predicted market price are compared to the actual market price. At the lowest reduction level (of 1.5% per day), the benefits of storage appear more achievable.

The sizeable influence of microbial damage on the shelf-life points to the requirements that need to be addressed when considering technological options in the Indian situation. Many have opined that the huge amount in losses of fruits and vegetables in India are due to gaps in the cold chain (Maheshwar and Chanakya, 2006). This study shows that the cold chain is only one major part of a set of postharvest solutions that should be adopted as a package. In this case, produce entered storage with incipient infections that could have been due to poor production or handling conditions. For farmers to benefit from cold storage, following good agricultural and management practices (GAP and GMP) are essential in order to produce a commodity that will benefit from value addition (cold storage) to its maximum extent. However, the lack of GAP and GMP is not a limiting factor when farmers market their fresh produce in the conventional same-day practice. The potential microbial infections are not perceived by the consumers or by the market officials, and therefore do not disadvantage the farmer. In most cases, because of the short life-cycle of a product in the market, the drawback is rarely recognized at all.

The other significant component in this solution package is pre-cooling. Rapidly removing field heat to reduce the fruit's metabolism is an essential part of the cold chain. Tomatoes in this study were placed under high-temperature conditions for more than three hours during sorting, packaging and transportation. Even at the cold store, the produce stayed at higher temperatures for more than ten hours during the initial pull-down period. The produce reached the set storage temperatures of 15°C after nearly 24 hours following harvest. This period is sufficient to cause significant microbiological damage that was further advanced during storage, though at a lower rate.

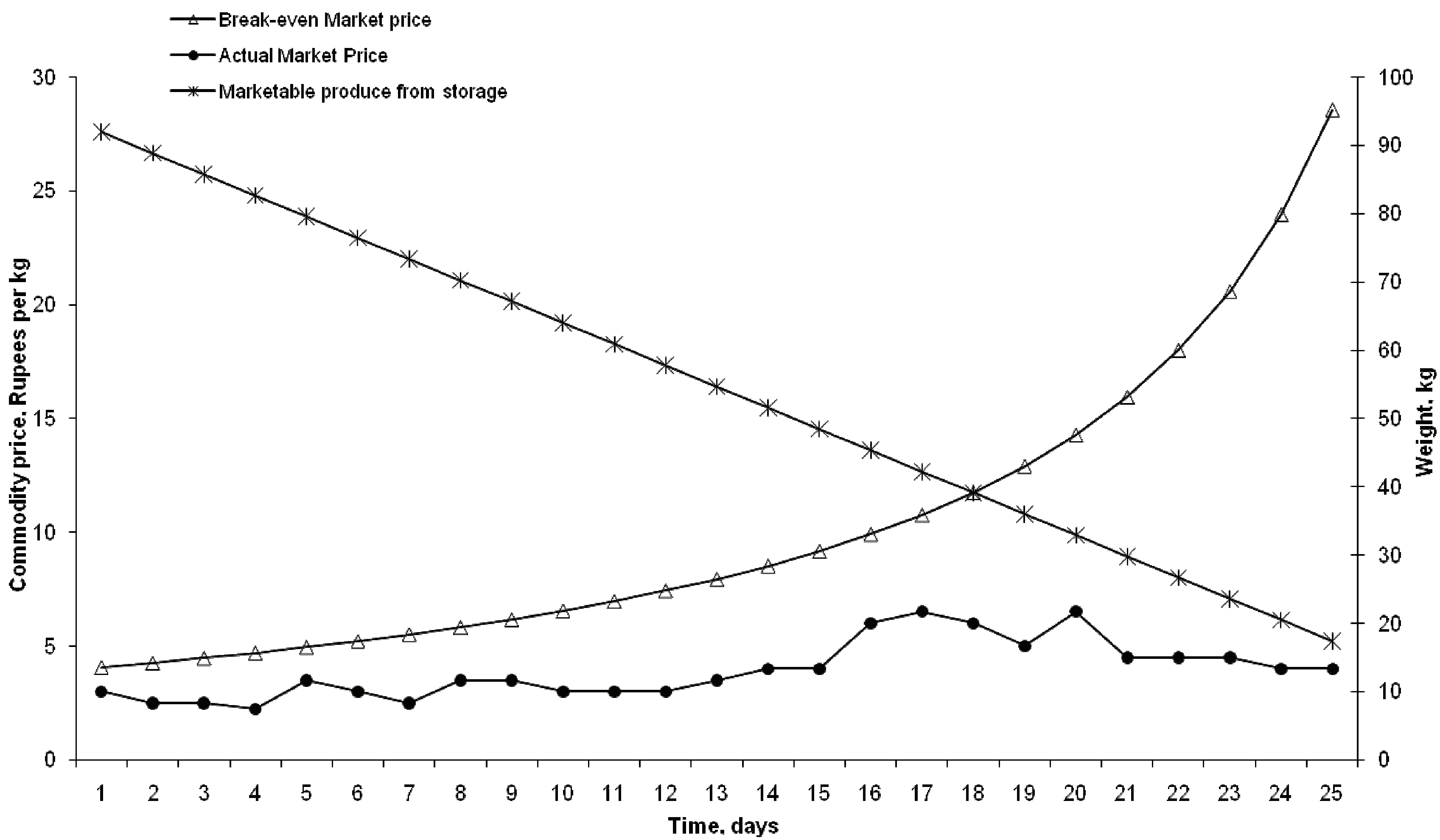


Figure 4. 32: Prediction of release time of the stored tomatoes onto the market for profitability

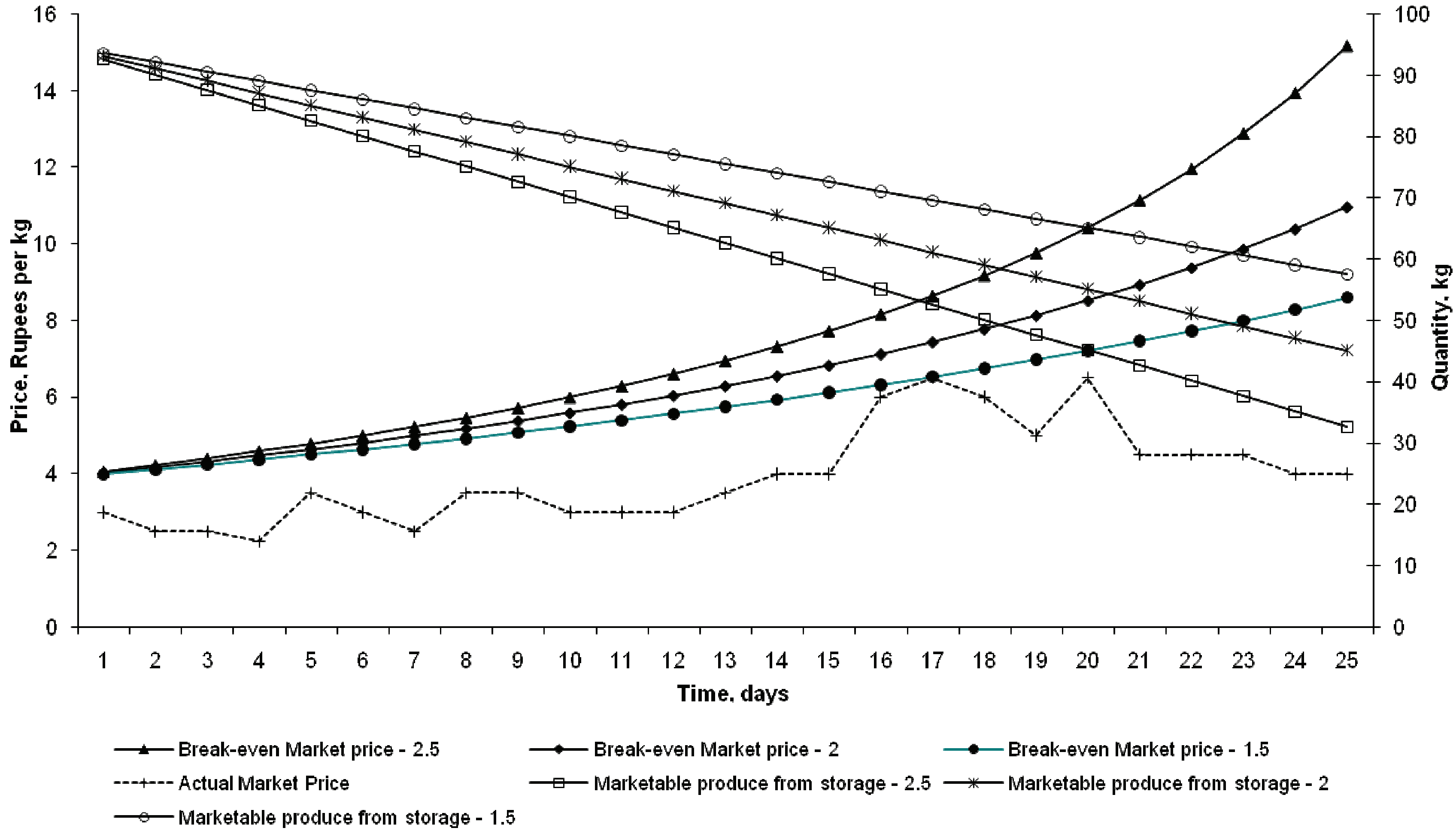


Figure 4. 33: Comparison of prediction scenarios of release time of stored tomatoes onto the market for profitability

4.6 Other Observations

During the course of this study, various other aspects of handling, transportation and storage were observed that could be of importance for the postharvest sector of the country.

Most of the produce handling during transportation and storage is manual. The use of forklifts or such mechanical devices to move or lift the product packages is minimal in most markets economic reasons. In light of this observation, cold stores appear to be higher than necessary. Normally, it is not possible to stack the produce higher than seven crates by manual loading. This factor could be useful in designing new cold stores to be operated by small farmers. Small cabin or container-type modular structures could be considered wherein the cooling can be achieved quicker than in a larger store.

Lack of awareness about the importance of relative humidity was evident. Most cold stores do not normally deal with high-moisture, living products. Commodities are usually processed or dried before storage, therefore they have little to no moisture content.

Figure 4. 34: The steam injector in the experimental cold room was located next to the temperature and humidity sensors.

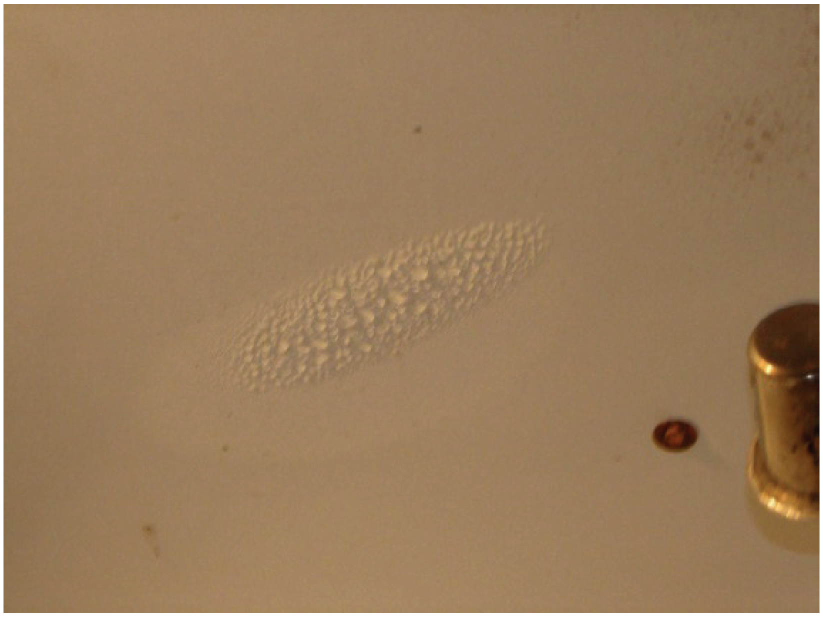


Figure 4. 35: Water condensation near the steam injector in the experimental cold store.

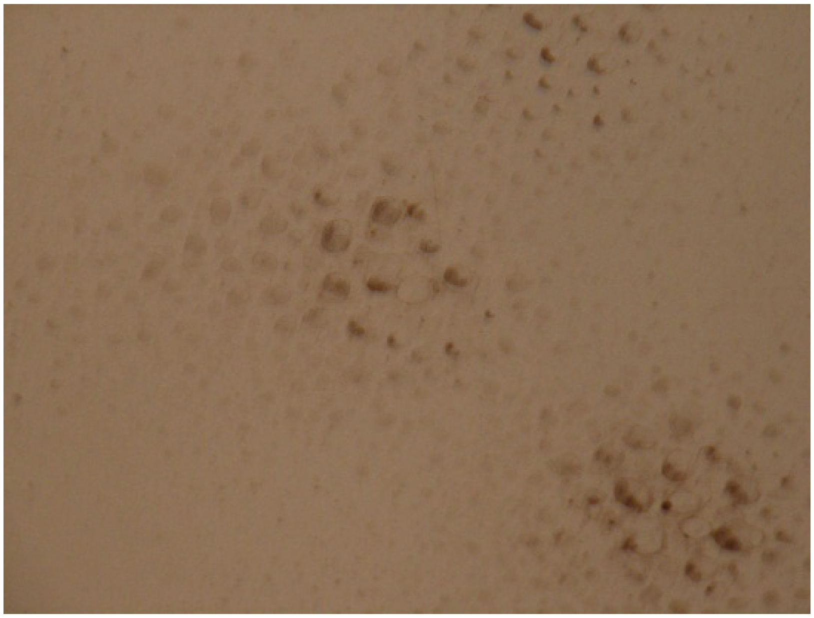


Figure 4. 36: Mildew on the walls of the experimental cold store.

Figure 4. 37: Mould on the ceiling next to the evaporator in the experimental cold store.

The use of steam to maintain the relative humidity at the experimental cold store was not only ineffective from an energy-wise point of view; it led to the growth of mould on the cold store's ceiling. The steam injected into the chamber through a coarselydesigned inlet (Figure 4.34) resulted in rapid condensation on the walls and ceiling close to the inlet (Figure 4.35). This condensation was gradually seen deposited on the produce in the chamber causing concerns of fungal inoculation to the commodity (Figures 4.36 and 37).

CHAPTER 5
CONCLUSION

In an attempt to consolidate their food supply, most developing countries in tropical regions are relying on appropriate postharvest technological interventions. The diverse horticultural products grown in large quantities during the conducive seasons need to be properly handled and stored in the supply chain to benefit both the consumers and the producers. High prevalent heat is a major source of retarding the storage life of these products and establishment of cold chain is identified as the prominent need in these countries. The current study was an exercise in the application of the cold storage as a short-term measure for hedging the market glut of tomato in the south India.

Though variations in the observations are large due to working with an uncontrolled, real-life situation, and the trends and functions obtained from such widely scattered data are not completely reliable, the results drawn from this study have brought to light several important factors that need to be addressed in the application of cold-storage solutions in the Indian postharvest sector.

1. Indian markets are not free. Commission agents and other externalities have a strong influence on the market price of produce. However, market prices seem to follow an empirically predictable function during different times of the year. It would be possible to describe a relationship between the time of year, and the arrival and pricing of commodities in an agricultural situation governed by seasonal rains and cultural factors. This could be done using more extensive market data and introducing meteorological parameters into the analysis.
2. Medium-sized farmers who can adopt GAP and GMP could store their higher-quality produce whilst immediately selling their lower-quality produce on the market. As such, they could sell their higher-quality produce when the market prices rise while cushioning their risk with the money made by the sales of lower-quality produce.

3. It is possible that high initial temperatures combined with a lack of pre-cooling resulted in high moisture loss at the beginning of storage, during the pull-down. This highlights the need for proper harvesting practices, postharvest handling practices and pre-cooling.
4. Since the difference in physiological weight loss between both cold-storage rooms was not statistically significant, it appears unnecessary for farmers to invest in high-cost temperature and R.H. controls in cold-storage systems. It is rather preferable to monitor the conditions within the cold storage and manually maintain the temperature and R.H. within an acceptable bandwidth.
5. The profitability of holding tomatoes in a cold store for short periods is directly influenced by the amount of produce lost during storage due to microbiological spoilage. There is therefore a need for proper production and management practices to minimize the incidence of postharvest diseases that can appear during storage.
6. Although it is generally assumed that India's high postharvest losses are due to gaps in the cold chain, this study demonstrates that the cold chain is but one important part of a set of postharvest solutions that must be adopted as a package. The adoption of a proper cold chain must be accompanied with proper production and management practices.
7. There is potential for using solar thermal sorption systems in India. Currently, the high capital cost of the equipment is restrictive. However, the technology is becoming more widely available, which will drive down the price of the equipment.
8. Biomass-based energy is more feasible than solar thermal energy, as its costs are lower and it is capable of generating higher temperatures in the absorption systems. India has a large cattle population, whose manure can be converted to biogas.
9. Farmers could use sorption refrigeration systems for a variety of produce, therefore spreading the initial cost of the systems over several income-generating activities.

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APPENDIX

Currency

1 Indian Rupee (INR, Rs) = 0.0257 Canadian Dollars (CAD)

1 CAD = 38.88 INR

Currency rates accurate as of August 26th, 2007

Units of measurement

1 quintal = 100 kg

1 lakh = 100 000

1 crore = 10 000,000