According to a USDA-Economic Research Service study in 2010, 18.9 billion pounds (8.6 billion kilograms) of fresh fruits and vegetables were lost annually due to spoilage, which constituted 19.6% of all US losses of edible foods that year. Studies consistently indicate that good temperature management throughout the cold chain is the most important – and simplest – method of delaying product deterioration. It is also important to note that quality loss in fresh produce is cumulative: each incident of mishandling reduces final quality at the consumer segment of the cold chain.

This article focuses on two potential temperature-related weak spots in the cold chain which, if handled optimally, can enhance the quality of fresh produce – and reduce losses – as it makes its way from the grower to the consumer:
- Pre-cooling
- Avoiding chilling injury

Specific examples are based on the handling of tomatoes.

**Pre-cooling**

In general, cooling is the foundation of produce quality protection. It extends the shelf life of fresh produce by reducing the rate of physiological change (respiration, ethylene production, enzymatic processes and water loss) and by slowing the growth of microorganisms. Proper pre-cooling can:
- Prevent quality loss as a result of softening by suppressing enzymatic degradation and respiratory activity.
- Prevent wilting by slowing or inhibiting water loss.
- Slow the rate of produce decay by slowing or inhibiting microbial growth (fungi and bacteria).
- Reduce the rate of ethylene production.
- Minimize the impact of ethylene on ethylene-sensitive produce.

Within hours of harvest, fresh produce held at ambient temperatures can suffer irreversible losses in quality. Even for chilling-sensitive commodities such as tomatoes, it is essential to remove excessive field heat quickly after harvesting. Certain rapidly developing decays such as bacterial soft rot can develop within a few hours after harvest if the tomato pulp temperature is 30°C (86°F) whereas at 16-20°C (61-68°F) the same decay will not appear for several days.

Commercial pre-cooling for perishable fresh produce aspires to rapidly remove at least 7/8 of the field heat from the crop by a compatible cooling method. Field heat can be defined as the difference in temperature between the temperature of the crop harvested and the optimal storage temperature of that product. The time required is known as the “7/8 Cooling Time”[^2]. Removal of the remaining 1/8 will occur during subsequent refrigerated storage and handling, with little detriment to the product.
Pre-cooling methods include room cooling, hydro-cooling, forced-air cooling, vacuum cooling, and use of ice. To achieve optimal cooling:

- The product must remain in the pre-cooler for sufficient time.
- The cooling medium (air, water and crushed ice) must be maintained at a constant temperature throughout the cooling period.
- The cooling medium must have continuous, intimate contact with the surfaces of the individual products.

The table to the right summarizes the trade-offs of the various pre-cooling methods as applied to fresh produce in terms of cooling times, water contact with the product (which can cause quality defects further down the cold chain), moisture loss (%) caused to the product, initial capital cost and energy efficiency.

In forced-air cooling refrigerated room air is drawn at a high flow rate through specially stacked containers or pallets by means of a high capacity fan. The product should be promptly removed from the forced-air pre-cooler upon achieving 7/8 Cooling. Forced-air cooling is recommended for most of the fruit-type vegetables and is especially appropriate for tomatoes that are susceptible to infiltration of water-borne decay organisms. An additional benefit to forced-air cooling immediately after harvest is that it tends to dry wounds, which decrease the chances for decay growth. The following table summarizes the recommended storage conditions and cooling methods for tomatoes, where FA = forced-air cooling and ROOM = room cooling (where the produce is loaded into a refrigerated room and the cold air is circulated by the refrigeration fans only):

### Chilling Injury

Chilling Injury (CI) is irreversible physiological damage that is caused when chilling-sensitive produce is stored below recommended temperatures but above freezing temperatures for extended periods. CI often becomes visible only after transferring the produce to non-chilling temperatures, such as the ambient temperature in a supermarket. Common visual symptoms of CI are surface lesions (i.e., pitting), water-soaking of the tissues, external and internal discoloration, tissue breakdown, increased susceptibility to decay and failure to ripen. CI also causes off-flavors and off-aromas.

Therefore, it is very important to transport and store chilling-sensitive crops at temperatures high enough to prevent CI, and yet low enough to slow down physiological activity. Crops that are chilling sensitive should be held at temperatures generally above 50°F (10°C). It is also important to maintain humidity levels so that condensation does not form on the product. Fungal spores germinate under high humidity (i.e., >95% RH) or in the presence of free water (i.e., condensation on the product).
If we look specifically at the effect of CI on tomatoes, over-refrigeration may cause an irreversible decrease in the volatile content and alter the flavor of tomatoes. In fact, volatile compounds in tomatoes stored for 3 days at 6°C significantly decreased and, after transfer to ambient temperature, some of the compounds were further reduced. However, in tomatoes stored for 4 days at the more optimal 20°C an increase in the attribute “tomato-like” odor, flavor and after taste were detected.\cite{1}

Other research has shown that storing green tomatoes at 2.5°C for only 3 days resulted in uneven ripening and development of decay due to CI.\cite{1} In ‘Sunny’ green tomatoes, flaccidity and delayed, uneven and non-uniform ripening occurred when the fruit were stored at or below 7.5°C for more than 5 days.\cite{1}

**Optimizing the Pre-cooling Process**

BT9’s Xsense® technology (www.bt9-tech.com) is a web-based, real-time, cost-effective solution currently available for monitoring and managing the pre-cooling operation in order to avoid the cycle undershooting and overshooting illustrated in Figure 1 below.

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**Figure 1: Pre-cooling Under/Overshooting**

**Pre-cooling Cycle Undershooting**
The pre-cooling operation is halted before achieving the target temperature (blue curve), which may compromise quality and shelf life of the fresh produce.

**Pre-cooling Cycle Overshooting**
The pre-cooling process is continued even after the target temperature (blue curve) is attained, resulting in energy waste.
With Xsense™, tags placed in proximity to the fresh produce being pre-cooled transmit real-time data regarding temperature, relative humidity and other parameters. An automatically generated alert precisely pinpoints when to cease the pre-cooling operation, as shown in Figure 2.

![Figure 2: Using XsenseTM to optimize pre-cooling](image)

Real-time Data and Reports to Minimize Chilling Injury

Data analytics and real-time reporting are among the advantages of the Xsense™ system that distinguish it from the traditional data loggers being used to monitor the cold chain today. Here are two examples of Xsense™ reports that are of immense value in dealing with chilling injury issues in the fresh produce cold chain:

- **Automatic E-mail and SMS alerts**: As soon as a pre-set low temperature threshold is breached, the system immediately notifies stakeholders via e-mail and SMS who now have the opportunity to take corrective actions in real-time and thus prevent the chilling injury that may occur as a result of the breach.
- **Pallets in Risk (PIR) Indicator**: The Xsense™ PIR indicator detects patterns of risk deduced from cumulative shipments as well as from individual shipments/pallets. Among other potential risks such as freezing or exposure to high temperature, the indicator flags pallets in risk of chilling. The indicator is based on risk definitions as a function of temperature conditions throughout the cold chain. Real-time PIR information is also of great value to wholesalers and retailers, allowing them to decide which pallets to sell to which markets, as well as to prioritize which pallets to deal with first.

Sources


