Advances in Precooling techniques and their implications in horticulture sector: A Review.

S. Senthilkumar[1], R.M. Vijayakumar[2], S. Kumar[3]

[1]Assistant Professor, RVS Padmavathy College of Horticulture, Sempatti- Dindigul Dist. (India)
[2]Professor and Head, Department of Fruit Crops, TNAU, Coimbatore-3. (India)
[3]Dean, RVS Padmavathy College of Horticulture, Sempatti (Dindigul Dist.) Tamil Nadu.

Abstract— *Maintenance of market quality from quality loss is vital importance for the success of horticultural industry. After harvest, many horticultural products are susceptible to deterioration and it is necessary to cool them as quick as possible. The process of precooling is the removal of field heat which arrest the deteriorative and senescence processes so as to maintain a high level of quality that ensures customer satisfaction. Different precooling methods employed to cool down the produce includes room cooling, forced-air cooling, hydro-cooling, package icing, vacuum cooling and cryogenic cooling. These methods use different modes and media for their function. Room cooling and forced-air cooling use cold air, hydro-cooling makes use of cold water, package iced products have direct contact with ice, vacuum cooling employs the evaporation of water and cryogenic cooling involves liquid nitrogen. Fruits are normally cooled with cold air, although stone fruits benefit from hydrocooling, while vegetables and flowers may be cooled by employing any of the above-mentioned cooling methods, depending on the physiology and market requirements. So, it has been pointed out that precooling is the most important of all the operations used in the maintenance of any desirable, fresh and saleable produce.*

Keywords— Post harvest, Precooling, Quality loss, Shelf life, Temperature.

I. INTRODUCTION

After harvest, many horticultural products are susceptible to deterioration and it is necessary to cool them as quick as possible. One important factor which is often under emphasized when considering the cooling of horticultural products is the lag time between harvesting and the commencement of precooling. Delayed pre-cooling increased the loss of water, lowers tissue firmness, and increased metabolic activities in fruits.

Precooling was first introduced by Powell and his coworkers in the US Department of Agriculture in 1904. Since then precooling has been given various definitions: the removal of field heat from freshly harvested produce in order to slow down metabolism and reduce deterioration prior to transport or storage; immediate lowering of commodity field heat following harvest; and the quick reduction in temperature of the product. With a reference [1] precooling is likely the most important of all the operations used in the maintenance of desirable, fresh and salable produce. Precooling grapes to a temperature of 0 to 2°C for four hours ensures storage life to 60 days [2].

II. LAG TIME BETWEEN HARVEST AND COOLING

Field heat can cause rapid deterioration of some horticultural crops and therefore it is desirable to remove this heat as quickly as possible after harvesting. In contrast, when it comes to produce quality, every minute counts and that precooling is among the most cost-effective and efficient quality preservation methods available to commercial crop produces as with reference [3].

In usual, refrigeration systems to be efficient and effective, so that the horticultural commodities be precooled prior to entering the cold chain. As a guide, as much deterioration can occur in 1 h at 25˚C as in a week at 1˚C, which highlight the necessity for precooling. For example, strawberries experience increasing deterioration losses as delays between harvesting and cooling exceeds 1 h [4].

III. INFLUENCE ON RESPIRATION RATE

It is imperative to have proper post-harvest cooling of fruits, vegetables and flowers to ensure the maintenance of maximum quality. The rate of deterioration after harvest is closely related to the respiration rate of the harvested product, therefore the reduction of respiration rate is essential to preserving market quality. Since the rate of respiration is influenced by temperature, precooling to remove the field heat before storage will reduce the respiration rate and hence deterioration will decline accordingly. As with reference [5], a reduction in temperature of 9.5˚C in grapes halved the rate of respiration and doubled their keeping quality.

The rate of aging can be reduced dramatically by cooling the flowers [6]. Rapid cooling and maintenance of the cool chain are thus essential for maintaining quality and satisfactory vase life of cut flowers. So, the optimum storage temperature for most cut flowers is 0˚C. Flowers kept at 20˚C deteriorate nine times faster than those kept at 0˚C.

However, as with reference [7], the fruit respiration of mechanical harvested (MH) berries was higher than hand harvested (HH) berries both under ambient and refrigerated conditions. At 22°C, MH blueberries reached respiration rates that were 31.1% higher than HH blueberries. Under refrigeration, MH fruits had 29.1% higher respiration rates than HH berries. In general, refrigeration diminished respiration by 79.3% and by 78.5% for MH and HH berries, respectively. The enhancement of respiratory activity in fruits may result from either an activation of enzymes at increasing temperature or as a response to fruit stresses such as that of bruising and mechanical damage. Therefore, those berries that were subjected to greater mechanical damage had accelerated respiration.

IV. INFLUENCE ON METABOLISM

The increase in the rate of deterioration is related to the metabolic processes of the crop. Within the plants temperature range, the rate of deterioration increases logarithmically with increasing temperature. As with reference [6], the metabolic rates double for each 10˚C rise in temperature. This is called the temperature quotient (Q10), which can be predicted by Van't Hoff rule as follows:

$$Q_{10} = \left[\frac{J_2}{J_1}\right]^{\frac{10}{t_1 - t_2}}$$

where J1 and J2 are the respirations at temperatures t1 and t2, respectively.

As with reference [8], a study in apples reported that pre-cooled fruits exhibited relatively slower loss in weight on the corresponding dates as compared to those without pre-cooling, had lower physiological weight loss of 3.9%, both in 2006 and 2007. This may be due to the slower loss of moisture from precooled commodities when higher relative humidity is maintained in the storage atmosphere. Such conditions can easily be achieved by lowering the temperature as the storage environment tends to be more saturated simply by reduction in temperature.

V. EFFECT OF RAPID COOLING ON ETHYLENE

The reduction in temperature has the added advantage of reducing the production and sensitivity of the produce to ethylene that accelerates ripening and senescence. Therefore, the faster and more promptly the field heat and hence temperature is reduced after harvest, the quicker these deteriorative processes are retarded and hence the more of the initial quality can be maintained. However, increased ethylene production, enzymatic activity and higher respiration rate during ripening results cell wall weakening and loss of firmness.

With reference to [9] the ethylene production did not greatly differ with treatment during the first 15 days of storage. Five days later, ethylene production of fruits precooled at 8-13˚C dramatically increased while that of the control and those precooled at 5˚C remained at levels comparable to the previous rates of ethylene production. The results seemed to manifest the influence of forced air cooling on ripening retardation, quality retention and shelf life extension of the fruits.

VI. CONSIDERATIONS IN ASSESSING THE NEED FOR PRE-COOLING

- Quality required at point of sale
- Fluctuations in market conditions and demand
- Growing, harvesting, distribution, storage conditions and facilities
- Growing area and market geography
- Economic values.

VII. QUALITY REQUIRED AT POINT OF SALE

The quality and freshness of delivered product is an essential service element, as quality is the single most important economic factor and having a significant relationship to customer satisfaction. The quality requirement of perishable products varies from product to product and depends on their intended use and the level of quality required for this purpose. Horticultural product quality maintenance is one of the most important services and so, cooling requirements of all commodities vary and depend on the characteristics, value, and shelf-life requirements of the products.

VIII. FLUCTUATIONS IN MARKET CONDITIONS AND DEMAND

Supply and demand for perishable crops is not always in balance and there can be large seasonal fluctuations in both quantity and price. Precooling in conjunction with the proper temperature management be used to provide the added market flexibility and demand. This is especially evident where there is great demand on certain days of the year such as roses on Valentine's Day, Lilies at Easter, and Poinsettia at Christmas as illustrated in reference [10] and this in turn causes highs and lows in market requirements. The market for vegetables is constantly changing and evolving especially the `exotic' crop market. It is recommended that precooling should be used in conjunction with the proper temperature management in order to provide the added market flexibility necessary to cope with these peaks and extra demand. With this added flexibility, losses due to over production can be avoided and maximum shelf life can be achieved.

IX. GROWING, HARVESTING, DISTRIBUTION, STORAGE CONDITIONS AND FACILITIES

The appearance, quality, and longevity of perishable produce depend upon conditions of cultivation, proper harvesting time and technique, and the distribution and storage conditions thereafter. With reference to [11], if harvesting produce at high temperatures or at an advanced stage of development or if produce is over fertilized, prompt cooling is essential so as to minimize quality losses. The conditions of distribution vary greatly and produce can be transported in boxes (various types) or loose in non-insulated or insulated, refrigerated or non-refrigerated vehicles. With this wide variety of transportation methods available precooling will give longer shelf life especially for temperature controlled conditions but even if the products temperature is allowed to rise later. With reference to [12] an initial 'flash' or `snap' cooling to a temperature between 0 and 5˚C resulted in the arrest of biological process for 8 h or more, thus prolonging potential shelf life.

With reference to [13] the delayed cooling treatment of 7 days at 20˚C prior to storage at 3 or 5˚C resulted in marked or complete suppression of soft scald and low temperature breakdown in early and late-harvested 'Honeycrisp' apples following 4 or 6 months of CA or RA storage. Delayed cooling also decreased the rates of ethylene evolution but did not affect the incidence of storage rot. For regions in which soft scald and low temperature breakdown cause significant economic loss, delaying the cooling of fruit prior to storage appears to be a beneficial step in minimizing disorder incidence.

X. GROWING AREA AND MARKET GEOGRAPHY

Increased competition and greater consumer demands leads to need for greater product reliability and availability. Perishable products require more uniform or faster cooling. So, proper temperature management is the most important key to the successful export. The current desire to reach more distant markets, prolong storage life, and market a product that better satisfies consumers, requires more uniform or faster cooling. With reference to [14] stated that 80% of the flower products in the Netherlands are exported and to safeguard the quality of the flowers, they are often cooled at 2 or 8˚C in cold stores.

XI. ECONOMIC VALUES

Product precooling rank as the most essential of the value added marketing services demanded by increasingly more sophisticated consumers. Economic benefits of early precooling of different products are better suited to certain cooling techniques so that cost efficiencies can be improved better.

XII. PRECOOLING CALCULATION - HEAT LOAD

It is essential that the heat load be removed quickly whatever cooling technique is used. It is imperative, therefore, to have an adequate amount of cooling capacity for effective precooling, however, it is uneconomical to have more cooling capacity available than is normally required. The composition of the total heat load (Q) comes from the product, surroundings, air infiltration, containers and other heat producing devices.

$$Q = mc_p(t_i - t_{ma})$$

Heat from respiration is seen as part of the product heat load, but it can in general be ignored in precooling heat load calculations, as the cooling is rapid. For accurate heat load calculation, an accurate determination of product temperature is essential. As a result of rapid heat transfer a temperature gradient develops within the cooling product, with faster cooling causing larger gradients. Consequently, temperature on the surface changes more rapidly, while the centre temperature changes more slowly. This is true as most of the product mass is in the outer portion, and thus large errors may occur by using the center temperature as a basis for heat load calculations. The mass average temperature is the single value achieved from the transient temperature distribution, which would become the uniform product temperature when the product is held under adiabatic conditions.

XIII. PRECOOLING TECHNIQUES

There are a variety of precooling techniques available for use in the horticultural industry. The principal methods of precooling highly perishable produce include room cooling, hydro cooling, forced air cooling, package icing, vacuum cooling and cryogenic cooling, with many variations and alterations within these techniques. In general most of the cooling is done at the packing houses or in central cooling facilities.

a) **ROOM COOLING:** Precooling produce in a cold-storage room or precooling room is an old well-established practice. This widely used method involves the placing of produce in boxes (wooden, fiberboard or plastic), bulk containers or various other packages into a cold room, where they are exposed to cold air. The cooled air is generally supplied by forced or induced draft coolers, consisting of framed, closely spaced and evaporator coils fitted with fans to circulate the air over the coils. Therefore, as to achieve fast and efficient cooling, care should be taken that the correct packaging (well vented) or containers and stacking patterns are used. With reference to [15] the liners in packages and paper curtains over the vegetable produce retard the cooling considerably.

However, for the best cooling rates to be achieved more space is required than for good storage management and thus some rearranging of the produce after cooling may be necessary to utilize the storage space fully. As much of the cooling is achieved by conduction, room cooling gives a slow and variable temperature reduction; therefore perishable produce used in this method must be tolerant of slow heat removal. With reference to [16] the quantities of vegetables stored daily varied considerably and that the rate of cooling was very variable, with less than 0.5˚C/h reduction on many occasions for room cooling. This indicates that much of the produce cooled was falling short of IIR recommendations that perishable products should be brought to their final storage temperature within 24 h.

A cooling room that is used to store cooled produce requires a relatively small refrigeration unit; however, if it is used to cool the perishable commodities a larger unit is needed. Capital costs and running costs vary according to individual circumstances and requirements. However, a specific case is presented where both running costs and capital costs of room cooling are less when compared with alternative rapid cooling techniques. This case also indicates that the throughput of room cooling is far less in comparison with other methods.

Room cooling has become increasingly difficult as more commodities are being handled in larger quantities and are packaged immediately after harvest due to better mechanization. These difficulties coupled with its slow and variable cooling extend the cold chain and therefore reduce the product life in subsequent storage. Most cited references report that room cooling can be used for most perishable produce which do not deteriorate rapidly after harvest such as beans (dry, sprouts), beets, cucumber, onion (dry sets), peppers, potatoes, parsnips, pumpkins, radish, rhubarb, tomatoes, garlic, herbs and turnips [17].

b) **PACKAGE ICING**: Although, unlike other cooling methods ice not only removes heat rapidly when applied, it continues to absorb heat as it melts. There are a variety of different methods in which ice is applied to the produce so as to achieve the desired cooling effect. Package icing involves direct placement of slush, crushed ice over the product in shipment containers. This method is sufficient where it is used; however, it can result in uneven cooling because the ice generally remains where it was placed until it has melted.

In liquid icing, ice slurry is used instead of plain crushed ice as it can sustain cooling requirements better. Liquid icing may be considered a hybrid of package icing and hydrocooling. The simplest form of liquid icing is where a mixture of water and finely crushed ice is pumped into open containers travelling along a conveyor under an injection nozzle. If produce has been packed and palletized in the field, the liquid ice can be injected into the packages through vents or hand openings. Liquid-icing distributes the ice throughout the commodity, i.e. placed in each individual package better, thus achieving improved ice/produce contact and hence better and more uniform cooling.

Another method of icing is top icing, or placing ice on top of packed containers. This is only used occasionally to supplement another cooling method. Because corrugated containers have largely replaced wooden crates, the use of top icing has decreased. Wax-impregnated corrugated containers have allowed the use of icing of products after packaging to continue; however, it is being replaced by hydrocooling and vacuum cooling. The major advantage of icing is that produce does not dry as it is cooled. With reference to [18] the water loss from broccoli precooled by hydrocooling and top icing gave similar results. Another advantage is that in addition to removing field heat, package icing can maintain low product temperature during transit and therefore refrigerated transportation may not be necessary for short transport duration. Although icing requires relatively small outlays of special equipment, a large weight of ice must be shipped, thus increasing costs, and also waterproof containers which are more expensive than normal are required for this cooling technique. Therefore, it is essential that produce be not allowed to rewarm once it is iced.

c) **HYDRO-COOLING:** Hydrocooling essentially is the utilization of chilled or cold water for lowering the temperature of a product in bulk or smaller containers before further packing. There are several different hydrocooler designs in operation commercially. Hydrocooling methods differ in their cooling rates and overall process efficiencies. Differences between the individual techniques are evident by the method of cooling and by the way that produce is moved or placed in the cooler. Various types of hydrocooler are available, some of which include conventional (flood) type, immersion type, and batch type [19].

The flood type hydrocooler cools the packaged product by flooding as it is conveyed through a cooling tunnel. With the batch system, chilled water is sprayed over the product for a certain length of time, depending on the season and the incoming product temperature. These hydrocoolers have a smaller capacity than conventional hydrocoolers and are therefore less expensive. A frequent complaint about both conventional and batch type hydrocoolers is that cooling by these techniques is not uniformly and hence may leave `hot spots' throughout the load. The bulk or immersion type cooler uses a combination of immersion and flood cooling. Loose produce is immersed in cold water, and remains immersed until an inclined conveyor gradually lifts the products out of the water and moves it through an overhead shower. In general products hydrocooled should tolerate being wetted and not be damaged by falling water or disinfectants that it may contain, hence hydrocooling is recommended for produce for which washing is part of their market preparation. With reference to [20] and [21] many vegetables are successfully hydrocooled such as sweet corn, celery, asparagus, radishes and carrots.

A risk associated with most hydrocoolers is the decay hazard associated with recirculated water, which leads to the possibility of decay producing organisms accumulating in the system, resulting in the contamination of the cooled produce [6]. To prevent this from occurring, mild disinfectant such as chlorine at concentrations of 100 ppm (measured as hypochlorus acid) or approved phenol compounds are used and therefore produce cooled by this technique must not be affected by the use of these chemicals. Another advantage of this technique is that it is very rapid in contrast to other pre-cooling techniques available.

Energy efficiency may be exceptionally low, unless the hydrocooler is operated at maximum capacity, or it is located inside a cold room or an insulated enclosure. Hydro-air cooling is an important and specialized area of hydrocooling in which a mixture of refrigerated air and water in a ®ne mist spray is circulated around and through stacks of the produce. The advantage of hydro-air cooling is the reduced water requirements and the potential for improved sanitation. With reference to [22] the immersion cooling was faster than hydro-air cooling in all cases tested, but that cooling rates for sweet corn are equal to or in some cases slightly better than those obtained in conventional hydrocoolers. Cucumber, mango and papaya are best pre-cooled by hydro-air cooling as compared to hydrocooling or forced air cooling [20].

With reference to [23] the treatment pre-cooling plus 50 ppm chlorine prevented peel desiccation, maintained both the amount of SSC in the flesh and high sensory evaluation scores, and extended the storage life of longan fruits.

d) **FORCED-AIR COOLING:** Forced air or pressure cooling is a modification of room cooling and is accomplished by exposing packages of produce to higher air pressure on one side than on the other. This technique involves definite stacking patterns and the bagging of stacks so that the cooling air is forced through (rather than around) the individual containers.

Produce can be cooled by a variety of different forced air cooling arrangements. These include (a) air circulated at high velocity in refrigerated rooms, (b) by forcing air through the voids in bulk products as it moves through a cooling tunnel on continuous conveyors, and (c) by encouraging forced air flow through packed produce by the pressure differential technique. Each of these methods is used commercially, and each is suited for certain commodities when properly applied. The product cooling rate is affected by numerous variables and, therefore, the overall cost of the forced air cooling will vary. Forced air coolers utilize centrifugal (commonly known as squirrel cage) or axial fans which push the cold air around the system. Fans are selected based on the criteria of required air flow and static pressure. Another aspect of forced air cooling is that converting existing facilities is often simple and inexpensive, provided that sufficient refrigeration capacity and cooling surfaces are available. With reference to [4] prompt cooled, non inoculated strawberries from the third and fourth harvests showed a higher incidence of decay than those from the earlier harvests.

The study affirms the assumption that to reduce the extent of decay problems, prompt cooling after harvest and subsequent storage at low temperature constitute important steps in order to retard development of strawberry fruit rots and to maintain acceptable fruit appearance.

With reference to [24] an experiment on pre cooling and heat treatment on antioxidant enzymes profile in mango and banana was made and the result highlighted the Alphonso mango and Robusta banana capacity to withstand various post harvest pre-cooling and heat stress conditions. Active oxygen species were generally produced by enzymatic and non-enzymatic pathway during cellular metabolism. The study showed that the level of expression of antioxidant enzymes during pre-cooling and heat treatment conditions dependent upon exposed temperature and underline the important role for protecting cellular apparatus during pre-cooling and heat treatments. Extent of recommendation of pre-cooling temperature and heat treatment of these fruits after pre-cooling at 5 ºC and 8 ºC can be made based on the levels of reactive oxygen species. Research into variations in the activities of other antioxidant enzymes and the action of other molecules with a non-enzymatic action may give a more complete picture of the response of Alphonso mango and Robusta banana fruits to postharvest oxidative stress and better explain its high resistance to this specific abiotic stress.

e) **VACUUM COOLING:** Vacuum cooling is achieved by the evaporation of moisture from the produce. The vacuum cooling process itself occurs in two fairly distinct phases. In phase one, the pressure in the vacuum chamber is reduced from atmospheric to about 20 mbar and, during this time, evaporation is slow and relatively little cooling takes place, i.e. temperature of the produce remains constant until saturation pressure at this temperature is reached. At approximately this pressure the flash point' occurs; this is the point where the water in the produce begins to vaporize, i.e. produce begins to lose moisture and cool rapidly [25]. For example, if the produce had an ambient field heat of 20˚C then the `flash point' would occur at 24 mbar. At this point the wet bulb temperature sharply increases as the air in the tank is evacuated and is replaced by the evaporated water vapour. This vapour has to be removed quickly in order to keep the overall cooling cycle to a reasonably length, and this is accomplished by the use of a condenser in the chamber.

Many investigations agree that vacuum cooling of fresh produce by the rapid evaporation of water from the product works best with products having a high ratio of surface to volume. Since water is seen as the primary refrigerant, it is a safe assumption that the quantity of heat removed from the product is directly related to the amount of water evaporated o€ the products surface. Lettuce is one of the many products that are ideally suited to vacuum cooling. Many researchers agree that other vegetables such as spinach, endive, escarole, parsley, asparagus, snap beans, broccoli, Brussels sprouts, cabbage, cauliflower, celery, green peas, sweet corn, leeks and mushrooms may also be vacuum cooled. However, only lettuce, cauliflower, celery, cabbage, spinach and mushrooms are reported as being cooled on a commercial scale. Strawberries can be cooled in 22±26 min even if they are packaged prior to cooling [23].

f) **CRYOGENIC COOLING:** The use of the latent heat of evaporation of liquid nitrogen or solid CO2 (dry ice) can produce `boiling' temperatures of -196 and -78˚C, respectively. This is the basis of cryogenic precooling. In cryogenic cooling, the produce is cooled by conveying it through a tunnel in which the liquid nitrogen or solid CO2 evaporates. However, at the above temperatures the produce will freeze and thus be ruined as a fresh market product. This problem is prevented by careful control of the evaporation rate and conveyor speed [26]. Cryogenic cooling is relatively cheap to install but expensive to run. Its main application is in cooling crops such as soft fruits, which have a seasonal production. Hence, by using cryogenic cooling the grower would not incur the high capital costs associated with alternative cooling techniques over such period of use. This system would seem ideally suited to the horticulture industry where production is seasonal however no documented research has been conducted yet into the success of this application. The high cost of liquid nitrogen, dry ice and other suitable non-toxic refrigerants make this process most suitable for relatively expensive products.

XIV. CONCLUSION

The importance of precooling can be clearly recognized as it is portrayed as an intricate and essential part of the proper temperature management of all horticultural crops. Precooling is in essence the removal of heat or the reduction in temperature of the perishable produce as soon as possible after harvest. This process slows the respiration rate and minimizes other deteriorative processes and thus helps to maintain quality at a high level. Precooling in conjunction with the proper storage or transportation allows for the extension of shelf or vase life of the horticultural produce which results in more satisfied customers at all levels of purchase.

Within precooling a variety of different techniques exist for use in the horticultural industry. Hydrocooling, vacuum cooling, room cooling, icing, forced air cooling, and cryogenic cooling are the principal methods in commercial use at present. Each of these individual techniques also has many variations, leading to a great diversity of perishable produce which may be precooled. As consumer awareness and sophistication are ever increasing due to the growing fear of chemical residues and the uncertainty surrounding genetically modified foods presently, and with the change to organic products continuing, alternative techniques of extending shelf life and maintaining high level of quality are being investigated. Precooling is one of the techniques which adheres to this ethos and should be applied widely throughout the entire horticultural industry to attain its true potential.

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