Fruits and vegetables are living vibrant system even after detachment from the parent plant. As living biological entities, they respire and transpire. Before harvest, when these perishable products are attached to the parent plant, losses due to respiration and transpiration are replaced by water, photosynthesis and minerals from the plant. After harvest, losses of respirable substrates and moisture are not replaced; therefore, deterioration occurs, soon followed by senescence. The physiological changes of respiration, transpiration and biosynthesis are affected by intrinsic (i.e. climacteric vs. non-climacteric commodities) and extrinsic (i.e. temperature, ethylene, \(O_2\) and \(CO_2\) concentration) factors (Kader et al., 1989). Senescence is the process that follows physiological maturity and leads to the death of a whole plant, organ, tissue (Watada et al., 1984). Shelf-life extension is the ultimate goal of most post-harvest physiology research (Borochov and Woodson, 1989). Shelf-life is the period a product remains acceptable during storage at any condition by whatever limiting criterion (Tijskens, 1995). Shelf-life extension may be achieved by many means but the principal techniques
are: (1) retarding deterioration of physiological processes or (2) preserving the tissue by inactivating the physiological processes, i.e. food preservation which incorporates such techniques as thermal processing, freezing, dehydration, etc. Obviously, post-harvest treatment is a very important step in maintaining product quality and extending the shelf-life. There are a variety of different post-harvest technologies available, among them precooling is considered to be a critical process (Halevy and Mayak, 1981 and Turk and Celik, 1993).

It is indicated that pre-cooling is critical in meeting consumer demands for high quality fresh produce (Sullivan et al., 1996). Pre-cooling was first introduced by Powell and his co-workers in the US Department of Agriculture in 1904. Since then pre-cooling 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 (Nowak and Mynett, 1985); and the quick reduction in temperature of the product (Rudnucki et al., 1991). It is pointed out that precooling is likely the most important of all the operations used in the maintenance of desirable, fresh and salable produce (Baird and Gaffney, 1976).

**Effect of LAG time between harvest and cooling:**

It is reported by various researchers that 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 (Gormley, 1975). Fast pre-cooling of tomatoes after harvest, reduces the rate of quality loss and extends the shelf-life (Jeong et al., 1996). The rate of pre-cooling of the fruits and vegetables immediately after harvest is a determining factor for their quality and durability in storage (Tonini et al., 1979). In contrast (Sullivan et al., 1996) states that 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 produce.

**Influence of precooling on the respiration rate and product quality:**

It is imperative to have proper post-harvest cooling of fruits and vegetables to ensure the maintenance of maximum quality. The rate of deterioration after harvest closely related to the respiration rate of the harvested product (Farragher et al., 1984 and Kadar et al., 1992), therefore the reduction of respiration rate is essential to preserve market quality. Since the rate of respiration is influenced by temperature, pre-cooling for removing field heat from freshly harvested fruits reduces microbial-activity, metabolic activity, respiration rates and ethylene production. This also decreases the ripening rate, diminishes water loss and decay, and thus, helps preserving quality and prolongs shelf-life of the fruits (Ferreira et al., 1994; Reina et al., 1995 and Winkler et al., 1974) indicated that a reduction in temperature of 9.5°C in grapes halved the rate of respiration and doubled their keeping quality. Hardenburg et al. (1986) mentioned that storage under low temperature has been considered the most efficient method to maintain the quality of most fruits and vegetables due to its effects on reducing respiration rate, transpiration, ethylene production, ripening, senescence and rot development. For every 10°C increase in temperature the rate or respiration is roughly doubled or even trebled. For example an apple held at 10°C ripens and respires about 3 times as fast as one held at 0°C. This increase in respiration has a direct impact on the shelf-life of fresh products (Jenny, 2014).

Precooling either alone or in combination with wax/chemical treatments and different storage conditions extended shelf-life, reduced Physiological Loss in Weight (PLW), reduced rate of ripening, reduced rate of respiration, reduced spoilage and preserved quality in several fruits and vegetables; viz., Banana (Grizzell and Bennett, 1966); Mango (Chattopadhyay, 1989; Waskar et al., 1997 and Krishnamurthy, 1988); Sapota (Shah, 1995); Blueberries (Hudson and Tietjen, 1981); Fig (Turk, 1989); Citrus fruits (Chalutz et al., 1974); Cherry (Manganaris et al., 2007); Sweet corn (Vigneault et al., 2007); Tomato (Shahi et al., 2012) and Plum (Martinez et al., 2003).

**Influence of 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. Reid (1991) reported that metabolic rates double for each 10°C rise in temperature.

**Effects 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 removed 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. Usually the ethylene production rate increases after harvesting leading to physiological injuries, or disease occurrence at high temperatures (up to 30°C) (Kader, 2002). However, ethylene effect can be slowed down by lowering the temperature of storage, reducing the $O_2$ (< 8%) and/or increasing the $CO_2$ levels (>2%) surrounding the produce (Kader, 2002).

**Considerations for precooling:**

*Product quality requirement in market:*

The quality and freshness of delivered product is an essential service element (Anonymous, 1999), as quality is the single most important economic factor. Shewfelt (1986) believes that for many products, precooling may be the single most important step in extending their shelf-life and maintaining the high quality required at customer level. The cooling requirements of all commodities vary considerably and depend on the characteristics, value, and shelf-life requirements of the products (Prince et al., 1990). Products such as apples, potatoes, bananas and pumpkins do not need to be precooled but may benefit from some cooling if ambient temperatures are high at harvest and produce such as asparagus, snap beans, leafy vegetables and broccoli are highly perishable and must be cooled as quickly as possible after harvest.

*Growing, harvesting, distribution and 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. Rudnicki and Nowak (1990) propose that if harvesting of produce is 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 current desire to reach more distant markets, prolonged storage life, and market a product that better satisfies consumers, requires more uniform or faster cooling.

**Precooling calculations considerations:**

*Heat load:*

It is essential that the heat load be removed quickly whatever cooling technique is used. Wade (1984) noted that precooling requires a much greater refrigeration capacity in comparison to that required for holding a product at a constant temperature or for slow cooling of a product. 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 (Wade, 1984). The composition of the total heat load comes from the product, surroundings, air infiltration, containers and other heat producing devices (Boyette et al., 1994c). The product heat load as depending on product temperature and cooling rate, quantity of product to be cooled in a given time, and specific heat of the product. 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.

*Cooling rates:*

The rate of cooling produce depends primarily on many factors including rate of heat transfer, difference in temperature between the produce and the cooling medium, thermal properties of the produce, size and shape of the produce, nature of the cooling medium, type of packaging (if any) and stacking arrangement. When warm produce is being cooled the rate of cooling is not constant but diminishes exponentially as the temperature difference reduces, i.e. product cooling follows a logarithmic function, with rapid cooling initially followed by a slower and slower rate. The rate of cooling varies over time; two single parameters have been adopted to describe the cooling process: cooling co-efficient (C) and half-cooling time ($Z$). The cooling co-efficient (C) represents the change in product temperature per unit change of cooling time for each degree temperature difference between the product and its surroundings. The ‘half’ and ‘seven-eighths’ cooling times are the times required to reduce the temperature difference between the product and cooling medium by one half ($Z$) or by seven-eighths ($S$), respectively.

**Precooling methods and applications:**

*Factors affecting cooling methods:*

The principal methods of precooling for highly perishable produce include room cooling, hydrocooling,
forced air cooling, package icing, vacuum cooling and cryogenic cooling, with many variations and alterations within these techniques. It was noted that while some products may be cooled by any of these methods without suffering any loss in quality, others may be affected adversely depending on the type of cooling technique applied (Wang, 1993). Various precooling methods were recommended for different fruits and vegetables. The choice of cooling method is influenced by the following factors (Kader, 2001).

Nature of product:
Different types of produce have different cooling requirements. For example, strawberries and broccoli require near-freezing temperatures, whereas, squash and tomatoes would be damaged by such low temperatures. Likewise, because of problems that can becaused by wetting of certain products. They are not suited to hydrocooling.

Product packaging requirements:
The package design and material can have an effect on the choice of cooling method and rate of cooling as indicated by Stanley (1989). Mitchell et al. (1972) also showed that small changes in package design can impact the cooling rate of the product greatly. Investigations by Arfin and Chau (1988) illustrated the effects of new vent-hole designs on the cooling rates of strawberries and found that new designs improved the cooling efficiency vastly, especially at low airflow rates. Faubion and Kader (1997) found that by changing the way that the produce is packed, it can dramatically change the cooling speed of the perishables and therefore influence the choice of cooling technique.

Product flow:
Some cooling techniques are much faster than others and therefore have different throughput of produce. If the volume of produce to be cooled per season, per day, or per hour is large, a faster cooling technique is needed so as to achieve the required output. The relationship of the cooling equipment and the packaging operation or the proper matching of equipment must also be considered so as not to interrupt the flow of the product through the plant.

Various researchers reported suitability of different precooling methods and/or precooling parameters; viz. running water hydro cooling (4-5 °C) superior over immersion (dipping) hydro cooling, room and ice cooling in view of shelflife of Mango (Putteraju and Reddy, 1997); cold water dipping (10 °C) better in view of reduced PLW and decay in mango (Chauhan et al., 1987); hydro cooling (5 °C) gave better shelflife and PLW advantage over air cooling and top icing in Banana (Nayak, 1999); hydro cooling (15 °C) gave highest shelf-life, lowered PLW and retarded ripening compared to other temperature and durations in Sapota (Suma, 2000); forced air cooling better than still air and hydro cooling for extending shelf-life in Grapes (Unde et al., 2003); hydro cooling at 12 °C better than 16 °C and 8 °C in mango (Kapse et al., 1997), forced air cooling better than hydro cooling in Nagpur Mandarin in view of PLW, decay and shelf-life (Ladaniya, 1995); forced air cooling better than hydro cooling in view of fungal diseases in green Tomatoes (Kaynas et al., 1995) and package designs affect cooling rate and uniformity in forced air cooling of Citrus fruits (Defraeye et al., 2014) etc.

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, fibre board or plastic), bulk containers or various other packages into a cold room, where they are exposed to cold air. Ryall and Pentzer (1967) showed that the liners in packages and paper curtains over the vegetable produce retard the cooling considerably. The best cooling rates to be achieved more space is required than for good storage management and thus some re-arranging of the produce after cooling may be necessary to utilize the storage space fully. In the studies by Lill and Read (1983) asparagus was room cooled to 8°C in 22 h and the recorded results demonstrated that even through the use of this slow precooling technique an extension of saleable life by 2 days is achievable.

Forced air cooling:
Forced air cooling pulls or pushes air through produce containers, greatly speeding the cooling rate of any type of produce. Many types of forced-air coolers can be designed to move cold air past the commodities. When utilizing a tunnel-type forced-air cooler, the canvas sheets must be well sealed over the top of the load, and pallet openings blocked for the cooler to function properly.
Package vents must be aligned between boxes to allow the air to flow across a pallet of boxes.

Forced air cooling was developed by Guillou to accommodate products requiring relatively rapid removal of field heat immediately after harvest. 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 (Boyette et al., 1994a). It was indicated that for successful forced air cooling operations, it is required that containers with vent holes be placed in the direction of the moving air and packaging materials that would interfere with free movement of air through the containers should be minimized (Arfin and Chau, 1988). 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. The product cooling rate is affected by numerous variables and, therefore, the overall cost of the forced air cooling will vary. These variables include product size and shape; thermal properties; product configuration (bulk or packaged); carton vent area; depth of product load during cooling; initial product temperature; final desired product temperature and air flow rate, temperature, and relative humidity (Lindsay et al., 1983). The cooling air comes in direct contact with the product being cooled and cooling is much faster than with conventional room cooling. This gives the benefit of rapid reduction in field heat and, therefore, quick product movement through the cooling plant. It was reported that it took 2 to 3 times longer than hydro cooling or vacuum cooling (Nayak, 1999), while it was stated that cooling by the forced air method was usually 4 to 10 times faster than room cooling but that hydrocooling and vacuum cooling was 2 to 23 times faster than forced air cooling. Researchers were examined the energy use of a variety of precooling techniques and found that forced air coolers gave the lowest efficiency due to high levels of heat input as a result of improper design and operation of the air moving system (Thompson and Chen, 1988); Baird et al., 1988) explained that when very rapid cooling is required forced air cooling is more costly than other precooling methods. Forced air cooling also used for a variety of vegetables including broccoli, cauliflower, green beans (Risse and Craig, 1989), celery, cucumber, mushrooms and tomatoes.

**Hydrocooling:**

Hydrocooling has been used since 1923 when it was developed as an outgrowth of celery washing. It is because of its simplicity and effectiveness that hydrocooling is a popular precooling method. 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. Various types of hydrocoolers are available, some of which include conventional (flood) type, immersion type, and batch type. 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.

The 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. Grizzell and Bennett (1966) illustrated that it is nearly twice as rapid as conventional hydrocooling methods, due to the fact that moving chilled water completely surrounds the exterior surface of the produce and hence facilitates quicker temperature reduction. Boyette et al. (1994b) also pointed out that the bulk type cooler has the added benefit over the flood type cooler of allowing greater packaging flexibility. Many vegetables are successfully hydrocooled such as sweet corn, celery, asparagus, radishes and carrots.

Main benefits of hydro cooling are that it is seen to prevent loss of moisture during the cooling process. Another advantage of this technique is that it is very rapid in contrast to other precooling techniques available. Field heat can be removed in 20-30 min using hydrocooling instead of several hours normally needed for forced aircooling. Experimental work conducted by Lambrinos et al. (1997) demonstrated that the capacity of hydrocooling may be at least twice as high as that of aircooling. Hydro cooling with ice and CaCl₂ for 30 min produces the best storage characteristics of tomatoes resulting increase in shelf-life up to 13 days as compared to air cooling for 24
hours, hydro cooling with raw water for 45 min, hydro cooling with ice water for 30 min (Shahi et al., 2012). At typical flow rates and temperature differences, water removes heat about 15 times faster than air (Boyette et al., 1994b). It is because of their relatively high cost, hydrocoolers must be operated for considerable periods each year to be economically justified.

**Contact or package icing:**

Before the advent of comparatively modern precooling techniques, contact or package icing was used extensively for precooling produce and maintaining temperature during transit. Crushed or flaked ice for package icing can be applied directly or as slurry in water (Thompson et al., 2002). Package ice can be used only with water tolerant, non-chilling sensitive products and with water tolerant packages.

In liquid icing, ice slurry is used instead of plain crushed ice as it can sustain cooling requirements better. The major advantage of icing is that produce does not dry as it is cooled. Gillies and Toivonen (1995) reported that 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 water-proof containers which are more expensive than normal are required for this cooling technique. Icing can be effectively used to cool products such as collards, kale, brussels sprouts, broccoli, radishes, carrots and onions.

**Vacuum cooling:**

Rapid cooling of horticultural produce can be carried out with vacuum cooling (Turk and Celik, 1993 and Thompson and Rumsey, 1984). Vacuum cooling is achieved by the evaporation of moisture from the produce. The evaporation is encouraged and made more efficient by reducing the pressure to the point where boiling of water takes place at a low temperature (Tambunan, 1994). The heat required to vaporize this water is removed from the product surface, hence the cooling rate is limited by heat and mass transfer (Tambunan et al., 1994), i.e. evaporation rate of water from the products surface and inner tissues. Therefore the rate of cooling depends primarily upon the ratio of surface area of the product to its weight or volume, the ease with which water is given up from the product tissues, the rate of vacuum drawn in the flash chamber and the temperature of the load at the start.

Many researchers agree that other vegetables such as spinach, parsley, asparagus, snapbeans, broccoli, cabbage, cauliflower, celery, green peas, sweet corn, and mushrooms may also be vacuum cooled (Sun, 1998). However, only lettuce, cauliflower, celery, cabbage, spinach and mushrooms are reported as being cooled on a commercial scale. The rapid cooling achievable by the use of vacuum cooling makes it more appealable and gives it a distinct advantage over other cooling techniques. Another advantage is that vacuum cooling can achieve uniform cooling throughout a package or lot of produce, provided the package or box is not hermetically sealed to allow free evaporation (Turk and Celik, 1993). Thompson and Chen (1988) investigated the energy efficiency of a variety of pre-cooling techniques and reported that vacuum cooling gave the best results as heat is only removed from the product which is being cooled. One disadvantage of vacuum cooling is that it causes weight loss in the produce being cooled due to the removal of moisture. Temperature reductions average 5 to 5.5°C for each 1 per cent of weight loss, regardless of the product cooled.

**Cryogenic cooling:**

The use of the latent heat of evaporation of liquid nitrogen or solid CO$_2$ (dry ice) can produce ‘boiling’ temperatures of -196°C 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 CO$_2$ 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 (Gormley, 1990). 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 period.

**Conclusion:**

The importance of precooling can be clearly
recognized as it is essential part of the proper temperature management of fruits and vegetables. 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-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 fruits and vegetables. 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 for most fruits and vegetables to attain its true potential.

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**WEBIOGRAPHY**