NOVEL PRE-COOLING TECHNIQUES AND THEIR EFFECT ON THE QUALITY OF COOLED FRUITS AND VEGETABLES

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ABSTRACT
Fresh fruits and vegetables are prone to spoilage in a short time (within 5 to 8 hours) after harvest, due to the presence of field heat, also known as sensible heat, and microbial activities. However, pre-cooling techniques, before further processing, offer to remove the field heat, affecting quality, shelf-life extension and market value. Therefore, information on the pre-cooling techniques and their effect on the quality of cooled fruits and vegetables is critical for process design and quality control. In the present work, novel pre-cooling techniques and their effect on the quality of cooled fruits and vegetables are reviewed. The quality parameters such as physical properties (like size, shape, and color), nutritional properties (like vitamins and minerals) and sensory (appearance, odor, taste, texture and overall acceptance) properties as affected by the novel pre-cooling techniques including hydrocooling, forced air cooling and vacuum cooling were presented. The quality of cooled fruits and vegetables is based on the process conditions which is highly dependent on the pre-cooling techniques. The mass composition, heat content and thermal property of products are reportedly considered as main factors for cooling efficiency. To produce cooled fruits and vegetables with high quality, more study and optimization of the pre-cooling techniques is necessary. The present work should provide critical information on the novel pre-cooling techniques and their effect on the qualities of cooled fruits and vegetables as affected by process conditions and the products for future studies.

KEYWORDS: Fruits and vegetables, Pre-cooling techniques, Field heat, Quality, Safety

1. INTRODUCTION

Fresh fruits and vegetables are important food materials with many qualities including vitamins and minerals (Gong *et al.*, 2009). However, quality stability is a major factor that determines their functionality and consumer's acceptance. Surprisingly, the presence of field heat (popularly known as sensible heat), affects quality and shelf-life of fresh fruits and vegetables (Aked, 2002; Kader and Rolle, 2004; Nzioki, 2013). According to Food and Agricultural Organization of the United State (FAO), about one-third of the harvested fruits and vegetables are lost due to field heat, poor handling and storage practices (FAO, 2011), resulting in low return in investment and thus pose serious challenge to local producers and food industry (Bradford *et al.*, 2018). In an attempt to solve this problem, cooling techniques are developed. Among several cooling techniques, hydrocooling, forced air cooling and vacuum cooling emerge as novel technologies. These technologies involve lowering the temperature of a freshly harvested product to a safe temperature prior to further processing, and are thus known as pre-cooling techniques. By lowering the temperature and reducing the activity of microorganisms in products, improvement in color, and better retention in vitamins and minerals have been reported for cooled fruits and vegetables that were pre-cooled by hydrocooling (Manganaris *et al*., 2007), forced air cooling (Aswaney, 2007; O‟Sullivan *et al*., 2017) and vacuum cooling (McDonald and Sun, 2000). In addition, a reduction in temperature lowers the heat content, energy requirement and processing costs. With these benefits, the pre-cooling techniques have been reported to preserve broccoli (Kochhar and Kumar, 2015), mushroom (Salamat *et al*., 2020) and cherry fruits (Manganaris *et al*., 2007).

During hydrocooling, samples are dipped in cool water or allowed to pass through a water cooling system (at a predetermined cooling time and temperature), where water gets absorbed into the samples through the cell structure (cell wall and cell membrane), providing a desirable firmness, crispness and turgidity (Kalbasi-ashtari, 2004; Kochhar and Kumar, 2015). The uniqueness of hydrocooling technique is in that it allows the combination of cooling and cleaning operations.

In the case of forced air cooling, cool air blows across products, creating a pressure difference between the product and the immediate environment, thereby removing heat content of the products. The effectiveness of this technique depends on three main factors including, temperature, air speed, and pressure (Aswaney, 2007; Mukama *et al*., 2017; Sullivan *et al*., 2017). For vacuum cooling (VC), normally applied for product with a large surface area, a uniform and rapid cooling is achieved. VC uses the principle of evaporating cooling to evaporate the moisture content in product in the form of vapor and thus, removing the sensible heat of products (Brosnan and Sun, 2001; McDonald and Sun, 2000).

Generally, the effectiveness of these novel pre-cooling techniques depend on two parameters viz: (1) the product (such as product size, shape and composition), and (2) the cooling rate which is hinged on the initial temperature, rate of flow of cooling media around the product and temperature difference between the product and cooling media (McDonald and Sun, 2000). The cooling conditions vary among the pre-cooling techniques and cause different effects on the final quality (Kochhar and Kumar, 2015). Since product quality remains an important parameter to consumer’s health and market choice as enhanced by different pre-cooling techniques (Rodriguez-Casado, 2016; Vad *et al*., 2019), it is important to understand the effect of pre-cooling techniques on the quality of cooled fresh fruits and vegetables with the aim of process integration and improvement. Therefore, this review focuses on the novel pre-cooling techniques and their effect on the quality of cooled fruits and vegetables. Characteristics and significance of fruits and vegetables to human health were first presented. Effect of hydrocooling, forced air cooling and vacuum cooling techniques on some quality of cooled fruits and vegetables were discussed, while some recent advances in cooling technology and future research considerations were highlighted. It is hoped that this review will provide useful information on the effect of pre-cooling techniques on the quality of cooled fruits and vegetables for the food industry.

2. CHARACTERISTICS AND SIGNIFICANCE OF FRUITS AND VEGETABLES TO HUMAN HEALTH

Fruits and vegetables have physical qualities (such as size and shape) and nutrients (such as vitamins, minerals and sensory properties) and phytochemicals that define their value. Typically, the physical qualities allow consumer acceptance, while the nutrients play significant roles in humans' nutrition (Vadiveloo *et al*., 2019; Vongpatanasin *et al*., 2016). Consumption of fruits and vegetables protects humans health due to the fact that many of the phytochemicals act as antioxidants, anticarcinogens, and immunomodulators (Rodriguez-Casado, 2016). The relative amounts of their phytochemicals depend on species and cultivars. Clinical studies reported that free radicals that mostly caused DNA damage and chromosome breakage can be inhibited by scavenging of oxidative agents and stimulate immune system through the intake of natural antioxidant found in fruits and vegetables (Vongpatanasin *et al*., 2016; Sharifi-Rad *et al*., 2018). In fact, the World Health Organization (WHO) has recommended daily intake of fruits due to their numerous health benefits (Rodriguez-Casado, 2016). In addition, epidemiological studies have supported the inverse relationship between regular intake of fruits and vegetables and the risk of cancer (Herr and Büchler, 2010; Latté *et al*., 2011; Manchali *et al*., 2012), heart disease (Rodriguez-Casado, 2016) and other coronary diseases (Filippini *et al*., 2017). All these numerous health benefits among many others have increased the interest in exploitation of physical and nutritional composition of fresh fruits and vegetables.

As mentioned earlier, fruits and vegetables vary in both physical and compositional properties, depending on type and variety. Typically, consumers pay attention to sensory satisfaction while evaluating fruits and vegetables. Consumer's attention is always drawn towards liking sensory property (appearance, odor, taste and texture) as the basis of their choice of selection and acceptance. Some evidence suggests that an increase in consumption of an apple cheery fruit is more strongly related to its flavor (Vad *et al*., 2019). Vadiveloo *et al.*, (2019) noticed some similarities and differences in the intake habits for peppers and pears. They investigated how positively or negatively proximate intake could influence liking, and willingness to purchase pears and peppers among 164 adults, considering color as a major factor. Their finding revealed that more than 36 Adults ate more peppers, based on the color condition as compared to other conditions. Also, the choice of eating pears was higher among adults, based on color when compared to other conditions. The findings suggest that there are more 'will' to purchase peppers and pears, based on color and therefore shows that color modestly increases proximal intake for pears and pepper (Vadiveloo *et al.*, 2019). More studies that reveal the choice of consumer of fruits and vegetables, based on a particular sensory property have been reported (Andersen and Hyldig, 2015; Lawless and Heymann, 2010). However, in some cases, consumers do not pay equal attention to all sensory properties. For instance, apple cherry taste is more significant to consumer, while odor is less significant (Vad *et al*., 2019). In the case of pears, color appearance is the predominant sensory property for the choice of selection (Vadiveloo *et al*., 2019).

Furthermore, fresh fruits and vegetables are rich in vitamins and minerals needed for efficient human body metabolism and good health (Dhital *et al*., 2018; Zhu, 2018). Importantly, their consumption provides a broad range of phytochemicals with huge potentials for prevention and/or amelioration of blood pressure in hypertensive patients (Rodriguez-Casado, 2016; Vongpatanasin *et al*., 2016), cardiovascular disease, stroke and kidney disease (Filippini *et al*., 2017; Manchali *et al*., 2012), and confer therapy against cancer (Herr and Büchler, 2010; Latté *et al*., 2011).

Notwithstanding, fresh fruits and vegetables are highly perishable in their natural state and need to be maintained after harvest to enhanced their quality. The rate of fruits and vegetables deterioration can be reduced by cooling (Brosnan and Sun, 2001; Delele *et al*., 2013; Tian *et al*., 2016), which helps to preserve quality within suitable environmental conditions. Although, cold chain technique has been recommended for safe-keep of harvested agricultural materials, about 23% quality is being lost in the process (Wu and Defraeye, 2018). This loss is attributed to adverse effect of temperature (in form of heat) on the materials before cold chain (see Figure 1) (Lo'ay and EL-Khateeb, 2019; Tassou *et al*., 2010). The quality loss due to disorderliness in physiological and biological processes (respiration and transpiration) within the produce cells signifies the importance of pre-cooling, as a promising technique for removing field heat from products, before storage or further processing (O"Sullivan *et al*., 2017). Pre-cooling offers a significant potential in bringing down products temperature to a pre-determined condition safe for their storage. Several pre-cooling techniques; vacuum cooling (Brosnan and Sun, 2001; McDonald and Sun, 2000); hydrocooling (Kalbasi-ashtari, 2004; Kochhar and Kumar, 2015); room cooling (Kienholz and Edeogu, 2002; Kochhar and Kumar, 2015), forced air cooling (Aswaney, 2007; Mukama *et al*., 2017; O"Sullivan *et al*., 2017), have been used to remove field heat, reduce activity of microorganisms, and thus enhance the quality of cooled products.

Figure 1: Typical effect of high temperature exposure (heat burn) on fresh tomato

3. EFFECT OF PRE-COOLING TECHNIQUES ON THE QUALITY OF COOLED FRUITS AND VEGETABLES

3.1 Hydrocooling technique

Hydrocooling is one of the most novel cooling techniques for freshly harvested fruits and vegetables. It involves spraying or dipping harvested product into cold water (temperature 4 ±1 ^{o}C) in order to reduce their temperature. In hydrocooling, water is absorbed into the product mass, reduces heat load and microbial activity, thereby preserving quality. The uniqueness of this method is that it combines cooling and cleaning (removal of debris and residual chemical) of agricultural products. Although, the technique is fast and efficient, its application is limited due to the fact that the used water can be reabsorbed into the product mass, if not quickly discarded, allowing food pathogen build up, thereby causing severe damage to the products. In an attempt to solve the problem of microbial build up in hydrocooling, Hopfinger (1989) suggests water treatment with chemical compounds such as chlorine and chlorine solution. The findings revealed that acidic pH and presence of iron (above 300 ppm) in water resulted in reduction of microbial activity in cellular tissue. Also, calcium (Ca^{2+}) present in fruit cell wall, in form of a pectin substance, serves as a cellular messenger and supports cell wall rigidity. Though, chlorine treatments have been shown to reduce the level of calcium present in the fruit cell, and encourage the occurrence of several disorder including cell wall breakdown (Poovaiah, 1993), some studies have been tailored towards finding a better approach to the approval of chlorine in hydrocooling systems. Kalbasi-ashtari (2004) deduced a phenomenon of infiltrating calcium chloride at moderate concentration during hydrocooling to improve the calcium cation present in the cell walls of peaches and pears thus, caused stable cell walls. Mostly all vegetables get cooled by hydrocooling due to their compatibility. In mature leafy vegetables, parent stalk is an important factor to physiological loss during hydrocooling. Kochhar & Kumar, (2015) investigated the effect of different pre-cooling methods on the quality and self-life of broccoli. They observed broccoli with stalk pre-cooled under hydrocooling method gave a lower physiological loss in weight, increase in L^*, a^* and b^* color values, increase in compression force (texture) and decrease in shivering at a steady increase in storage period when compared to broccoli without stalk (Figure 2). Manganaris *et al*. (2007) reported the potential of hydrocooling followed by 1 week cold storage (0 ^oC, 95 % R.H.) and observed a delayed in the deterioration and senescence of cherry fruit, maintaining a higher quality, as indicated by reduced stem browning and surface shriveling. In the same vein, addition of $CaCl_2$ to ice water increased the firmness (up to 60%) and lowered the pectin hydrolysis and weight loss of peaches and pears up to 30 % and 40 %, respectively (Kalbasi-ashtari, 2004). The sensory analysis also showed that peaches and pears pre-cooled with ice water containing $CaCl_2$ had significant higher firmness and more attractive appearance, color and flavor than air cooled samples. Devani *et al*. (2011) reported that hydrocooling (13 ^oC) for 4 hr can keep kesar mango up to 32 days, as compared with untreated fruits 25 days shelf life. The results on the shelf life, physiological loss in weight (PLW), texture, total soluble solids, acidity and total sugar show that, hydrocooling is an ideal cooling method to increase the domestics and export marketing of kesar mango fruits.

3.2 Forced air cooling

Forced air cooling is another important method used to reduce the temperature of freshly harvested fruits and vegetables. It could be regarded as a promising technology because firstly, compared with vacuum cooling, it has low investment cost. Secondly, it can be used for a wide variety of fruits and vegetables which justifies its installation economically (Salamat *et al*., 2020). Forced air cooling can reduce the respiration rate and ethylene production in agricultural products. Caparino *et al*. (2012) attributes fungi infection and severe decay damage of fresh produce to related factors, among which production of ethylene during respiration is significant. The faster and promptly reduction of temperature has added advantage in reducing the production and sensitivity of products to ethylene production.

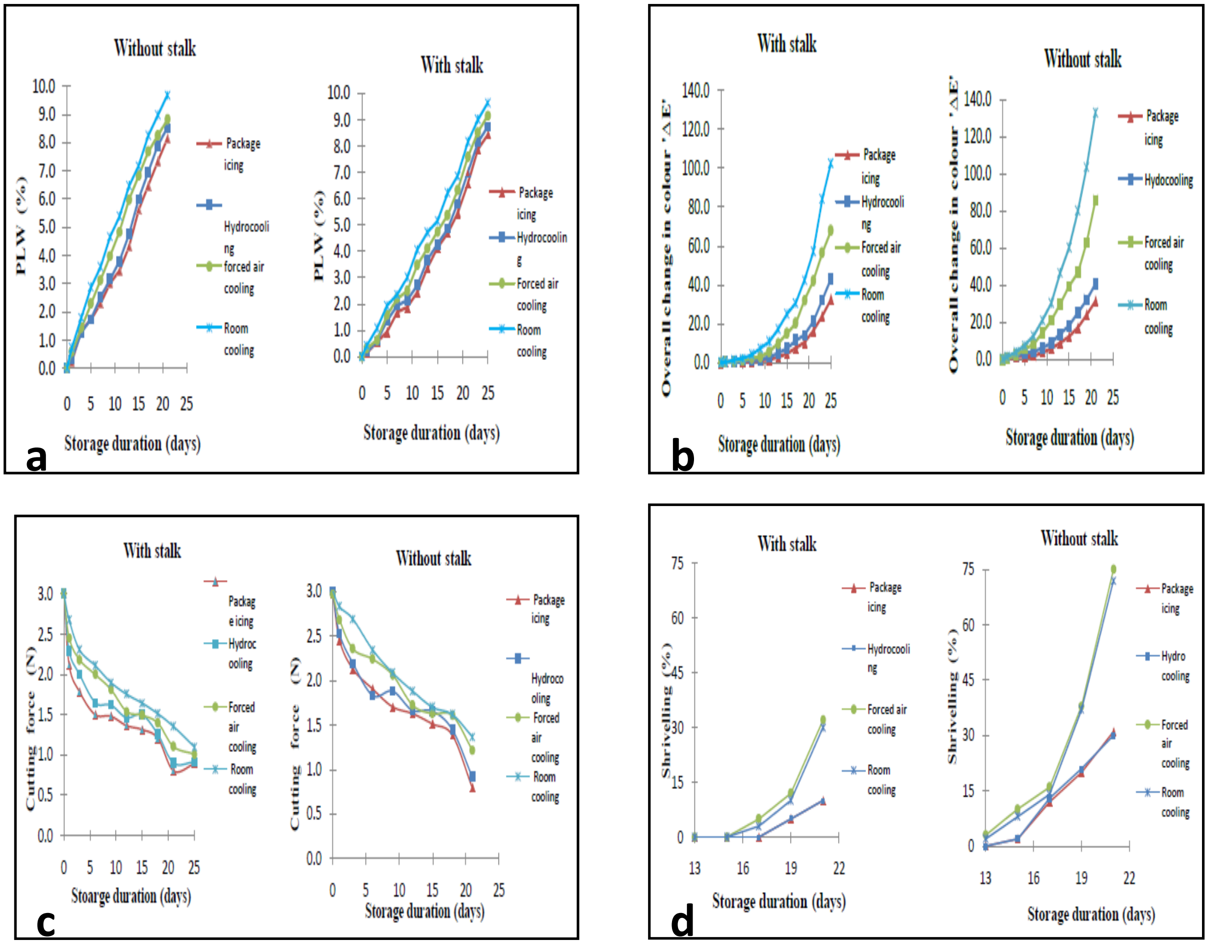

Figure 2: Effect of different pre-cooling methods on (a) physiological loss in weight (PLW), (b) overall change in color, (c) cutting force and (d) shriveling in cold stored of broccoli (Adapted from Kochhar and Kumar (2015)

Forced air cooling have been proved to be efficient in removing field heat from broccoli (Kochhar and Kumar, 2015) and mango (Devani *et al*., 2011) as quickly as one-fourth to one tenth time needed to cool by conventional room cooling. Yan *et al*. (2018) reported that forced air cooling (at 0 ^{o}C, 24 hr) can significantly maintain the quality (such as titratable acidity (TA), total soluble solids (TSS), pH, color and flavonoids) of apricot by enhancing antioxidant activity after storing for 20 days at 0 ^{o}C.

In forced air cooling, there are three main parameters (i.e temperature, pressure and air speed) that are needed in system design. Typically, air speed in the range of 1 to 3 cfm/ lb is sufficient enough to lower the temperature of main plant-based food materials (Aswaney, 2007). Importantly, the air velocity has significant effect in cooling rates of food products (Kumar *et al*., 2008). In the design of forced air cooling process of strawberry, O"Sullivan *et al*. (2017) investigated the mechanisms through which different design parameters affect the rate and uniformity of cooling. The results indicated that the vent area has a significant effect on the cooling rate, but not on its uniformity and therefore requires periodic air reversal, improving the rate and homogeneity of the cooling process.

3.3 Vacuum Cooling

Vacuum cooling (VC) offers rapid and uniform cooling of produce with a large surface area (Song *et al*., 2016). Its operation is based on the principle of evaporating cooling using temperature and pressure differences as operating parameters in a vacuum. When cellular water contained in cells of fruits and vegetables undergo a vacuum, it evaporates in form of vapor, thereby removing the sensible heat of products to the atmosphere (Brosnan and Sun, 2001; McDonald and Sun, 2000). However, the choice of VC relies on the product, moisture content, and surface to mass ratio of the products. Generally, VC is used for product with high moisture content and larger surface area (McDonald and Sun, 2000). Vacuum cooling technology comprises of vacuum chamber, gate, pump ventilation valve and electrical control unit. Figure 3 shows a typical vacuum cooling process. When a fresh fruit or vegetable (with initial temperature T_i), is placed into the vacuum chamber and the gate is closed, the vacuum pump is switched on, while the air is being evacuated and chamber pressure starts to decrease (Figure 3a). From Figure 3b, the chamber pressure is smaller than the atmospheric pressure, although higher than the initial pressure P_{sat} (known as saturation vapor pressure corresponding to T_i), it is not sufficient to remove heat content in product. As a result, there is no notable change in product temperature. When the chamber pressure reaches P_{sat}, water inside the product starts to evaporate and latent heat is released (Figure 3c). The sensible heat loss is approximately equivalent to latent heat of vaporisation of water. The technique allows the chamber pressure to be reduced to the flash point as soon as possible otherwise the vacuum pump will not be able to evacuate the air and no cooling will be further achieved. Therefore, the generated vapor being continuously removed by the vacuum pump reduces the chamber pressure to below P_{sat} (Figure 3d). This encourages water evaporation to continue and thus the cooling process. The cooling process stops when the desirable product temperature T_f is reached (Figure 3e). Then, the ventilation valve is opened, air is re-admitted into the chamber and the product is taken out of the chamber and stored at the recommended temperature (McDonald and Sun, 2000).

However, many studies have been reported on the effect of vacuum cooling on quality and safety of fresh fruits and vegetables (Carlos *et al*., 2018; Lin *et al*., 2008). Song *et al*. (2015) reported that respiration rate and enzymatic activity has a link to sensory, color changes and ascorbic acid content of fresh cellular tissues as affected by vacuum cooling. For example, respiration rate of leafy cabbages was lowered during vacuum cooling, with preserved quality (Zhu *et al*., 2018). Vacuum cooling factors (200 Pa, 40 min, and 30 % v/v) gave a weight loss and end point temperature of 0.34 ± 0.01% and 2.0 ± 0.0 °C, respectively, leading to a percentage profit of 99.66 ± 0.01% of broccoli (Carlos *et al*., 2018). Lin *et al*. (2008) demonstrated that vacuum cooling can rapidly reduce the temperature of Longman from 28 to 7 ^oC with 11 min, and subsequently preserve its quality.

Although, vacuum cooling had proved to be efficient in preserving fresh fruits and vegetables, weight loss is reportedly high for some products, and high cost of vacuum cooler has limited its application. Unlike in vacuum cooling, where air enters the vacuum chamber during pressure recovery stage at the end the cooling process, modified atmosphere vacuum cooling (MAVC) uses gas mixture consisting O_2, CO_2, and N_2 to achieve modified atmosphere storage, an improvement in vacuum cooling method. Zhiwei *et al*. (2018) used MAVC to preserved morphological structure of cabbages, including flowering cabbage, Chinese cabbage and green cabbage. The results indicated that MAVC enhanced color, sensory, ascorbic acid, chlorophyll and catalase (CAT) activity, and reduced the rate of respiration and the activity of peroxidase (POD) during storage (for 21 days under 4 ± 0.5 °C, R.H. 90 -95 %). Table 1 shows the effect of novel pre-cooling methods on quality of cooled fruits and vegetables.

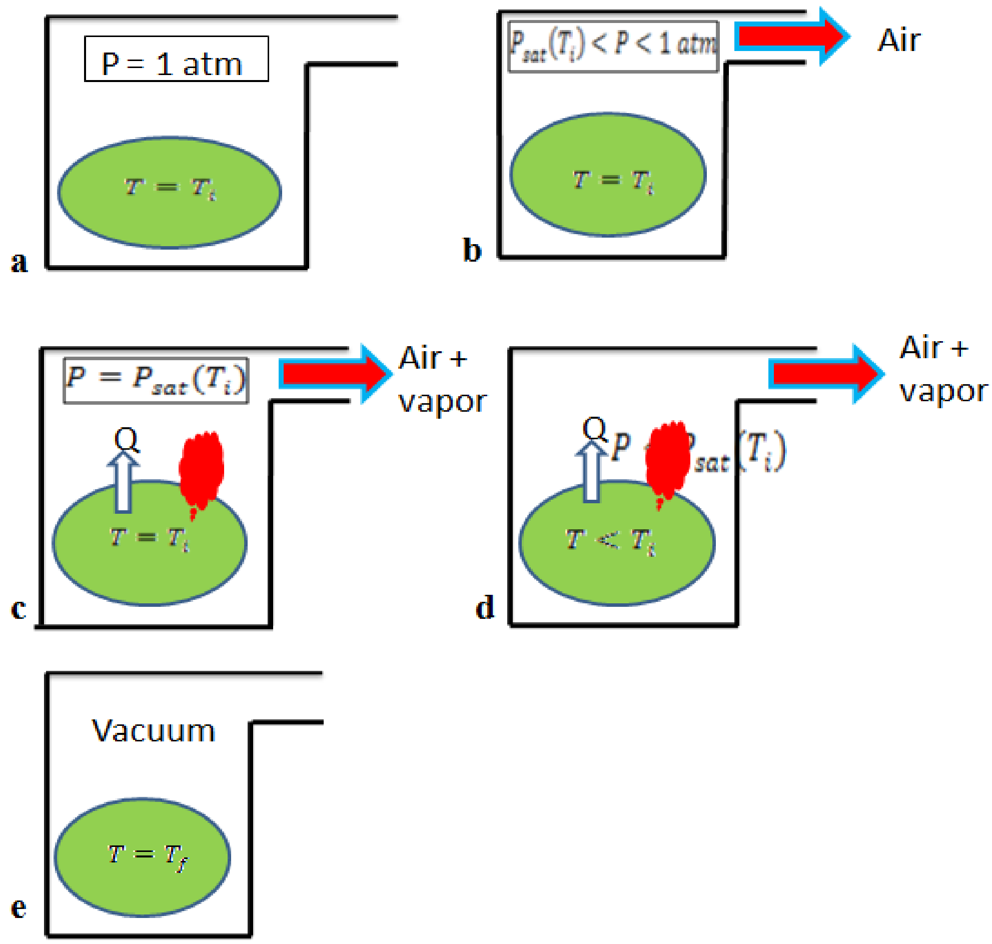

Figure 3: A typical vacuum cooling process

Table 1: Effect of novel pre-cooling methods on some quality of cooled fruits and vegetables

Products	Pre-cooling Methods	Pre-cooling Conditions	Quality Attributes Analyzed			General Observation	References
			Physical	Sensory	Nutritional		
Peaches and pears	Hydrocooling	Ice water + 2% (W/W) $CaCl_2$, and ice water + 100 ppm chlorine respectively for a holding time of 24h, 45, 30, 30 and 30 min until products temperature reaches 4 ºC	Firmness, pH, total soluble solids, weight loss	Appearance, color, firmness and flavor	Total acids	Addition of $CaCl_2$ to ice water increased the firmness (up to 60%) and lowered the pectin hydrolysis and weight loss of peaches and pears up to 30 % and 40 % respectively. Sensory analysis also showed that peaches and pears pre-cooled with ice water containing $CaCl_2$ had significantly higher firmness and more attractive appearance, color and flavor than air cooled samples	Kalbasi-ashtari (2004)
Sweet cherry	Hydrocooling	Hydrocooling follow by week cold storage (0 ºC and 95 % R.H.)	cracking, decay, external and soluble solids	Color, surface shriveling and overall acceptability	-	Results indicated that hydrocooling delayed the deterioration and senescence of cherry fruit, maintaining a higher quality, as indicated by reduced stem browning and surface shriveling	Manganaris *et al.* (2007)
Kesar mango	Forced air cooling and hydrocooling	forced air cooling (13° C) and hydr cooling (13° C) for 4 hr follow by cold storage at 13 ºC and 16 ºC	Physiological loss in weight (PLW)	Texture	total soluble solids, acidity and total sugar	Result indicated that the Kesar mango fruits treated with hydrocooling (13° C) for 4 hr could be kept up to 32 days, as compared with untreated fruits 25 days shelf life and in cold storage at 13° C kept up to 38 days, as compared with ambient condition 19 days shelf life	Devani & Karetha (2011)
Broccoli	Room cooling, forced air cooling,	Broccoli was pre-cooled to 2°C using four methods viz. room	Decay, shriveling, texture,	Color	-	It was observed that package icing and hydrocooling were better techniques of cooling	Kochhar & Kumar (2015)

	hydrocooling and package icing	cooling, forced air cooling, hydrocooling and package icing	Physiological loss in weight (PLW)			compared to forced air cooling and hydrocooling. The shelf-life and quality of broccoli could be maintained up to 18 days in broccoli with stalk and 15 days in broccoli without stalk respectively under cold storage conditions	
Broccoli	Vacuum cooling, ice-water cooling, and cold room cooling	Cold room cooling (0 – 3 ºC) follow by storage (at 5±1°C) for 30 days	weight loss, respiratory rate, chlorophyll	fresh, withering rate and rotting rate	vitamin C, reducing sugar content	It was observed that vacuum cooling was the most effective method for extending the shelf life of postharvest broccoli in terms of cooling rate, respiration rate, chlorophyll, vitamin C, reducing sugar and sensory properties	Tian *et al*. (2016)
Apricot	Forced air cooling	Forced-air pre cooled for 24 hr at 0 ºC, and then stored at 0 ºC for up to 20 days	pH	color	Titratable acidity (TA), total soluble solids (TSS), flavonoids	Results indicated that forced air cooling treatment slowed down a decrease of titratable acidity (TA) and total soluble solids (TSS) during storage period, whereas it had no effect on pH and L* value	Yan *et al*. (2018)
Broccoli	Vacuum cooling	Pressure (200-600 Pa), Time (20-40 min), broccoli weight (200-500g), water volume (2-6 %, v/v)	Weight loss and end temperature	-	-	Pressure (200 Pa), time (40 min) and water vol (3%, v/v) gave the best weight (273.5-278 g)	Carlos *et al*. (2018)
Cabbages	Modified atmosphere vacuum cooling (MAVC)	MAVC gas mixture consisting of 7 % O_2, 7% CO_2 and 86 % N_2 follow by storage for 21 days under 4 ± 0.5 °C, R.H. 90 -95 %).	Respiration rate, chlorophyll, and color	General appearance, shape, odour, wilting, bacterial decay and physiological disorders	Ascorbic acid	The results indicated that MAVC enhanced color, sensory, ascorbic acid, chlorophyll and catalase (CAT) activity, and reduced the rate of respiration and the activity of peroxidase (POD) during storage	Zhiwei *et al*. (2018)

4. ADVANCES IN COOLING TECHNIQUES

Several research efforts have been geared towards minimising weight loss, water loss and microbial build up during cooling whilst reducing the effect of field heat, microbial activity, respiration rate and ethylene production in harvested fruits and vegetables. The use of disinfectant such as sodium hypochlorite and thiabendazole in hydrocooling has been applied as an effective method in reducing metabolic activity during cooling of harvested fruits and vegetables (Arah *et al.*, 2016). Though, in-take of sodium hypochlorite possesses significant risk to humans' health, causes liver, bladder and kidney problem, some other compounds including chlorine dioxide (ClO_2), 1-methylcyclopropene (1-MCP) and calcium chloride ($CaCl_2$) are all effective alternatives to sodium hypochlorite (Arah *et al*., 2016), owing to their wide pH range with no harmful effect to human health.

To improve on forced air cooling technique, a wet deck system and dry coil has been designed to provide air of low temperature and higher level of relative humidity so as to reduce the weight loss of products (Arah *et al*., 2016).

Moreover, vacuum cooling (VC) has been integrated with modified atmosphere (MA) system in reducing weight loss and ensuring better quality (Zhu *et al*., 2018). However, a careful study that describes the theory behind each advance is recommended for global approval. Table 2 shows the advantages and limitations of novel cooling technologies for fresh fruits and vegetables.

5. CONCLUSION AND FUTURE TRENDS

Fresh fruits and vegetables are affected due to the presence of field heat and high temperature exposure, and thus become unmarketable as it damage their appearance, taste and nutritional qualities. Pre-cooling techniques particularly hydrocooling, forced air cooling and vacuum cooling techniques are novel and beneficial for removing field heat by lowering the temperature of harvested products, thereby preventing quality loss. Currently, none of the methods may completely solve the problem of quality loss in fresh fruits and vegetables without robust understanding of the interaction of the methods with internal systems of the products. Although, the pre-cooling techniques have made great impacts on preservation of fresh fruits and vegetables, challenging issues still remain and should be considered in future studies.

In order to enhance the hydrocooling technique, the use of chlorine dioxide (ClO_2), 1-methylcyclopropene (1-MCP) and calcium chloride ($CaCl_2$) treatment is required. In the future, more studies are needed focusing on the effect of ClO_2, 1-MCP, and $CaCl_2$ and/or their combination to cellular tissue during hydrocooling operation. Since forced air cooling favorably lowered the temperature of harvested products to a level safe for their storage, finding the best conditions in terms of operating parameters (time, temperature and air speed) that could maintain the cellular tissue and ensure cell structure stability is necessary for process optimisation.

Table 2: Advantages and limitations of novel cooling technologies for fresh fruits and vegetables

Methods	Effect	Advantages	Limitations	Applications
VC	Removal of water vapor from produce.	Rapid cooling; uniform temperature distribution; the cooling process can be stop at a pre-determined temperature and pressure	Weight loss; majorly for leafy vegetables with larger surface area	Cabbage; lettuce; mushroom; broccoli
MAVC	Reduction in rate of respiration through pre-set gases mixture (O_2, CO_2 and N_2) during pressure recovery stage.	High efficiency; extend self-life; reduce oxidative metabolism; slow down chlorophyll degradation	Expensive; moisture loss; cell membrane damage	Flowering cabbage; chinese cabbage; and green cabbage.
Water assisted UV-C	Removal of field heat and decontamination of cooling water	Non-toxic; residual free; low cost; low energy consumption	Overheating of product can cause quality loss; exposure to high wave length cause damage produce cell	Limited application; broccoli
PEF C	Removal of field heat and deactivate microbes	Higher microbial inactivation; enzyme destruction	Expensive to run	Limited application; strawberry
Cryogenic cooling	Uses latent heat of evaporation of liquid nitrogen or solid CO_2 (dry ice) to produce `boiling' temperatures of -196 and -78^{0}C and cause CO_2 to evaporate consequently cools the product	Rapid cooling	Expensive to run; at higher temperature, the product will freeze and cause harmful effects to produce; difficult to control.	Limited application; apples
High speed (740 m/min) jet hydrocooling	Remove field heat fast and extend self-life	Efficient, simple and reliable; decrease moisture loss, rinse while it cools relatively low cost and little maintenance.	Only suitable for ice tolerance fresh products; cold water recirculation can allows for contaminants to be absorbed into the food mass and cause deterioration	Carrots, sweet corn, broccoli, cantaloupes

Where: VC – Vacuum cooling, MAVC- Modified atmosphere vacuum cooling, PEF C- Pulsed electric field cooling

Despite good number of researches on the novel pre-cooling techniques, few studies are reported on thermal conductivity and mass transfer. Information on the thermal conductivity and mass transfer would be of great benefits for studies on quality control; therefore, more insightful study should focus on the correlation between heat and mass transfer and quality of cooled fresh fruits and vegetables during hydrocooling, forced air cooling, and vacuum cooling operations. Emerging techniques like fourier transform infrared spectroscopy (FTIR) that can detect the mobility of molecules would be of great benefits for studies on mass transfer.

In conclusion, relationship between respiration and quality attributes of cooled products need to be studied over a range of storage periods. These future investigations would provide valuable information on the best ways to preserve the quality of cooled fresh fruits and vegetables.

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