CHAPTER 2

Literature review

2.1 Postharvest Quality

Horticultural crops are living organisms after harvest and must remain alive and healthy until they are processed or consumed. The energy needed to stay alive comes from food reserves in the produce through a process called respiration. Heat energy is released during respiration. However, the rate of release depends on the type of produce, maturity, injuries and internal temperature. Temperature plays a significant role on the overall respiration rate since respiration requires the action of over 50 enzymes and the level of enzyme activity is affected by temperature.The effect of temperature on respiration rate is often qualified by determining the Temperature Coefficient (Q_{10}).

$$Q_{10} = \frac{\text{Respiration rate at } (\mathrm{T}\,℃ + 10\,℃)}{\text{Respiration rate at T}°C}$$

The Q_{10} can be calculated based on the number of $ml \cdot kg^{-1} \cdot h^{-1}$ of CO_2 evolved or O_2 absorbed. Generally, the respiration rate (Q_{10}) is increased by a factor of 2 to 4 for each temperature increase of 10 °C. The rate of respiration of some common produce at different temperatures are shown in Table 2.1

Table 2.1 Heat of respiration of produce at different temperatures (17)

Commodity	Respiratory heat generated per unit mass ($mW \cdot kg^{-1}$)			
	0°C	**5°C**	**10°C**	**15°C**
Apples	10-12	15-21	41-61	41-92
Asparagus	81-237	161-403	269-902	471-970
Blackberries	46-68	85-135	154-280	208-431
Blueberries	7-31	27-36	69-104	101-183
Cabbage	12-40	28-63	36-86	66-169
Cauliflower	53-71	61-81	100-144	136-242
Celery	21	32	58-81	110
Corn, Sweet	125	230	331	482
Leeks	28-48	58-86	158-201	245-346
Lettuce, head	27-50	39-59	64-118	114-121
Mushrooms	83-129	210	297	---
Onions	7-9	10-20	21	33
Oranges	9	14-19	35-40	38-67
Peaches	11-19	19-27	46	98-125
Pears	8-20	15-46	23-63	45-159
Raspberries	52-74	92-114	82-164	243-300
Strawberries	36-52	48-98	145-280	210-273

Source: Singh and Heldman, 2014.

The physiological processes that occur within the commodity after harvest are directly linked to its quality. They lose quality and potential storage life including weight, texture, flavor, nutritive value and appearance. Produce temperature is one of the most important factors affecting the postharvest life and quality of vegetables which affect the rate of quality loss caused by physiological and biological processes, it is necessary not only to reduce produce temperature but to cool it as quickly as possible after harvest to maintain a level of quality that meet the needs of customers.

2.2 Precooling Method

Precooling is the rapid removal of heat from freshly harvested produce. It is the key component in the preservation of quality for perishable fresh produce in postharvest systems and also very closely linked to the other operations such as handling and storage. There are several methods and techniques of precooling were developed including room cooling, hydro-cooling, forced-air cooling, ice cooling and vacuum cooling. Precooling as quickly as practical is therefore a very important requirement for maintaining optimum produce quality, especially for those types with naturally high respiration rates. Other benefits resulting from precooling fruits and vegetables include extends the shelf life and thus the opportunity for sale before the produce is no longer marketable (18). For example, comparison of estimated cost for two tons of mangoes harvested at the peak of the season (June 5 to 20) are handled either at ambient temperatures (30 to 35°C) or via an integrated cold chain (15°C) where cooling costs are relatively high (Table 2.2).

Table 2.2 Comparison of estimated cost and expected benefits related to cooling mangoes and maintaining the cold chain during handling, storage, transport and marketing.

	Ambient temperature	**Cold Chain**
Postharvest losses	35%	10%
Quality classes:	20% highest 50% second 30% lowest	50% highest 30% second 20% lowest
Total volume sold	2,600 lbs	3,600 lbs
Marketing period	June 15-June 28	June 15-August 1
Average price/lb ($)	0.50	1.25
Sales - cost of cooling ($)	1,300	3,500

Source: Wills *et al*. (2016).

2.2.1 Room cooling

Room cooling is one method used for produce sensitive to free moisture or surface moisture. Because this type of cooling is slow, room cooling is only appropriate for very small amounts of produce or produce that does not deteriorate rapidly. When using room cooling, produce is simply loaded into a cold room, and cold air is allowed to circulate among the cartons, sacks, bins or bulk load. (Figure 2.1). This cooling method is best suited to less perishable commodities such as potatoes, onions, and winter squash since highly perishable crops will deteriorate too much before being adequately cooled. On the other hand, 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 (1).

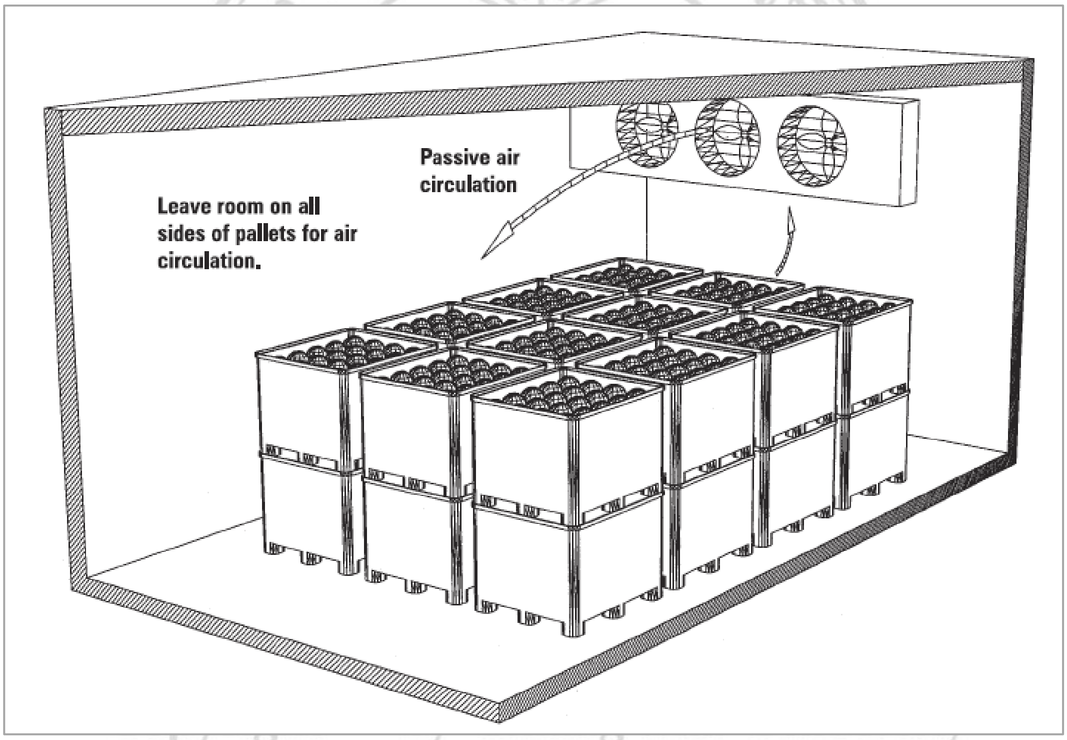

Figure 2.1 Room cooling.

Source; http://eagri.org/eagri50/HORT381/lec08.html

2.2.2 Hydro cooling

In hydro cooling, cold water is used to pre-cool produce by immersed in a tank of circulating cold water or as in other techniques, cold water is sprinkled or sprayed over the produce. Immersion hydrocoolers usually take longer to cool produce than shower type coolers. This method of precooling is faster than forced air cooling because water in direct contact with the produce has a higher heat removal capacity than air. Produce to be hydro-cooled can be spread out in a single or multiple layers, left in open field bins or be packed in vented plastic or wooden boxes. Containers need to be vented on the top to allow water to flow into the container and around the produce. Hydro-cooling works well for produce such as radishes, sweet corn, root crops, and celery, but does not work well for potatoes to be stored, sweet potatoes, bulb onions, garlic or other commodities that cannot tolerate wetting. Strawberries and cauliflower should not be cooled by this method because it results in rapid spoilage of the produce. Hydrocooling requires particular attention to water quality and sanitation. Chemicals may be used to kill molds and bacteria in the water and on the produce (19).

Cucumbers could be hydrocooled using water at temperatures below the recommended storage temperature of 10°C, it is not recommended that water temperatures below 6°C be used for the hydrocooling of cucumbers or that the product is cooled down to 1.7°C, due to increased risk of chilling injury development (20). Three cultivars of sweet corn were precooled immediately after harvest using a hydrocooler system, hydrocooled sweet corn cobs kept a high standard of quality up to 21 days by conserving high total soluble solids and moisture contents and maintaining excellent quality index. (21)

2.2.3 Forced-air cooling

Forced air cooling is used mainly for bulk produce and palletized produce. It is the most versatile and widely used of all cooling methods. In forced air cooling, chilled air is forced to flow around each piece of produce. This close contact of chilled air with the produce results in rapid, even cooling throughout the mass of produce. The air can be channeled to flow either horizontally or vertically. In a horizontal flow system, the air is forced to flow horizontally from one side of the pallet load to the other through holes in the sides of the pallet bin or containers (Figure 2.2). In a vertical flow system, the air is forced to flow vertically from the bottom to the top of the pallet through holes in the bottom of the pallet, and containers if used, then out the top (Figure 2.3). Although the cooling rate depends on the air temperature and the rate of air flow, this method is usually 75–90% faster than room cooling. Horizontally-directed forced-air cooling (HFC) and vertically-directed forced-air cooling (VFC) treatments resulted in higher cooling rates in the carrots, lettuce, and strawberries than cold room cooling

(CRC) treatment. Cooling by HFC and VFC was two to four times faster than cooling by CRC. However, under the CRC treatment, moisture loss from the produce was least (22). In these systems, condensation on the produce can be minimized by a simple cover placed on top of the stack of containers, which prevents the entry of ambient air during handling. To minimize moisture loss in room and forced air cooling, the evaporator of the refrigeration system should have as large a surface area as practical. Also, the evaporator should not be run at a temperature much below freezing as this practice causes undue drying of the air. Excessive air flow should also be avoided to minimize moisture loss (23).

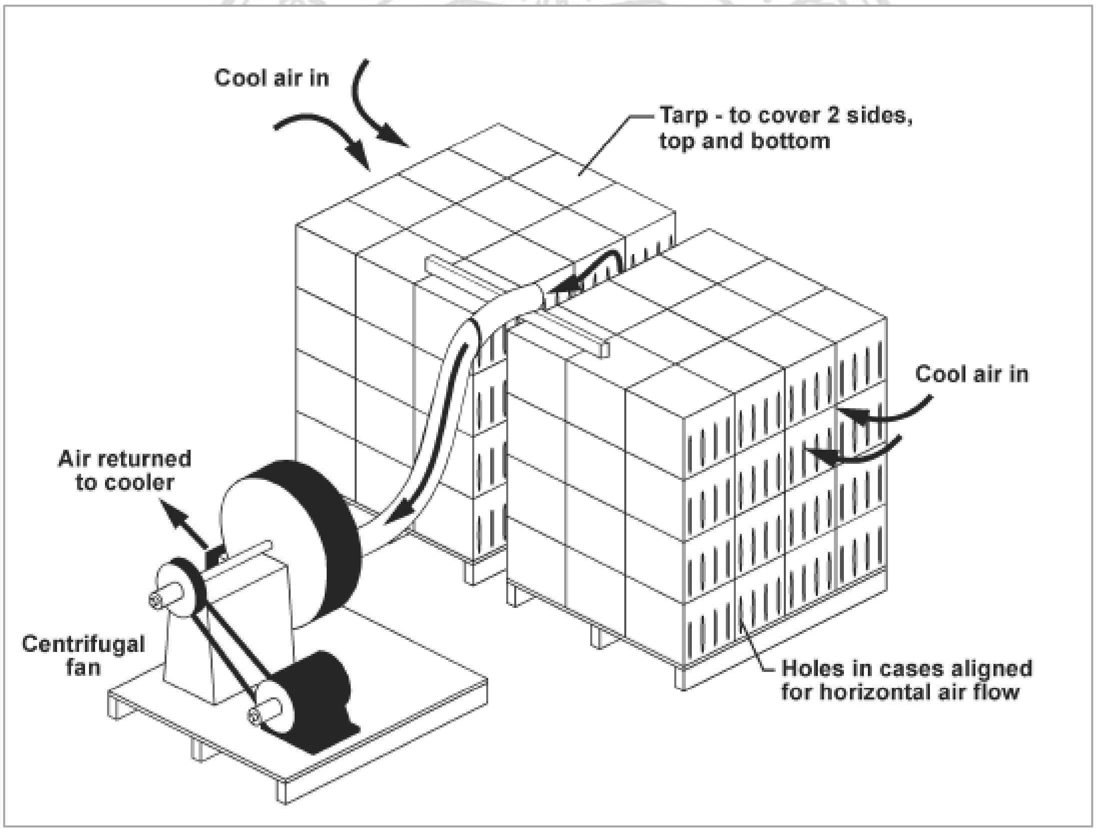

Figure 2.2 Forced horizontal air flow.

Source: http://eagri.org/eagri50/HORT381/lec08.html

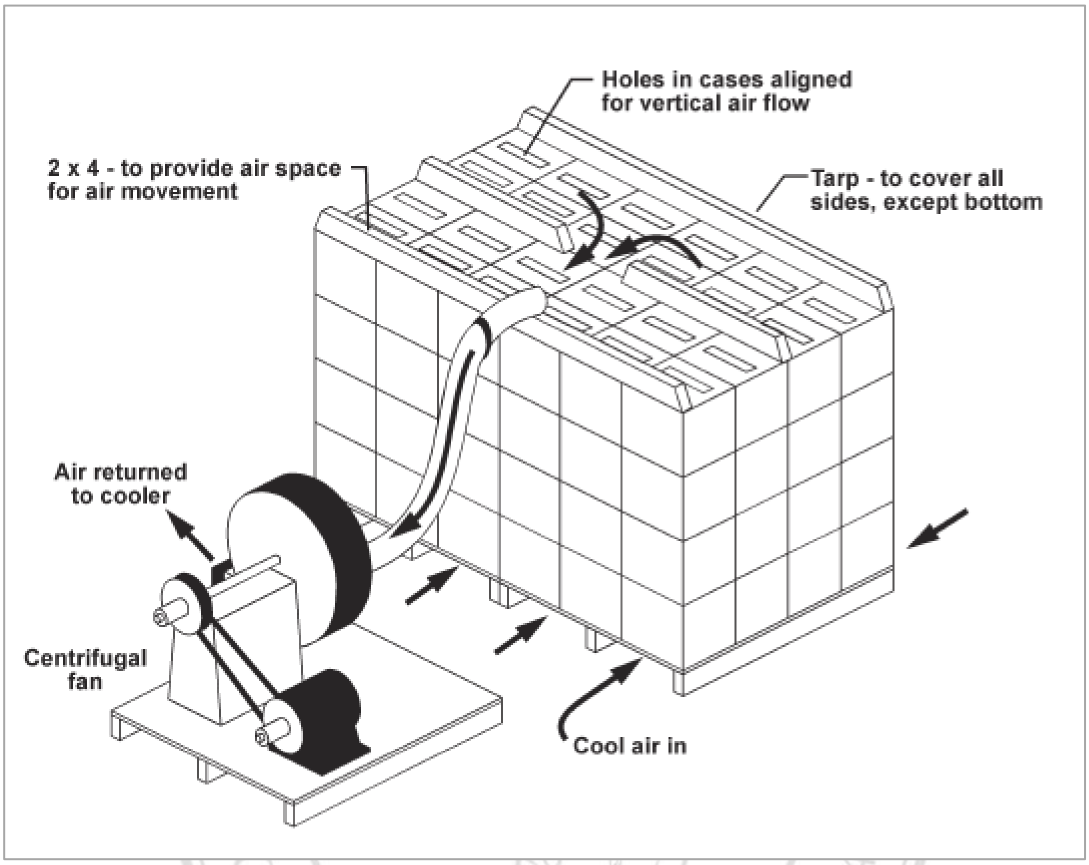

Figure 2.3 Forced vertical air flow.

Source: http://eagri.org/eagri50/HORT381/lec08.html

2.2.4 Contact Icing

Contact icing has been used for both cooling and temperature maintenance during shipping. The ice must come into direct contact with the produce in order to cool. The use of ice to cool produce provides a high relative humidity environment around the product and can reduce the rate of water loss in commodities sensitive to moisture loss. There are two types of contact icing: top icing and package icing (24).

Top icing: Top icing involves placement of crushed ice over the top layer of product in a container prior to closure. Although relatively inexpensive, the cooling rate can be fairly slow since the ice only directly contacts the product on the top layer. However, care should be taken to avoid blockage of vent spaces in the load, this restricts airflow, which results in warming of product in the center of the load during shipment. Ice should also be “tempered” with water to bring the temperature to 32°F (0°C) to avoid freezing of the product (25).

Package Icing: Crushed ice distributed within the container is known as package icing. Cooling is faster and more uniform than for top icing, but it can be more labor intensive to apply. Another advantage is that in addition to removing field heat, package icing can maintain low product temperature during transportation. 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. (1)

2.2.5 Vacuum cooling

Vacuum cooling has been used as an effective method for pre-cooling certain type of horticultural produces such as vegetables and fruits to prolong their storage life by reducing postharvest thermal deterioration (3). The principle of vacuum cooling is based on the rapid evaporation of moisture from the surface and within the produces. When water evaporates, it needs to absorb heat in order to maintain higher energy level of molecular movement at gaseous state. The amount of heat required is called latent heat, which must be supplied from the produce or from the surroundings that consequently are refrigerated (2). The basic principles of the vacuum cooling process are described as follows:

1. At atmospheric pressure (1013 mbar), the boiling temperature of water is 100°C. This boiling point changes as a function of saturation pressure therefore at 23.37 mbar the water boiling temperature will be 20°C and at 6.09 mbar, it will be 0°C.

2. To change from the liquid to vapor state, the latent heat of vaporization must be provided by the surrounding medium, so that the sensible heat of the produce is reduced.

3. The water vapor given off by the produce must be removed (Figure 2.4).

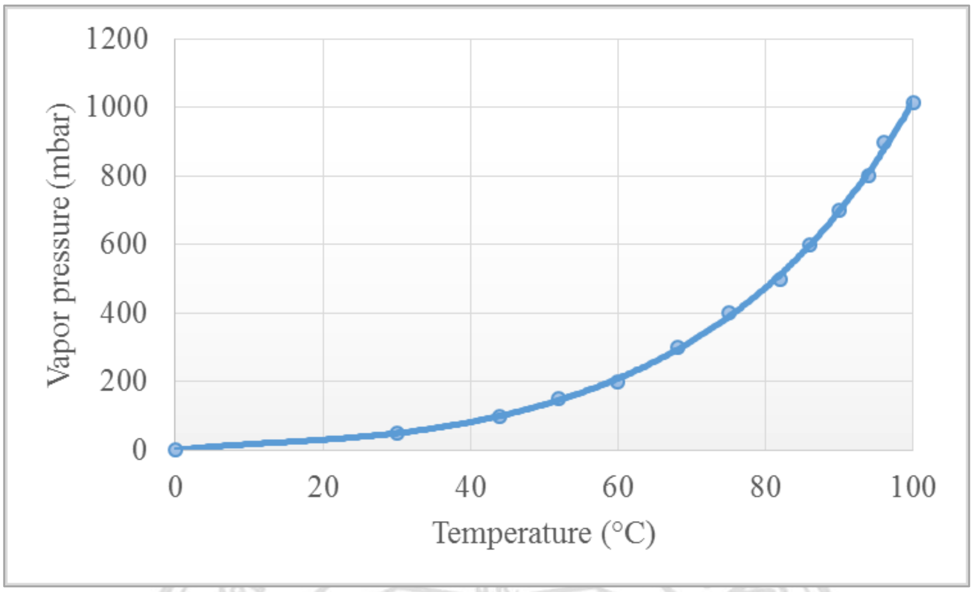

Figure 2.4 Water Vapor Saturation Pressure Curve

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, so 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, therefore produce begins to lose moisture and cool rapidly. 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 vapor. This vapor 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. The pressure is further reduced and cooling continues until a pressure corresponding to the desired final saturation temperature is reached. In practice, most operators do not reduce the pressure below 6.09 mbar (saturation pressure corresponding to a temperature 0°C) because of the extra work involved and the freezing potential at reduced pressures.

2.2.6 Vacuum cooling of vegetable

The effective of vacuum cooling are mainly related to the ratio between its evaporation surface area and the mass of produces. It is the best suitable for produce with high surface area to mass ratio, as it is an evaporative cooling method. It has been used as an effective method for pre-cooling certain type of horticultural produces such as lettuce, spinach, cauliflower, bok choy, bean sprouts, mushroom, celery, artichokes, green onions, cabbage and other leafy vegetables which are achieved through evaporating part of the moisture of the produce under vacuum condition and prolong their storage life by reducing postharvest thermal deterioration . The final produce temperature can be controlled precisely through the regulation of the final surrounding pressure that is usually set at no less than 6.5 mbar for food produce, otherwise freezing may occur, causing damage to the produce (3, 4).

2.2.7 Vacuum cooling of lettuce

Vacuum cooling was applied to crisp head lettuce before wrapping in unperforated polyvinyl chloride or polyethylene films or after packaging in perforated PP bags. They were vacuum cooled for about 20 min in order to reduce head temperature from around 20°C to 1–3°C. Subsequently all vacuum-cooled cartons were immediately stored at 2°C. After 2 week of cold storage. The result show that the effect of vacuum cooling was not significant on weight loss and wilting. Moreover, vacuum cooling was only useful in decreasing both pink rib and heart-leaf injury of lettuce after the marketing period (26). Vacuum cooling was an efficient method and suitable for cooling of vegetables such as iceberg lettuce. The vacuum cooling (at 0.7 kPa) of iceberg lettuce is 11.5 times faster than conventional cooling (at 2°C) (Tables 1 and 2). Mass loss during vacuum cooling is unavoidable due to the essence of vacuum cooling. However, mass loss for vacuum cooling (3.5% at 0.7 kPa) is also comparable with the conventional cooling (2.4% at 6 °C)(27). In term of theoretical analysis of vacuum cooling process based on thermodynamic principles which is limited mass loss based on the decrease in temperature during the vacuum cooling process. The calculation has shown that vacuum cooling is consume about 2 times less energy than conventional refrigeration system. It is considered that the energy consumption for the conventional refrigeration systems increase linearly with the weight of the produces. However, the energy consumption for the vacuum cooling does not change with the amount of the produce (28).

The mathematical model was used to predict the variation of the vacuum pressure in the chamber and the temperature distribution and weight loss variation of iceberg lettuce. It was found that the differences of the temperature between the simulation and the experiments were within 1 °C. The amount of water evaporated from the iceberg lettuce by simulation was 3.32% during the whole vacuum cooling, while the tested water loss rate was 2.97%, the maximal deviation of weight loss was within 0.59 %. The simulation results agreed well with the experimental data. The surface and the center temperature profiles of the iceberg lettuce during vacuum cooling by test and simulation was cooled from 18 to 1.41 °C (center temperature) within 32 min. It proves that the temperature distribution inside the lettuce is almost homogeneous at the end of vacuum cooling, which demonstrates that vacuum cooling is one of the most effective methods to remove the field-heat from fresh fruits and vegetables (29). The following experiments were performed to correlate the three differences pressure reduction rate of vacuum cooling (faster cooling rate; 15 min; moderate cooling rate: 30 min and lower cooling rate: 60 min) on microstructure, ultrastructure, physical and chemical quality of iceberg lettuce. Results revealed that the moderate pressure reduction rate achieved the maximum values of tissue firmness, ascorbic acid and catalase. The trend in the macroscopic results agreed well with that of the ultrastructure results. For example, the lowest value for catalase under faster cooling rate corresponded with severe injury of the membrane system. Similarly, the more severe the destruction of the membrane system was, the lower the tissue firmness (30).

2.2.8 Comparison of precooling method

Vacuum cooling is a widely used rapid evaporative cooling technique, considered as one of the most effective cooling methods which can be applied to fresh fruit, vegetables, cut flowers, meat production, fish and sauces. In term of energy use, efficiency of cooling systems varies with the type of cooler used. Vacuum coolers are the most efficiency, followed by hydrocoolers, water spray vacuum cooler, and forced-air cooler. On the other hand, there are several factors effect on the difference of efficiency among the precooling method such as levels of non-product heat input and the operational procedures during process can also contribute to differences between cooler types. Moreover, the variable among cooler of the same type can cause using of cooler at maximum capacity and type of commodity cooled in vacuum cooler, (cauliflower cools less efficiency than head lettuce). The most suitable cooling method to precool cauliflower in terms of cooling time and energy consumption was vacuum, followed by the high and low flow hydro and forced-air precooling methods, respectively. The highest weight loss was observed in the vacuum precooling method, followed by the forced-air method. During the precooling process, weight gain was observed in the cauliflower heads precooled with the low and high flow hydro method, while those precooled with forced-air and vacuum methods exhibited weight loss. The cooling methods used were compared in terms of power requirement; the vacuum precooling method had the maximum power requirement, followed by the low and high flow hydro and forced-air precooling methods, respectively (31). Vacuum precooling is the most appropriate method for the storage of the cauliflowers under controlled atmosphere and room conditions in terms of quality parameters, followed by the high and low flow hydro and forced-air precooling methods. Furthermore, the storage of cauliflower without precooling resulted in a significant decrease in quality parameters (32). For leafly vegetable, vacuum cooling seem to be the appropreate method due to rapidly and efficiently when it is compared with conventional cooling method. On the other hand, it has been noted that the mass loss is higher for vacuum cooling when it is compared with conventional cooling (28). Moreover, vacuum cooling treatment may increase in the mechanical injury of the leaves, increasing the fragility of the leaves and causing cell damage lead to reduce slightly the sensory quality of leafly vegetable (33).

2.3 Physico-chemical quality of lettuces

Baby Cos lettuce or romaine lettuce (*Lactuca sativa* var. *longifolia*) is a variety of lettuce which grows in a tall head of sturdy leaves with a firm rib down the center and belongs to the botanical family of *Asteraceae*. The characteristics of this variety is head forming lettuce, deep green and long leaves with a crisp texture and deep taste. Baby cos lettuce is an excellent source of vitamin A (in the form of carotenoids), vitamin K, folate and molybdenum. Moreover, it is extremely low calorie content and high water volume. Lettuce is very popular probably due to its crispness and attractive yellow-green color which can undergo changes in color due to chlorophyll degradation and browning appearance. Color is one of the main attributes, along with texture, that characterizes the freshness of most vegetables. However, the processing of vegetables promotes a faster physiological deterioration, biochemical changes and microbial degradation of fresh produces which may result in degradation of the color, texture and flavor. A relatively slight modification of the atmosphere within the package was applied for reducing physiological disorders, weight loss, wilting, and improve quality of winter iceberg Coolguard lettuce during 2 weeks at 2 °C followed by 2.5 days at 12°C and vacuum cooling was useful in decreasing both pink rib and heart-leaf injury after the marketing period (26). In term of chemical compound of fresh produce are relate to antioxidant activity and health-promote bioactive compound. The chemical compound of baby cos lettuce was varying from inner and outer leaves as shown in Table 2.3 (6).

Table 2.3 Chemicals compound of baby cos lettuce

Chemical compound	**mg g $^{-1}$ DM**
Total soluble solid	22.4-74.4
Chlorophyll (a+b)	12.5-13
Carotenoids	2.2-2.4
Total ascorbate (ASC)	8-10
Total phenolics	2.2-2.4

Vacuum cooling of lettuce with moderate pressure reduction rate (10,000–600 Pa within 30 min) was superior in terms of its quality. The result demonstrated that lettuce had achieved the maximum value of ascorbic acid and maximum firmness after cold storage at 1°C with 85% relative humidity (RH) for 2 weeks (30).

2.3.1 Bioactive components from leaf vegetable produces

Bioactive compounds are defined as non-nutritional substances that are found in very low concentrations in foods and that intervene in the secondary metabolism of vegetables and may have a significant effect on human health. Generally bioactive compounds in plants can be classified according to their chemical structure as antioxidant, vitamins, polyphenols, terpene derivatives, sulfur compounds, minerals, polyunsaturated fatty acids, dietary fiber, phytoestrogens and phytic acid (34).Current literature associated with education about some active metabolites from leaf vegetable materials are increased due to the perception of consumers of the health benefits and nutraceutical of these metabolites are considered as bioactive compounds (35). Scientific studies using cell culture and animal model studies have shown that polyphenols derived from vegetables can cause lipolysis, decrease lipid accumulation and induce apoptosis in adipose tissue. Currently, fruits and vegetables are the best sources of potential phytochemicals to reduce the risk of obesity appear to be: the red varieties of onion, lettuce, capsicum and curly kale. The experiments showed that the optimal combination of dietary phytochemicals can cause a positive response with the pathways which control the initiation and development of obesity and related chronic diseases (36). Generally, most of the bioactive compounds have a marked antioxidant capacity, which is revealed by their ability to trap oxygen radicals, nitrogen radicals, and organic radicals. They have been studied cancer prevention, heart disease, and other diseases (34). Lettuce are the most popular vegetables in salads which are attributed to a large supply of antioxidant compounds mainly vitamin C and polyphenols (flavonols and anthocyanins) as well as the fiber content. It was found that romaine lettuce showed the highest content of phenolic compounds, vitamin C and folates, with their recognized to be beneficial to human health. Phenolic compounds also have the capacity to extend shelf life when the lettuce is consumed in whole-head. Mini Romaine showed the highest content of organic acids and lipophilic compounds including carotenoids and chlorophylls, which have been accepted to antioxidant properties (37). The analysis of five varieties of lettuce species by HPLC-DAD-MS/MS ESI shows that the identification of two substances not previously reported in lettuce including quercetin and luteolin rhamnosyl-hexosides. Moreover, there are difference between qualitative and quantitative profile of polyphenols among lettuce species. Caffeic acid derivatives were the main phenolics in green varieties, while flavonols were found higher quantitative in red varieties and escarole. The amount of phytochemicals and antioxidant capacity contained in fruits and vegetables may vary depending on several factors including cultivar variations, environmental conditions, agronomic practices especially, harvesting factors such as the handling of postharvest procedures. In addition, food processing and produce storage factors also influence the level of phytochemicals present in the fruit and vegetables and their produces. However, novel processing techniques may offer a potential alternative to reduce the thermal impact on thermally unstable phytochemicals. The modified atmosphere packaging and low temperature used during storage of fresh-cut produces help maintain the levels of bioactive compounds over longer periods (38). Therefore, optimization of processing and storage factors are an important step to reducing the dissolution of phytochemicals for the health benefits (39).

2.4 Application of artificial neural networks (ANNs) for fresh produces.

An artificial neural network was developed to predict kinetics of ascorbic acid degradation in asparagus during blanching at different temperatures. The most common neural network is Feed-forward Back Propagation (FFBP) (Figure 2.5). For FFBP, the network includes an input layer, hidden layers, and an output layer. They can have more than one hidden layer, however, theoretical works have shown that a single hidden layer is sufficient for FFBP to approximate any complex non-linear function. (40).

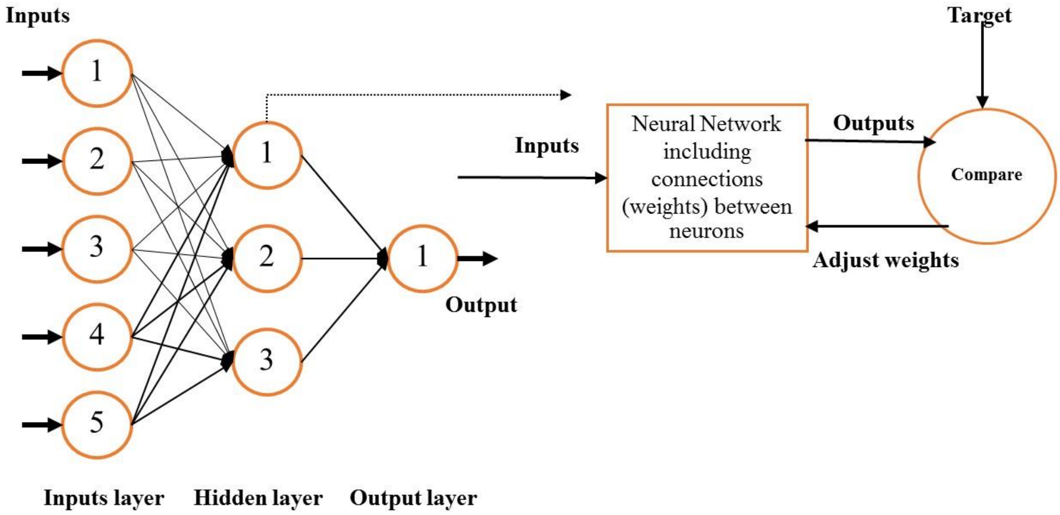

Figure 2.5 Typical structure and basic principles of artificial neural networks

Artificial neural networks can be used to predict the shrinkage and rehydration ratios of carrot undergoing different drying techniques in terms of normalized fractal dimension and moisture content. The result showed that the optimal models can predict the shrinkage percentage and rehydration ratio with R^2 values greater than 0.969 in all cases, offering better predictive performance than with traditional regression techniques. Moreover, models based on fractal dimension and moisture content were found to have a very good predictive value for the properties of dried carrots (41). A feed-forward neural network trained with an error back-propagation algorithm was used to evaluate the effects of pressure, liquid/solid ratio and ethanol concentration on the total phenolic content of green tea extracts. It was found that the trained network resulted a minimum value of the MSE (0.03) and the maximum value in the R^2 (0.9571), which implied a good agreement between the predicted value and the actual value, and confirmed a good generalization of the network. In addition, the total phenolic content of the actual measurement under the optimum predicated extraction conditions was 582.4 ± 0.63 mg/g DW, which was well matched with the predicted value (597.2 mg/g DW). This suggested that the artificial neural network model described in this work is an efficient quantitative tool to predict the extraction efficiency of green tea polyphenols (42). Neural network modeling was used to predict antioxidant activity and phenolic compound content of different varieties of banana, drying state and extract type with high accuracy. The results of empirical evidence showed that it is possible to train a neural network with one neuron in the hidden layer, to predict antioxidant activity based on the phenolic content with R value of 0.90 for the whole dataset (43).

2.5 Electrochemical analysis for measurement bioactive compound in fresh product

In recent years, there has been an increase of interest on sensors and rapid methods of analysis (44). The most widespread sensors are based on temperature, relative humidity, carbon dioxide, color, pH or electrical conductivity transducers (45). Despite they are rapid, simple and inexpensive, they result useless in the assessment of the potential bioavailability and biological activities of lettuces. The most widely used methods for determination of phenolic compounds in plant extracts are based either on liquid chromatography, or on photometric reactions or complexation carried out with spectrophotometer (46). The antioxidant activity of dietary phenols is often determined by measuring the radical scavenging activity of sample extracts (FRAP, TEAC, TRAP, DPPH and ORAC assays). These methods lack in accuracy because of variations due to sample turbidity or human errors during the experiment (47). A better knowledge can be achieved by liquid chromatography systems (HPLC-DAD and HPLC MS/MS) as the qualitative and quantitative difference of lettuce samples can be observed through the comparison of the resulting polyphenol profiles (48). However, such analysis typically requires significant amount of time, specialized operators and expensive equipment. Alternatively, the so-called “electronic tongues” have gained a growing popularity in recent years, especially in the field of food quality control. An electronic tongue is defined as “a multisensor system, which consists of a number of low selective sensors and uses advanced mathematical procedures for signal processing based on the pattern recognition (PARC) and/or multivariate data analysis” (9, 10). The existing literature on electronic tongues is extensive and comprises the combination of different sensors, such as electrochemical, potentiometric, conductimetric, optical, and piezoelectric transducers (48). The growing success of such analytical approach is mainly attributed to its simplicity, fast detection, affordability, miniaturization possibility and suitability for on-line or at-line detection (49).

Recently, a Coularray detector is increasing in popularity. This detector consists of coulometric electrodes deployed in series and independently poised at potentials between -1000 and 2000 mV. Coulometric detection is an absolute method, such that peak area can provide a means of quantification by relating area directly to sample mass using Faraday’s law, when the number of electrons being transferred is known. When using the Coularray, the analytical signals are usually higher than those obtained with the amperometric detector. For a given sample, a signal profile can be obtained as results of its content and quality of redox species. Indeed, Coularray can be viewed as an electronic tongue that utilizes the response across adjacent coulometric detectors as a molecular fingerprint. Pattern recognition procedures can be then applied for the identification of the samples (12-15). Although more than 1000 redox species have been detected with Coularray detector, these reported protocols are somewhat tedious, requiring columns and complex gradient elution profiles (16). Moreover, Coularray is rarely used with simple flow injection systems and its application as electronic tongue for solving pattern recognition problems is surprisingly unusual. Furthermore, despite the extensive research on pattern recognition, to the best of our knowledge no study has used electronic tongues with Coularray detector for investigating the effects of cooling techniques on lettuce quality.