Review on the controlled and modified environmental conditions towards the reduction of the chilling injury of peaches

Cristina Rodrigues[1], **Pedro D. Gaspar**[1, 2], **Maria P. Simões**[3], **Pedro D. Silva**[1, 2] and **Luís P. Andrade**[3, 4]

1: University of Beira Interior, Rua Marquês d'Ávila e Bolama, 6201-001, Covilhã, Portugal
e-mail: dinis@ubi.pt, web: http://www.ubi.pt

2: C-MAST - Centre for Mechanical and Aerospace Science and Technologies, Covilhã, Portugal

3: School of Agriculture, Polytechnic Institute of Castelo Branco, Qt.ª Sr.ª Mércules, 6001-909 Castelo Branco, Portugal

4: CATAA – Zona Industrial de Castelo Branco, Rua A, Castelo Branco, Portugal.

Abstract: *The peach is a stone fruit with a very juicy yellow flesh, smooth skin and a taste that satisfies the most demanding palate. The quality of this fruit is usually determined by texture, appearance, scent, flavor, nutritional value and food safety. At the marketing level, there is a concern for valuing visual properties, resistance, manipulation and fruit preservability, allowing a longer lifetime and less food waste. Being the peach a very sensitive fruit, which deteriorates and ripens very quickly at environment temperature, it requires conservation in cold. This is the usual method for delaying the product deterioration, both in perception of the consumer as in nutritional value, allowing to extend its shelf life. However, this process causes the chilling injury. This damage is a physiological disturbance, induced by low temperatures, which affects the quality of the fruit, reduces its storage and shelf life and impairs the organoleptic characteristics of the peach. This paper provides a review of the studies assessing the chilling injury and evaluates its consequences on peachs, providing the ideal conservation parameters of air temperature and humidity, in order to improve or enhance organoleptic characteristics.*

Keywords: *Peach, Organoleptic characteristics, Chilling injury, Environmental conditions.*

1. INTRODUCTION

The peach [*Prunus persica* (L.) Batsch] is a stone fruit, also known as drupe (Simões, 2016), very appreciated by the most demanding consumers (DGADR, 2018). Initially, the scientific name *Prunus persica*, emerged from a European belief because this fruit was from Persia. The ancient Romans referred to peaches as *malum persicum* ("persian apple"), later deriving in *pêche* and from there came the term "peach" (Campbell, 2004). Although the scientific name *Prunus persica* is originated from Persia, it is to be noted that this fruit arose and was first cultivated in China. It was introduced in Europe at the beginning of the Roman era and emerged in the United States of America (USA) during the 19th century. Between 1999 and 2001, the world production of this fruit was, approximately, 13.5 million tons, 40% of which is produced in Asia, 30% in Europe and 10% in America (Aubert & Milhet, 2007). According to FAO (2014), there was an increase in the world production of peach and nectarine with values of approximately 22.8 million tons, distributed over an area of 1.5 million hectares, of which 66.1% were produced in Asia, 19.8% in Europe and 9.9% in America. China is the world's main producer, representing 54.6% of the production and 48.7% of the area. Table 1 shows the five countries with the highest productivity levels, of which three are European, Spain, Italy and Greece, followed by the USA. Portugal is ranked 36th as a world producer, with annual production of 41 thousand tons, distributed over 3.6 thousand hectares (FAO, 2014; Simões, 2016).

In Portugal, the main peach producing region is Beira Interior, due to its excellent edafoclimatic conditions, being an added value for the production of these fruit species (Simões, 2016). The agricultural year of 2015/2016, according to data from the National Statistics Institute (INE), showed very high average air temperatures and low precipitation, resulting in a hot and dry climate. Consequently, in the following months there was a marked decrease in average temperature and a high precipitation, being the month of May the rainiest of the last 22 years.

Table 1. Main countries producing peach and nectarine in 2014 (FAO, 2014).

Country	***Production***		***Area***	
	Tonne (T)	**%**	**Hectare (Ha)**	**%**
China	12 452 377	54.6	728 354	48.7
Spain	1 573 640	6.9	86 118	5.8
Italy	1 379 428	6.1	74 478	5.0
Greece	962 580	4.2	50 270	3.4
USA	959 983	4.2	50 602	3.4
Portugal	**41 053**	**0.2**	**3 610**	**0.2**
World	22 795 854	100	1 494 837	100

The meteorological conditions allowed the increase of water reserves, however, they made agricultural practices difficult, forcing, to an intensification of phytosanitary treatments, in order to combat the cryptogamic diseases that arise under these conditions. In the case of peach and nectarine, adverse weather conditions influenced the production of these fruits, resulting in a marked decrease in production in 2016, about 31% face to 2015 (Figure 1). Thus, in 2016, Portugal presented a production of 32 thousand tons, distributed by 3.8 hectares (INE, 2016).

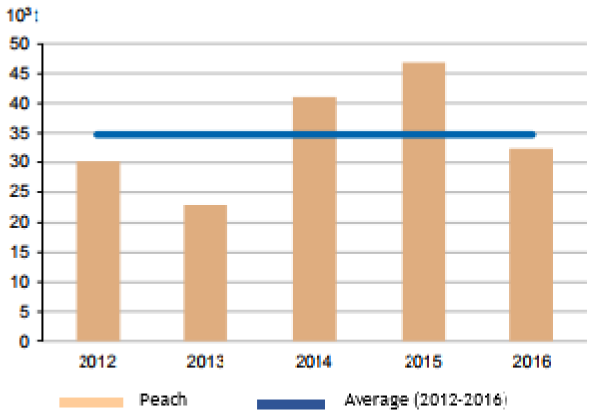

Fig. 1 – Peach production in Portugal from 2012 to 2016 (INE, 2016).

According to INE (2016), in 2016, the main peach producing region in Portugal was the Center Region, accounting with 60.9% of the area and 55.3% of production (Table 2). Followed by Alentejo Region with 19.3% of the area and 29.9% of production and the North Region with 12.3% of the area and 4.1% of production. The peach of Cova da Beira, according to the General Directorate of Agriculture and Rural Development, is a fruit that belongs to several varieties of the species *Prunus persica Sieb.* and *Zucc.*. Its production results from the existence of different varieties in the region, such as *Dixired*, *Red Top*, *J. H. Hale*, *Merril Franciscan*, *Black*, *Rubidoux*, *Carnival* and *Halloween* (DGADR, 2018). The production of the region of Beira Interior is mainly due to the particular climate. Beira Interior is crossed by the river Zêzere and is located between mountains Serra da Gardunha and Serra da Estrela, providing cold, a mild spring and protection against the atlantic winds. Associating these characteristics with the good aptitude of the soils, the ideal conditions for the production of the Cova da Beira peach, recognized as a peach with specific characteristics (DGADR, 2018). Mostly, this region is composed of two types of soils, the dystrophic cambisols and the dystrophic fluvisols. Most of the peach orchards are located in dystrophic cambisols (63.1%), due to the moderate erosion of the material caused by the small proportion of clay and organic matter and by the high permeability, resulting from its coarse texture, fundamental characteristics for good development of orchards. On the other hand, there are peach orchards that are next to the banks of the Zêzere river, corresponding to the dystrophic fluvisols (27.7%). In this case, the soil is characterized by a higher clay content, in relation to the cambisols, resulting in higher fertility, although they can present a poor drainage, due to the material deposition resulting from erosion. There is, however, a small number, but growing, of peach orchards that are located in lithosols eutrics (6.2%) and humic cambisols (3.1%) (Simões, 2016).

Table 2. Portugal production area and productivity by region, in the year 2016 (INE, 2016).

Region	***Area***		***Production***	
	Hectare (ha)	**%**	**Tonne (T)**	**%**
North	476	12.3	1321	4.1
Center	**2355**	**60.9**	**17882**	**55.3**
Lisbon Metropolitan Area	94	2.4	574	1.8
Alentejo	746	19.3	9648	29.9
Algarve	194	5.0	2864	8.9
Azores	0	0.0	0	0.0
Madeira	0	0.0	0	0.0
Portugal	3865	100.0	32289	100.0

2. ORGANOLEPTIC CHARACTERISTICS AND PEACHC EVALUATION PARAMETERS

The quality of the peach trees and, consequently, the quality of the fruit is influenced by the location of the orchards. Thus, there is a need to describe the organoleptic characteristics of the peach and the parameters of evaluating of its quality. The fruits of the peach tree are also known as drupe, characterized by a thin exocarp, designated skin, a flesh and juicy mesocarp, called a pulp/flesh, and a hard and lignified endocarp, designated a pit, usually containing one or two seeds in its interior, as can be observed in Figure 2. Thus, the fruits can be quite diverse, differing in shape, exocarp coating, endocarp adhesion to mesocarp and the staining of the epicarp and mesocarp. In the case of peach, the coating of the epicarp is by indument, that is, the outer layer that lines the fruit contains a soft skin with fur. The color and the coloration homogeneity of the epicarp can present a great diversity, varying, generally, between the yellows, whites or reds shades, being the majority of the peaches contain a pulp of yellow color (Lurie & Crisosto, 2005; Aubert & Milhet, 2007, Simões, 2016).

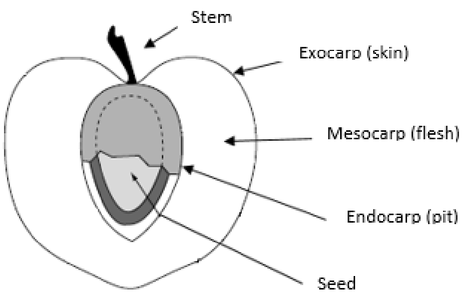

Fig. 2 – Diagram of a typical peach (Aubert & Milhet, 2007; Simões, 2016).

The quality of the fruits is generally determined by its texture, appearance, aroma, flavor, nutritional value and food safety. Thus, it is necessary to indicate which parameters to evaluate and which will serve to characterize them, according to production, commercialization/marketing and consumption perspectives. At the production level, is valued the productive capacity that is directly related to the yield of the cultures, which main parameters are the global weight of production, the weight of the fruits (caliber), the resistance to pests and diseases and the resistance to manipulation.

The properties related to the visual appearance, hardness, manipulation resistance and preservability of the fruits are valued at the commercialization level. These characteristics allow to extend the shelf life. Finally, at the consumption level, in a first step, are valued the visual characteristics, such as color, shape, absence of defects and the size of the fruits. In a second phase are valued the taste characteristics, such as hardness, texture, succulence and the taste of the fruits, that determine your demand. Still, at the level of consumption are valued aspects related with food safety and the nutritional value. In this case, food safety is related to the labeling that each product contains, while the nutritional value appears related to intrinsic non-observable characteristics (Simões, 2016). In this peach specific case, the nutritional value allows to conclude that is a fruit rich in ascorbic acid (vitamin C), carotenoids and phenolic compounds and a good sources of antioxidants (Lurie & Crisosto, 2005). In addition to the sensory parameters, it is also necessary to describe the peach quality evaluation parameters. The parameters normally used for this evaluation are, the color, the size, the hardness, the soluble solids tenor (SST) and the acidity (Zhang *et al.*, 2011; Simões, 2016). These parameters are often evaluated because of their importance at the normalization level and of technical decisions, as well as the simplicity of the required devices, as for example scales (weight), calibrators (caliber), penetrometers (hardness) and refractometers (SST). For the evaluation of the acidity and coloration, it is necessary to use devices and techniques more complex and time-consuming (Simões, 2016). Then, the main characteristics of each quality parameter of peaches are enumerated very succinctly:

a) Color is used by producers as the first indicator of the maturation status. This is determined with the naked eye, by the pigments of the epicarp, being able to vary between the shades yellow, red or even rayed. In technical terms, is also determined, through the use of a reflectance colorimeter. This parameter is widely used in the decision to harvest of a fruit. However, the relationship between the coloring state and the maturation stage may not be sufficient to proceed to harvesting. The coloration is strongly influenced by climatic conditions, resulting in the ideal coloration of the fruit, however the right coloration may not occur in the ideal maturation state for consumption (Cáceres *et al.*, 2016; Simões, 2016). Harvesting is an important procedure, since it is directly related to post-harvest quality and fruit conservation. When the fruit is harvested at an immature phase the fruits present greater hardness, a higher acidity and smaller organoleptic quality, at the level of taste and texture. On the other hand, the manipulation of the product at the market level will be easier. However, when the fruit reaches its maturity in the tree there is a greater acceptance, by consumers although their susceptibility to bruising and deterioration becomes faster. Therefore, to achieve the optimum maturity in the peach harvest, it is necessary to perform maturation tests, which take into account the analysis of the caliber, the hardness and soluble solids (sugar content) (Bonora, 2013; Simões, 2016).

b) The size of the fruits can be evaluated in a simply form, through weight, or in a more accurate form through caliber. The evaluation through weight is expressed in grams (g). Usually the weight of the peaches varies between 50 g and 500 - 600 g. On the other hand, evaluation through caliber is done by measuring the equatorial diameter of the fruit and the value is expressed in millimeters (mm). This measurement uses manual calibrators in which, small quantities of the fruit are required and industrial calibrators using high quantities. There are various caliber classes that are designated by letters, depending on the fruit, which help in the homogeneity of the fruit, as shown in Table 3 (Simões, 2016).

Table 3. Caliber classes and respective peach size and weight (Simões, 2016).

Designation Calibers	***Equatorial range (mm)***	***Weight (g) Range of values / Average***	
AAA	≥ 90	>332	
AAA	81 the 90	245 – 332	290
AA	74 the 80	165 – 245	220
A	68 the 73	155 – 165	170
B	62 the 67	120 – 155	135
C	57 the 61	94 – 120	106
D	51 the 56	< 94	

c) Hardness is the most important quality parameter, because it determines the harvesting date and works as the indicator of the state of maturity of the fruits. It is evaluated using penetrometers, where the resistance that the pulp of the fruit exerts to penetration is determined (up to 1 cm deep). When the hardness value is high, the fruit shows a low state of maturation (immature), a high resistance to manipulation and low organoleptic characteristics. When the hardness is low, the fruit shows a more advanced state of maturation, a lower resistance to manipulation, but more intense organoleptic characteristics (Simões, 2016). According to previous studies, the range of hardness more favorable to harvest, ensuring a greater expression of the organoleptic characteristics and not compromising handling, is between 5 and 6 kg/0.5 cm^2 (Simões, 2008). In the case of Cova da Beira region, where the temperatures during the summer are very high, a decrease in hardness of fruit was observed, (0.20 kg/0.5 cm^{-2}/day to 0.24 kg/0.5 cm^{-2}/day), when the average daily temperature is 22 °C to 25 °C (Simões, 2016).

d) Soluble solids tenor (SST) is related to the sugar content of each fruit and is one of the most appreciated parameters by consumers. This is determined through use of a refractometer, which evaluates the quantity of soluble solids (SS) present in fruit juice, through the refraction of the light incident on the juice drops. The resulting light refraction is proportional to the quantity of soluble solids present in the juice, essentially consisting of sugars. The sugar content increases during fruit maturation and this parameter is enough influenced by the soil and climatic conditions associated with the production site, by the cultural techniques carried out by the producer and by factors intrinsic to the plants, particularly the position of the fruits and the load of the plants. The soluble solids tenor is expressed in percentage (%) or ºBrix (Bonora, 2013; Simões, 2016).

e) The acidity is also one of the parameters that presents a great influence in the quality of the fruit before the consumer. This is determined based on a titration and is expressed in $meq_{malic\ acid}/L_{juice}$ or $g_{malic\ acid}/L_{juice}$, being the malic acid, the main organic acid present in the fruit. In the case of peaches, the classification of this parameter is distinguished in cultivars of high acidity, for values ranging from 7 to 9 $g_{malic\ acid}/L_{juice}$, and in low acidity cultivars, for values ranging from 3 to 5 $g_{malic\ acid}/L_{juice}$ (Simões, 2016).

3. CHILLING INJURY

The chilling injury (CI) is characterized as a physiological disturbance, induced by low temperatures, but not negative, that affect fruit quality (Meng *et al.*, 2009) and harms lifetime at storage (Lurie & Crisosto, 2005). The brown color the peach mesocarp (pulp), evidence one of the visual symptoms of this damage, which develops more rapidly between one and two weeks, when fruits are stored at temperatures between the 2.2 ºC and 7.6 ºC, being known as the interval of death. In this conditions, and as can be seen in Figure 3, the peach will also present a floury pulp, a dry texture, lack of flavor and, in more advanced cases, the peach eventually undergoes a separation of the pulp and form cavities. In addition to the chilling injury, the discoloration of the mesocarp is also due to the oxidation of the phenolic compounds. Thus, these compounds have a double action, that is, help in the discoloration of the pulp, when subjected to storage at high temperatures, and allows the peach to have a good antioxidant power, common feature in this fruit (Crisosto *et al.*, 2004; Lurie & Crisosto, 2005; Meng *et al*., 2009; Pan *et al.*, 2016).

Fig. 3 – Chilling injury symptoms and evolution over time (Lurie & Crisosto, 2005).

The chilling injury is generically influenced by the combination of storage temperature and the period of storage time (Lurie & Crisosto, 2005; Pan *et al*., 2016). For peach, cold storage is the most commonly used method, since it includes an effective technology (Zhang *et al.*, 2011), has the ability to delay the deterioration of the product, both in terms of the consumers perception and of nutritional value (Tsantili *et al.*, 2010), and, still, prolongs the shelf life of the peach (Zhang *et al.*, 2011). The time and success of the conservation process depends on biological factors, such as, the fruit respiration, transpiration and the action of ethylene. The fruit respiration is considered the most adequate index to express physiological activity, as well as the storage potential. It is a biological process under aerobic conditions by which organic compounds, especially carbohydrates, are degraded into simpler products (carbon dioxide and water) and heat.

$$(C_6H_{12}O_6) + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O + \text{Heat}$$

This process involves the oxidative decomposition of the organic constituents of the fruit and loss of food reserves (sugars, organic acids and starch). These losses will lead to a decrease in nutritional value (energetic and vitaminic), reduction of quality characteristics, such as flavor, weight and texture and, consequently, aging of the fruit, called senescence (Pinto & Morais, 2000; de Souza e Silva *et al*., 2005).

The fruit respiration is measured by the respiration rate and is related to their degradation, that is, the higher the rate of respiration, the greater the degradation of the products. The peach has a moderate respiratory rate (Pinto & Morais, 2000). It is, still, necessary to highlight the importance of the quantification of the heat released, essential for the estimation of refrigeration and ventilation needs. During the fruit respiration process, there are gas exchanges with the environment, such as CO_2 production and O_2 consumption. When the level of O_2 consumed is low, the combustion is incomplete and the formation of by-products that give an abnormal flavor to the fruits occurs (Pinto & Morais, 2000; de Souza e Silva *et al*., 2005). The respiration rate is expressed in mg of CO_2 per kg_{fruit} per hour. In general, all products have a low respiration rate when the temperature is at 0 °C. Although the respiration rate varies in some cases, this tends to be more stable when temperatures vary between 0 ºC and 5 ºC. This temperature range is the most suitable for fruits that are stored for longer periods and a promote greater conservation of its organoleptic characteristics. Thus, when refrigeration is rapid a reduction in the metabolic activity occurs, an aging control and, consequently, a more effective conservation (de Souza e Silva *et al.*, 2005).

The transpiration, one of the most important biological phenomena for a good conservation process, is influenced by external factors, such as temperature, relative humidity, air circulation during storage and also by the characteristics of the product, such as morphological characteristics, surface/volume ratio, epidermis damage and maturation status. The fruit transpiration consists, essentially, in the evaporation of water from the tissues. This is a problem, since the loss of water from the fruit after harvesting results in salable weight loss and the decrease of appearance and texture, that are very appreciated by consumer´s (Pinto & Morais, 2000).

The peach is known to be climacteric fruit dependent on the sensitivity of ethylene. Ethylene is a natural hormone derived from plant metabolism and responsible for regulating the growth, development and tissue senescence of the fruit. In this case, ethylene has the ability to trigger the fruit ripening process (Pinto & Morais, 2000). To slower down this process the CO_2 concentration is increased, the O_2 concentration is decreased and the temperature is set between 0 °C and 5 °C (de Souza e Silva *et al.*, 2005). On the other hand, the rate of ethylene production tends to increase with maturation, physical damages, diseases and with the temperature increase (Pinto & Morais, 2000). Thus, the increase in the storage period is obtained by reducing the atmospheric pressure at the storage site, which causes a reduction in the ethylene production rate (Pinto & Morais, 2000; de Souza e Silva *et al.*, 2005).

For the conservation process to be ideal, and meets all the above characteristics, it is necessary to analyze the factors prior to harvesting, during and after harvesting. The analysis of these factors plays an important role in obtaining an ideal conservation method so that the fruit does not suffer any damage, while maintaining its organoleptic characteristics. The analysis of the optimum harvest time is important, because in the case of an early harvest, there may be several consequences, as a lower weight of the fruit, poor quality and, at the end of conservation, an irregular and incomplete maturation. If the harvest is carried out at a later stage, the conservation capacity will be lower, and will appear the physiological changes and the fall of fruit, as well as the appearance of cuts and molds. Thus, after determining the ideal harvest season, this should be done with care and the fruits should be harvested with the stem and without leaves (Pinto & Morais, 2000). After harvesting, it is necessary to store the fruits, depending on their characteristics and the intended purpose. For an effective storage, it should give prominence the cleaning of the fruits, in order to prevent fruit damage, and to facilitate the ventilation, and the classification of the fruit is needed, to avoid damaged and infected products. The cleaning process consists of removing all the particles outside the fruit, such as earth particles, stones and plant remains. The classification of fruits is based on its commercial quality, the state of maturation and in the physiological characteristics, following the marketing standards published by the official entities (Pinto & Morais, 2000; de Souza e Silva *et al.*, 2005). After harvesting, in order to remove heat from the fruit quickly and efficiently, pre-cooling methods are used. When the fruit is in the refrigeration chamber, the ideal storage temperature depends on the total refrigeration capacity of the equipment and the air velocity that passes through the evaporator and reaches the product. While the fruit does not reach the ideal temperature, there is an increase in water loss and a decrease in the maximum storage time. In most refrigeration chambers, the air circulation is moderate, so the water loss is smaller and the storage time longer (de Souza e Silva *et al.*, 2005). Thus, the fruit should be quickly refrigerated after harvesting so that at an early phase, a rapid decrease in temperature occurs and, then the temperature stabilizes. The pre-cooling methods depend, also, on the thermal properties of the fruit (specific heat, thermal conductivity and heat transfer resistance of the fruit surface), its nature, initial and final temperature, temperature and properties of the cooling medium, requirements related to packaging and economic issues (Pinto & Morais, 2000; de Souza e Silva *et al.*, 2005). The main pre-cooling methods are succinctly enumerated (Pinto & Morais, 2000; de Souza e Silva *et al.*, 2005):

a) **Forced air cooling:** consists of cold air flow directly on the fruit. This method is quite versatile and can be incorporated into the existing refrigeration chambers. It does not require highly sophisticated technology and can be used on a vast range of products. However, to prevent water loss, and consequently the weight loss of the fruit, the environment must contain a high relative humidity (about 95%).
b) **Water cooling:** consists of the use of cold water in immersion processes and sprinkling on the fruit. This method is faster than the forced air cooling, in this case, the dehydration of the fruit does not occur. Thus, to ensure the effectiveness of this method, it is necessary that the water reaches the largest possible fruit surface and its temperature be is as cold as possible, without damaging the fruit.
c) **Ice cooling:** consists of rapid refrigeration, compared to the previous methods, however it is only effective in products that tolerate direct contact with water and ice. In this case, packaging should be water tolerant and present small holes for the process of draining water. The main disadvantage of this method is the costs associated with the manufacture of specific packaging.
d) **Vacuum cooling:** consists of placing the packaged product inside of an airtight chamber, in order to evacuate the air from the package. This is the most efficient and fastest method, because when the product undergoes this type of cooling will occur a decrease in pressure and the boiling point of the water. Consequently, the water on the fruit surface evaporates. The main advantage of this method is the speed at which pre-cooling takes place. However, this method is recommended only for products that have a good area/volume ratio. Since the equipment required presents high costs, their use is limited to a specific scale of products.

Table 4. Pre-cooling methods (de Souza e Silva *et al.*, 2005).

	Pre-cooling methods			
Variable	**Forced air**	**With water**	**With ice**	**In vacuo**
Time	2 – 8 h	20 – 40 min	2,5 h	20 – 40 min
Weight loss	Small	No	Moderate	Small
Consequences	No	Disease propagation	Freezing the product	Freezing the product
Energy consumption	High	High	Moderate	High

4. METHODS AND TREATMENTS THAT RETARD/PREVENT CHILLING INJURY

In the last years, and according to several investigators, the chilling injury has been considered the main problem for the peach refrigeration industry (Shan *et al.,* 2016). Several methods, techniques and treatments to overcome or alleviate the development of this phenomena have been tested, always with the perspective of preserving the organoleptic characteristics of the peach. Thus, a number of pre-harvest and post-harvest manipulations that can be used to delay the onset of the chilling injury symptoms will be discussed below.

4.1 Controlled Atmosphere

The controlled atmosphere (CA) has been a widely analyzed technique. According (Lurie & Crisosto, 2005), a controlled atmosphere with 17% CO_2 and 6% O_2 at 0 °C, is ideal for storage peaches, delaying deterioration and prolonging its shelf life. In order to the storage process to be efficient, the ideal will be to increase the CO_2 concentration and decrease the O_2 concentration. These conditions allow the peach to have a longer storage life and prevent the appearance of the brown color of the mesocarp, the floury pulp, the lack of flavor and the formation of cavities. However, the most important concentration that delays the appearance of chilling injury and all its symptoms is the CO_2 concentration. Study with nectarines *Fantasia, Flavortop* and *Flamekist,* demonstrates that a controlled atmosphere with 10% CO_2 and 10% O_2, at 0 °C, for six weeks, allows to prevent the appearance of the typical symptoms of chilling injury and, provides, a distinct flavor and juiciness to the fruit. In addition, storage at controlled atmosphere, along with a treatment based on AVG (aminoethoxyvinylglicine). The application of about 150 ppm of AVG in the fruits, seven days prior to harvest, followed by storage at 0 ºC, in 90% ± 5%, during eight weeks under controlled atmosphere with 17% CO_2 and 6% O_2, guaranteeing the efficiency of this technique at the commercial level reference. Thus, a decrease in acidity is confirmed, increased soluble solids, lower ethylene production, greater firmness, as well as, a delay in peach maturation and coloring, ensuring its quality and characteristics (Cetinbas *et al.,* 2012).

4.2 Intermittent Warming

Over the years, intermittent warming (IW) techniques or ripening controlled that allow to reach the ideal point of maturation have been analyzed as ideal conservation methods, achieved by controlling the temperature and specific time periods (Lurie & Crisosto, 2005). The effectiveness of this technique consists in storing the fruit, after harvesting, at 0 °C and, then, every ten to fourteen days subject the fruit to a higher temperature (around 20 °C to 24 °C) during one day. In these conditions, there is an improvement and preservation of the peach characteristics such as flavor, texture, aroma, succulence and hardness, organoleptic characteristics highly appreciated by the consumer´s (Shinya *et al.*, 2014), consequence the peach shelf life increases and a delay in chilling injury and deterioration of the fruit is observed (Lurie & Crisosto, 2005). In addition to these advantages, this technique allows the increase of ethylene production which, according to, can contribute to a good conservation of the peach during cold storage (Zhou *et al.*, 2000; Lurie & Crisosto, 2005), and increase the formation of esters, improving the flavor and aroma quality of the peach (Xi *et al*., 2012).

4.3 Ethylene and Ethylene Inhibitors

Ethylene and ethylene inhibitors are used to delay the symptoms of chilling injury (Lurie & Crisosto, 2005). However, ethylene during the storage can be detrimental, because it has the ability to trigger a rapid maturation process and deterioration of the fruit (Pinto & Morais, 2000; Lurie & Crisosto, 2005). Nevertheless, according to these authors, the presence of ethylene during cold storage may contribute to good conservation. In the treatment of *Fairlane* and *Flamekist* nectarines with ethylene at 0 °C, it was not verified color change, nor a rapid maturation process. Thus, it is possible to conclude that a storage with ethylene production and a temperature of 0 °C, contributes to the normal maturation and prevents the appearance of a floury pulp (Zhou *et al*., 2001; Lurie & Crisosto, 2005). According to Lurie & Crisosto (2005), the use of ethylene inhibitors, such as 1-MCP in peaches, also prevents normal ripening in cold storage (Lurie & Crisosto, 2005).

4.4 Glycine Betaine Treatment

Glycine Betaine (GB) treatment demonstrates promising results in control or reducing chilling injury in several types of fruits (Rodríguez-Zapata *et al*., 2015; Jin *et al.*, 2015). Glycine betaine is a neutral compound that plays an important role in maintaining the osmotic pressure of cells, protection of proteins or enzyme function and in regulating plant stress (Mansour, 1998). This compound has been found to be effective in controlling or reducing of chilling injury in cold storage, on bananas (Rodríguez-Zapata *et al*., 2015) and in loquats (Jin *et al.*, 2015). Shan *et al.* (2016) inserted peaches in a glycine betaine solution, with a concentration of 10 mM, during 10 minutes. Afterwards, the peaches were air-dried during 30 minutes and stored at 0 °C for five weeks. It was considered a very promising treatment in peaches, both in terms of increasing energy content and decreasing membrane damage, as well as in the increase in the amount of ý-aminobutyrix acid (GABA) (Shan *et al*., 2016). This compound is partially responsible for the reduction of chilling injury (Cao *et al.*, 2012), by the increased activity of antioxidant enzymes and by preserving a high energy state (Yang *et al.*, 2011).

4.5 Methyl Jasmonate treatment

The treatment based on methyl jasmonate (MeJA) reduces the symptoms caused by the chilling injury, maintaining the fruit hardness and postharvest quality during the storage period (González-Aguilar *et al.*, 2001, Gonzalez-Aguilar *et al.*, 2001; Aguilar *et al.*, 2003; Yao & Tian, 2005). In the research conducted by Meng *et al.* (2009), peaches were stored for three weeks at 5 °C, and at intervals of three days at a temperature of 20 °C. After observation, a decrease of the chilling injury index was observed and therefore it was considered a very effective treatment (Meng *et al.*, 2009). The quality of the fruit was maintained, the damage caused by the chilling injury decreased and the integrity of the cell membrane, as well as the activity of the antioxidant system increased (Meng *et al.*, 2009; Cao *et al.*, 2009).

4.6 Ultraviolet Radiation (UV)

Ultraviolet radiation allows to control chilling injury and delay senescence in different fruits (González-Aguilar *et al*., 2001; Gonzalez-Aguilar *et al.*, 2004; Erkan *et al*., 2008; Yang *et al*., 2014). Fruit senescence is associated with an increased in the oxidative damage of proteins, lipids and nucleic acids, by reactive oxygen species (ROS) and, therefore, its production and removal should be strictly controlled (Mittler, 2002). Mitochondria are the main sites of ROS formation. The accumulation of these species can damage the integrity of the mitochondria membrane, resulting in irreversible mitochondrial dysfunction (Møller, 2001), being one of the main causes of senescence in several fruits (Wu *et al.*, 2016). In the study performed by Yang et al. (2014), the storage of peach subjected to UV radiation with a wavelength of 254 nm, at 20 °C, relative humidity of 90± 2%, for eight days, are the ideal conditions to guarantee the efficacy of the treatment (Yang *et al*., 2014). It was concluded that UV treatment delayed senescence of the peach, through inhibition of the respiration rate (Yang *et al*., 2014). Table 5 summarizes the studies defined above. This analysis intends to compare temperature ranges, humidity, storage time, the applied technique, assessment of chilling injury and, consequently, the main results and the technique advantages.

5. CONCLUSIONS

Chilling injury is the main limitation of cold storage over a long period of time. This type of storage is the most used, in the conservation of fruit, because it has the capacity to delay the deterioration of the product, both in terms of perception towards the consumer and in terms of nutritional value. The symptoms of chilling injury impair visual quality and nutritional quality, limiting, therefore, its commercialization. Thus, it is possible to conclude that the appearance of these symptoms in cultivars depends so much on biological/genetic factors, such as respiration, transpiration and ethylene action, and essentially from external factors, such as temperature, relative humidity and circulation of air, and still by product characteristics, as morphological characteristics, surface/volume ratio, damage to the epidermis and state of maturity.

In order to maintain fruit quality during the marketing period it is necessary to implement techniques or treatments that delay the symptoms of chilling injury, resulting in high quality fruit on the market. Thus, it is necessary to inform producers, transporters, receivers and consumers on short-term solution techniques to reduce the development of symptoms caused by cold damage. In conclusion, the research of new and better techniques to delay the development of the chilling injury is relevant for the post-harvest activity of peach production.

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Table 5. Summary of methods and treatments that retard/prevent chilling injury.

Treatment/Technique	***Conditions***	***Storage time***	***Temperature***	***Relative Humidity***	***Occurrence of chilling injury***	***Results***	***Advantages***	***Reference***
Controlled Atmosphere (CA)	Controlled Atmosphere (17 % de CO_2 + 6 % de O_2)	42 days	0 ºC	-	No	Prevents the appearance of typical symptoms of chilling injury.	Delays the deterioration of the fruit. Prolongs the useful life of the fruit.	(Lurie & Crisosto, 2005)
Intermittent Warming	Intermittent Warming	21 days	0 ºC after harvest and 20 ºC the 24 ºC for one day.	-	No	Improvement and preservation of characteristics at the level of taste, texture, aroma, succulence and hardness of the peach.	Increased fruit shelf life. Delay of fruit decay. Increased production of ethylene.	(Zhou *et al.*, 2000; Lurie & Crisosto, 2005; Xi *et al.*, 2012).
Ethylene Inhibitors	Ethylene Inhibitors (1-MCP) and Intermittent Warming	12 - 14 days	0 ºC in storage and 20 ºC in intermittent warming.	-	No	Delay the chilling injury. Extends the useful life of the peach.	Good conservation. Better quality of the taste and aroma of the peach.	(Zhou et al., 2001; Lurie & Crisosto, 2005)
Glycine betaine treatment (GB)	Glycine betaine solution (10 mM)	35 days	0 ºC	-	No	Increased amount of GABA. Reduction of chilling injury.	Increase in energy content. Decrease of membrane damage.	(Shan *et al.*, 2016)
Treatment with Methyl Jasmonate (MeJA)	MeJA	21 days	5 °C at intervals of three days at 20 °C	-	No	Decrease in chilling injury index. Lower content of phenolic compounds.	Decrease of chilling injury. Better fruit quality. Reduction of injury caused by chilling injury.	(Meng *et al.*, 2009)
Treatment with Methyl Jasmonate (MeJA)	10 mmol/L MeJA and hot air treatment	4 days	37 ºC for three days 5 ºC for 24 hours	-	No	High sucrose content. Increased tolerance to chilling injury.	Increased shelf life.	(Yu *et al.*, 2016)
Exposure to Ultraviolet Radiation (UV)	Ultraviolet radiation with a wavelength of 254 nm	8 days	20 ºC	90 ± 2%	No	It delays the senescence of the peach. Decreases chilling injury.	Increases peach shelf life. Decreases the peach deterioration.	(Yang *et al.*, 2014)

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