Moroccan Journal of Biology
Number 17 (2020)
http://www.fst.ac.ma/mjb
e-ISSN: 2351-8456 - p-ISSN: 1114-8756

Enhancing postharvest quality of *Opuntia ficus-indica* L. in southern Morocco

Mohamed Sedki[1,2], Aissam EL Finti[1], Abdelhamid El Mousadik[1]

[1]*Ibn Zohr University, Faculty of Science, Department of Biology, Laboratory of Biotechnology and Valorization of Natural Resources, 80000 Agadir*
[2]*National Institute of Agronomic Research, Kénitra*

Abstract

Moroccan cactus fruits are a nationally valued commodity. However, methods of storage are poorly documented. This study evaluated the use of chilling storage temperatures on shelf-life and quality of fruit and determines the optimal stage for fruit harvesting. Fruits were harvested at three maturity stages: S1 (green), S2 (green-yellow) and S3 (yellow-orange). Fruits were sorted for absence of defects and size uniformity. Fruits were arranged following a randomized design with: temperature of storage (4, 8, and 15°C) and maturity. Fruits were grouped into 9 treatments and kept for 6 weeks in ventilated storage at 4°C (85-90% relative humidity 'RH'), 8°C (80-85% RH), and 15°C (65-70% RH). After 15 days of storage, fruits were sampled and transferred to room-temperature conditions (20°C, 65-75% RH) for 12 hours to assess external color, total soluble solids, weight, and electrolytes leakage, plus 5 d in order to simulate a marketing period and assess physiological disorders (chilling injuries) and decay. Storage at 8°C of medium-ripened fruits allowed anextension of shelf life up to 30 d without adverse effects on the fruits with very low and economically tolerated rates of cold and rot damage. Storage at 4°C was shown to be effective in reducing rot, but limits storage time to less than 15 d because of the development of cold damage. Storage at 15°C showed no cold damage to the fruit throughout the storage period but resulted in a high rate of decay. Adhering to cold-storage and maturity stage enhances the production and sustainability of *Opuntia ficus-indica*.

Keywords: Cactus, Storage, Maturity, Productivity, Sustainability.

Introduction

Cactus pear (*Opuntia ficus-indica L.*) is a tropical fruit that attracts great interest due to its nutritional and antioxidant properties (Corbo *et al.*, 2005). The growing demand for this fruit has challenged postharvest and food technologists to develop procedures to lengthen storage life. Mexico and Italy account for most of the worldwide production and export following to Basile & Foti (1996). The cactus is widely represented in the Moroccan agricultural landscape and it is plentiful from July to November. It exists in the form of spontaneous and traditionally cultivated plantations, which are harvested for the consumption of fresh fruits. Morocco dedicates a total area of 120,000 ha to growing cactus fruit with a production of about 1,000,000 tons/yr. Over half of this area is situated in southwestern Morocco in the region of Sidi Ifni with a production of 500,000 t (Agrotech, 2010).

Cactus pear is used as an animal feed during periods of drought limited to arid and semiarid areas of Morocco. However, the species is greatly undervalued, due to: (i) overproduction during the July-November period, coinciding with the availability of other seasonal fruits such as cucurbits, grapes, apricot, peach, and nectarine induces a

CONTACT M. Sedki & A. EL Finti ✉ sedkimed@gmail.com, a.elfinti@uiz.ac.ma
Department of Biology, Faculty of Science, Ibn Zohr University, BP 8106, Agadir 80000 Morocco

competitive market for the consumer's choice. Consequently, each year, up to 40% of the production of prickly pear cactus fruits is lost. 56% of the production is sold traditionally at low prices that benefit intermediaries to generate a low level of income in comparison with Italy and Mexico; (ii) low/varied prices depending on time, variety, and demand that influenced the choice of harvest date result in the average price for the *O. ficus-indica* cv. 'Aissa' fruit is 15 MAD/box (30 kg), while that of cv. Moussa is 50 MAD/box; (iii) unavailability of this fruit in agro-industrial forms due to the lack of handling and packaging houses, recovery units in drying or processing. These constraints directly contribute to the deterioration of fruit and significant losses on post-harvest.

Losses of fruits are additionally due to biotic and abiotic problems that hinder the process of maturation. Packaging and post-harvest fruit storage are the main causes of the deterioration of fruit quality and the loss of a significant part of production. Many authors have shown that physical damage occurring during harvest is significant and constitutes the main factor that facilitates postharvest rots development (Cantwell, 1986; Rodríguez-Félix, 2002). Physical injury results from poor handling at harvest and post-harvest; non-suitable storage conditions favor fungal rots development, weight loss, wilting, softening, and off-flavor development (Mayberry & Hertz, 1992; Cantwell, 1995). The damaged stem-end is the most serious mechanical injury. In addition, numerous micro-wounds, during harvesting, affect the skin of the cactus pear fruit due to the presence of surface having tufts of glochids (Schirra *et al.*, 1999a). Harvest damage to the peel and stem-end of cactus fruit will lead to attack by numerous pathogens and result in fruit decay (Cantwell, 1995).

Common postharvest pathogens found in cactus fruits are mostly fungi and include *Fusarium* spp., *Alternaria* spp., *Chlamydomyces* spp., and *Penicillium* spp. (Schirra *et al.*, 1999b; Rodríguez-Félix, 2002). Major postharvest decay of cactus pear fruit is due to *Penicillium* spp. which can infect the fruit through injuries in the peel according to Schirra *et al.* (1999a), yeasts and bacteria also cause decay following Schirra *et al.* (1999b).

The cactus fruit is highly perishable (Cantwell, 1995), and has a shelf life of a few days in marketing conditions at 20°C (60-70% RH) (Rodríguez-Félix, 2002). These are non-climacteric fruits with low ethylene production (0.36 mg or 0.2 μL/kg.hour at 20°C) and low respiration rates (27 to 36 mg or 15 to 20 μL of CO_2/kg.h at 20ºC) (Cantwell, 1991; Corrales-García *et al.*, 1997; Rodríguez-Félix, 2002). It has been reported that ethylene production is similar in fruits harvested at different stages of maturity and increases gradually during storage (Cantwell, 1991). This low ethylene production gives the cactus fruit a very weak physiological activity (Cantwell, 1995).

The water loss of the fruit after harvest is a notable factor which causes a decrease in commercial weight and appearance (Corrales-García *et al.*, 1997), loss of firmness and reduction of sugar (Cantwell, 1995; Saenz-Hernandez, 1995; Saenz, 2000). As the maturation stage progresses, softening of the skin makes the fruit increasingly susceptible to physical damage during handling (Cantwell *et al.*, 1985). Thick-skinned fruits of some varieties prove to be firm and resistant to handling during harvesting and packaging as discussed in Mondragón-Jacobo & Bordelon (1996). The colour of fruits plays an important role in consumers' acceptance as well as agro-industrial processes. To minimize post-harvest losses, different techniques are used to improve its shelf life and preserve quality.

In Southwest Morocco, prickly pears are fully dried and known locally as 'Tousrimt', Tozlimt or Touchriht when dried as pieces of pulp. However, this technique is limited to traditional practice and the supply of local markets, which does not absorb and enhance all production. The conservation of fruit through pulp processing has been expanded in countries producing and exporting prickly pears. In Morocco, the technique was initiated during the last decade by some local associations. However, fruits are sold on a small scale only through their presentation at regional and national events.

The orientation towards foreign markets in many countries producing and exporting prickly pears is a new alternative adopted to absorb the production and improve the added value of this product. Thus, the efforts deployed under the Green Morocco Plan were translated in 2011 by the construction of a cactus fruit packing station in Sidi Ifni with a packaging capacity of 100 t/day. The first fruits exported according to the official statistics of the Economic Interest Group GIE 'Sobar Sidi Ifni' took place in 2012 with 54 t followed by 100 t in 2013 intended mainly for Canada, the United Arab Emirates and France. However, these exported quantities are small because of the limited quantities required by the importing countries and the high sorting differences (90% in 2012 and 80% in 2013). These height culls are mainly due to poor fruit handling at the field level (injured fruits, harvest poor, small sizes, crop conditions, stage of maturity at harvest, etc.) and the lack of control of storage conditions at the packinghouse. Cold storage is the most familiar and useful way to safeguard some quality and freshness of fruit for lengthened shelf life, increasing post-harvest lifespan of most horticultural products (Wang, 1994) by delaying respiration, ethylene production, maturation, senescence, undesirable metabolic changes (Wang, 1994; Hebert, 1995; Rodríguez-Félix, 2002).

Chilling in storage is a means of reducing rapid invasion by pathogens (Couey, 1982). Cold storage of cactus fruit is developed in cactus producing countries around the world. It has shown interesting results on improvement of fruit shelf life and the preservation of quality for both locally marketed and exported fruits. Schirra *et al.* (1999a) reported that without refrigeration, fruits deteriorate in a few days due to their senescence and development of rot. As a result, a wide range of cactus fruit storage temperatures have been documented in the literature in terms of cultivar, stage of maturity, harvest period and production conditions. In fact, the use of cold storage reduces quality losses of fruits and vegetables and reduces water loss by reducing the vapor pressure deficit (Cantwell, 1986). However, as with most tropical and subtropical fruits, prickly pears are sensitive to cold injury, commonly known as 'chilling injury' when stored at low temperatures (Cantwell, 1995; Schirra *et al.*, 1999a). This physiological decay is responsible for the physiological and biochemical alteration of plant tissues followed by the appearance of external and internal symptoms Lyons & Breidenbach (1987).

Several approaches have been detailed, to aid understanding of the mechanisms of chilling injury development in relation to the responses expressed by fruits and vegetables following their exposure to low temperatures storage. These responses include visual and physiological symptoms that could be used as indicators to assess the severity of the cold damage. Generally, visual symptoms of chilling injury in cactus fruits include pitting, small dark surface discolorations and bronzing of the peel, and increased susceptibility to decay (Cantwell, 1995).

Electrolyte leakage is one of the physiological symptoms that occurred due to low temperature storage. It is defined as ions losses at the cell membrane and used by many authors as an indicator of chilling injury to quantify the alteration of the cell membrane permeability (Cabrera *et al.*, 1992; Lurie *et al.*, 1994). Storage at low temperature causes an increase in electrolyte leakage of sensitive tissues to chilling injury.

Several researchers have used electrolyte loss as an indicator of cold damage to quantify the alteration of cell membrane permeability (Cabrera *et al.*, 1992; Lurie *et al.*, 1994; Schirra *et al.*, 1999b) reported that cactus pear stored below 5°C is chilling sensitive. Furthermore, some investigations have shown that this tropical fruit suffers from chilling injury when the storage temperature is lower than 10°C (Schirra *et al.*, 1999b; Cantwell, 1995; Rodríguez-Félix, 2002; Inglese *et al.*, 2002).

However, researchers have reported that some cultivars such as Tuna fruits are more tolerant to chilling injury Corrales-García *et al.* (1997). Furthermore, it has been reported that the studies carried on a series of varieties showed that chilling occurred in a red-fruit variety after only 2 weeks at 6°C (Cantwell, 1995). Fruits from other varieties were held for several weeks without signs of chilling. According to these documented results, the sensitivity of cactus fruits to chilling injury depends on the cultivar. The sensitivity of cactus fruit to cold damage also depends on the conditions of growth and development of the fruit, the harvest period and the stage of maturity (Gorini *et al.*, 1993; Cantwell, 1995; Schirra *et al.*, 1999a). Ripe fruit is more susceptible to decay but less prone to chilling injury than fruit harvested at the early-stage green or breaker stage according to Schirra *et al.* (1999a). Late season fruits developed chilling injury after storage at 5°C for 15 d and were more susceptible to chilling injury than early season fruits as highlighted in Rodríguez-Félix *et al.* (1992).

The recommended storage temperature for cactus pears depends on variety, ripening stage, harvest season, harvesting conditions, cultural practices and environmental conditions (Cantwell, 1995; Gorini *et al.*, 1993). Indeed, (Cantwell, 1995) reported that cactus fruits could be stored at 5-8 ° C and 90-95% RH for 2-5 weeks. According to Corrales-García *et al.* (1997), storage at 5 to 7.5 ° C is generally recommended in the duration of about three weeks.

In addition, Gorini *et al.* (1993) showed that storage temperatures recommended for prickly pears range from 6 to 8 ° C with 90 to 95% RH. Schirra *et al.* (1999a) reported the same temperatures for a storage period ranging from 4 to 6 weeks. Along with the storage temperature, the stage of maturity of the fruits at harvest is a determining factor for commercialization (Cantwell, 1995) and the fate of the fruit during storage. The skin color (rotating) or the concentration of total soluble sugars (12-15%) is often important indicators for fruit harvesting. According to, variations in recommended storage temperatures and susceptibility to cold damage may be expected and should be further investigated across cultivars, stage of maturity and harvest period. In Morocco, no study on the cold storage of Moroccan cactus fruits is available in the literature, which justifies the current research on the use of cold storage, to preserve the quality and prolong the duration of fruit life in post-harvest. Consequently, objectives of the present study were: (a) to evaluate the possible use of chill and none chill storage temperature on the shelf life and the quality parameters of the fruit; (b) to determine which harvest mature stage fruit is appropriate.

Material and methods

Plant material

This study was carried out on *Opuntia ficus-indica* fruits cv. 'Aissa'. The fruits were harvested from a traditional plantation located in Mesti, 15 km from the town of Sidi-Ifni, south-west Morocco. The cultivar Aissa is a spineless local genotype. Fruits were manually harvested in July at three mature stages: S1: green stage (just slightly before peak fruit maturation), S2: green-yellow stage (about 50% of full color development), and S3: yellow-orange stage (100% full color development). Fruit were cut with a small part of the mother cladode attached and transferred the same day to the laboratory. Afterward, fruits were sorted for absence of defects (mainly harvesting damage) and for size uniformity. Spines and glochids were removed manually using rubber gloves and cloth (Figure 1).

Figure 1. Cactus fruits (cv. 'Aissa') harvested at three maturity stages (S1, S2, S3) and stored for 45 d at 4, 8, and 15°C.

Fruit sampling and storage conditions

486 selected fruits were arranged according to a randomized complete design with two factors: Storage temperature (4, 8, and 15°C), and fruit mature stage (green, green-yellow, and yellow-orange) performed in three replicates. Fruits were grouped into 9 lots corresponding to 9 treatments. They were put into cardboard boxes and were kept 6 weeks in a ventilated storage room at 4°C (85-90% relative humidity 'RH'), 8°C (80-85% RH), and 15°C (65-70% RH). After 15 d storage at each temperature used, the fruits were sampled and transferred to room-temperature conditions (20°C and 65-75% RH) for 12 h to assess external color, total soluble solids (TSS), weight loss, and electrolytes leakage, and for 5 d in order to simulate a marketing period (SMP) and assess physiological disorders (chilling injury) and decay.

Fruit quality assessment

Physicochemical analysis

Fruit weight, total soluble solids, pH, and external color determinations were monitored immediately after harvest and at the end of each storage period for different treatments. External color of fruits was measured with a Hunter Lab colorimeter Model Konika Minolta CR-400. The variables L [brightness with values from 0 (black) to 100 (white)], a [with values from -60 (green) to +60 (red)], and b [with values from -60 (blue) to +60 (yellow)] were measured (McGuire, 1992) and used to calculate a color index (CI) according to (Dominguez, 1992) and CI = a*b/L for coloured fruits. Weight loss was calculated using the equation:

$$WL(\%) = 100*(Wi - Wf)/Wi$$

Where: WL=Weight loss, Wi=Initial fruit weight in grams (g), and Wf=Final fruit weight at the end of the indicated storage period in grams (g).

The total soluble solids were determined with a hand-held refractometer (DIGIT 032). The fruit was pressed in order to obtain the juice needed for measurement. The results were expressed as degrees Brix (°Bx). Measurement of pH was carried out in pulp juice using a Microprocessor pH Meter 99621 of BioBlock Scientific (Portugal). According to Serek *et al.* (1995), determination of electrolytes leakage (EL) was carried out on peel disks of 10 mm diameter and 2 mm thick for a total weight of 2 g. They were taken from the equatorial zone of fruit in epidermal tissues of peel without cuticle using a surgical blade. Disks were placed in glass beakers and were washed three times with distilled water. They were then covered with 40 mL of 0.4M Mannitol solution and incubated for 2 h at room temperature (20°C) on orbital shaker (Stuart orbital shaker of Stuart Scientific CO LTD (Great Britain) at 120 rpm. After 2 h incubation, a first measurement of the electrical conductivity (EC_1) of the solution bathing the disks was determined using a conductivity meter (InoLab Cond Level2, Wissens chaftlish Technische Werkstatten, Germany). The solution bathing the disks are then weighed and frozen at -20°C for 24 h followed by boiling for 5 min to completely damage the plant tissue. After cooling at ambient temperature, the solution was weighed and adjusted with deionized water to their initial weight. The final electrical conductivity (EC_f) was measured after stirring at 120 rpm for 30 min. Electrolyte leakage was calculated using the formula:

$$EL(\%) = (EC_1/EC_f)*100$$

Visual assessments of external appearance

At the end of cold storage and after SMP, fruits were examined for chilling injury and decay. Chilling injury incidence was estimated visually and was expressed in chilling index (CIx). It was performed by using a scale of 0 - 3 (0: no damage, 1: slight injury, 2: moderate injury, 3: severe injury) taking into account the number and size of affected areas on the fruit peel Schirra *et al.* (1999a). To obtain weighted average for a CIx, the number of fruits in each CI rating was multiplied by the designated number and an average was calculated and a CIx was calculated from the formula: CIx=[(number of fruit with slight CI*1)+(number of fruit with moderate CI*2)+(number of fruit with severeCI*3)]/(total number of fruit evaluated), according to Cohen *et al.* (1994) and Schirra *et al.* (1996). The fruits were unacceptable to the consumer if they have CIx ≥ 1 following Al-Qurashi & Awad (2012).

Decay was categorized as rots caused by *Penicillium italicum* Wehmer, *P. digitatum* Sacc., or as miscellaneous rots by unidentified agents, and the percentage of infected fruit was calculated. General fruit appearance was subjectively rated on fruit without infections or physiological defects using a scale: 0 = no presence of rot, 1= presence of rot according to Schirra *et al.* (1999a).

Statistical analysis

Analysis of variance (ANOVA model one-way) was performed by STATISTICA for Windows, Stat Soft Inc. (2010) according to two factors randomized complete block design. Mean comparisons were performed with Newman-Keuls's test, P= 0.05.

Results and discussion

Physical parameters evolution during cold storage

Weight loss

The results showed significant increase in weight loss during cold storage (Table 1). Similar results were reported by Corrales-García *et al.* (1997) on Copena-Torreoja, Amarillo Montesa, and Copena T-5 cultivars kept at 9°C for three months. However, storage temperatures at 4 ° C and 8 ° C reduced the weight loss compared to 15°C. They allowed good fruit appearance up to 30 d of storage and the recorded weight loss values are lower than 7%. This value is tolerated at the export level and does not affect the visual appearance of cactus fruits according to Rodríguez-Félix *et al.* (1992). In addition, the stage of maturity of the fruit showed a significant effect on weight loss throughout the storage period. In fact, fruits harvested at full maturity (yellow-orange) showed an increase in weight loss compared to the other stages of maturity for all storage temperatures.

External coloration

Fruit color plays a very important role for the commercial quality and consumer acceptance. It is one of the most important quality criteria for fruit selection regarding the agri-food industry. The results obtained showed that the external coloring of fruits evolved from green to orange during storage. This color change occurred as a function of storage time and temperature (Table 1). The color variation was so slow with 4 and 8°C temperature compared with 15°C. Temperatures of 4 and 8°C have, thus, allowed to maintain a good coloration up not only to 15 d of storage for the fruits harvested at the early maturity (green) and mid-mature (yellow-green) stages, but also up to 30 d for fruits harvested at the early stage of maturity.

Table 1. Weight loss and color index of cactus fruits (cv. 'Aissa') harvested at three maturity stages (S1, S2, S3) and stored for 45 d at 4, 8, and 15°C.

Duration	Stage	T (°C)	Weight loss (%)	Color index
Harvest	S1	-	-	-2.65[a]
	S2	-	-	-0.41[b]
	S3	-	-	2.11[c]
15 days	S1	4	1.70[a*]	-2.54[a]
		8	2.33[b]	-2.04[a]
		15	3.14[d]	-0.81[b]
	S2	4	1.79[a]	-0.39[b]
		8	2.39[b]	-0.25[b]
		15	3.21[d]	1.56[c]
	S3	4	2.21[b]	3.26[d]
		8	2.79[c]	4.89[e]
		15	3.84[e]	5.92[f]
30 days	S1	4	5.89[a*]	-2.27[a]
		8	6.36[b]	-1.67[a]
		15	9.17[e]	1.29[b]
	S2	4	6.25[b]	0.65[b]
		8	6.86[c]	2.04[c]
		15	9.28[e]	4.02[d]
	S3	4	7.16[cd]	4.64[d]
		8	7.39[d]	5.72[e]
		15	10.10[f]	7.21[f]
45 days	S1	4	8.02[a]	-2.00[a]
		8	9.57[b]	-1.21[a]
		15	11.15[c]	2.93[c]
	S2	4	8.10[a]	1.51[b]
		8	9.45[b]	2.57[c]
		15	11.21[c]	5.11[d]
	S3	4	8.99[b]	5.51[d]
		8	9.59[b]	6.05[d]
		15	11.24[c]	7.28[e]

Chemical parameters evolution during cold storage

Total soluble solids (TSS)

The sugar content of the fruit represents a quality criterion of first choice for fresh consumption of cactus fruits. This essential criterion indicates the good quality of the cactus fruit. As a non-climacteric fruit, the cactus pear is characterized by a lack of starch as a carbohydrate reserve and there is no significant increase in sugar content after harvest (Tucker, 1993). The results showed a slight increase in TSS at 30 d of storage for all treatments (Table 2). This increase is due to hydrolysis of complex carbohydrates other than starch following Cantwell *et al.* (1985). Beyond 30 d, the sugar content in the fruit decreased.

Table 2. TSS content, pH and electrolytes leakage of cactus fruits (cv. 'Aissa') harvested at three maturity stages (S1, S2, S3) and stored for 45 d at 4, 8, and 15°C.

Duration	Stage	T°C	TSS (°Brix)	pH	Electrolytes leakage (%)
Harvest	S1	-	11.27[a]	5.93[a]	18.47[a]
	S2	-	12.11[b]	5.82[a]	21.07[b]
	S3	-	12.73[b]	6.00[a]	25.41[c]
15 days	S1	4	11.29[a*]	6.28[b]	41.94[b]
		8	11.31[a]	6.37[b]	35.84[ab]
		15	11.72[ab]	6.46[b]	31.69[ab]
	S2	4	12.18[abc]	6.32[b]	32.03[ab]
		8	12.29[abc]	6.44[b]	27.60[a]
		15	12.43[abc]	6.49[b]	26.92[a]
	S3	4	12.80[bcd]	6.38[b]	33.47[ab]
		8	12.91[cd]	6.31[b]	32.14[ab]
		15	13.51[d]	6.00[a]	28.80[a]
30 days	S1	4	12.16[a]	6.42[c]	67.57[d]
		8	13.76[b]	6.50[c]	54.80[c]
		15	12.58[a]	6.35[c]	44.41[abc]
	S2	4	13.51[ab]	6.47[c]	48.46[abc]
		8	14.16[b]	6.51[c]	43.41[abc]
		15	13.29[ab]	6.40[c]	36.51[ab]
	S3	4	13.13[ab]	6.12[b]	52.51[bc]
		8	14.44[b]	6.00[b]	47.66[abc]
		15	12.18[a]	5.83[a]	35.30[a]
45 days	S1	4	12.09[a]	6.39[b]	77.88[d]
		8	12.69[ab]	6.33[b]	72.24[cd]
		15	11.98[a]	5.87[a]	57.38[ab]
	S2	4	13.38[b]	6.21[b]	60.60[abc]
		8	13.47[b]	6.40[b]	56.90[ab]
		15	12.13[a]	5.85[a]	51.40[ab]
	S3	4	11.93[a]	5.90[a]	65.28[bc]
		8	12.62[ab]	5.84[a]	60.75[abc]
		15	11.42[a]	5.70[a]	49.01[a]

This result is in agreement with Alvarado y Sosa (1978) which reported a slight variation in soluble solids and sugars in fruit after 2 weeks of storage at 20°C. This decrease may be related to biochemical changes in the fruit and senescence that stimulates the sugars breakdown Corrales-García *et al.* (1997). Moreover, the decrease in total soluble solids recorded after 30 d of storage may also be due to the increase in fruit weight's loss (Cantwell, 1995; Saenz-Hernandez, 1995; Saenz, 2000). The evaluation of the storage temperature and the stage of maturity on the soluble solids content during cold storage showed no significant difference between the treatments. Sensory evaluation has been poorly integrated into cactus fruit studies and the need to adopt this criterion according to Kuti (1992) in this type of study; it seems very useful for determining consumer preferences regarding different cultivars and cacti maturing stages.

The pH measurement

The results of the pH evolution of the juice during cold storage are shown in Table 2. The recorded values showed that the pH increased after 15 d of storage for all treatments except the treatment relative to the temperature of 15°C associated with the complete mature stage, which showed a stable pH during this period. Al-Qurashi & Awad (2012) also noted an increase in pH values from 5.7 to 6.0 in cactus fruits stored at 2°C for 30 d. Rodriguez *et al.* (2005) also reported a rise in pH concerning the fruits stored at 2°C and 8°C for 28 d. This increase in pH was explained by a cessation of CAM metabolism in fruit during storage, which resulted in low acidity (Rodriguez et al., 2005). These values are maintained for up to 30 d, after which the pH has decreased. Fruits stored at 15°C displayed slightly lower pH values than those recorded during storage at 4 and 8°C, and experienced a decreasing trend throughout the storage period. In addition, the decrease in pH after 30 d of storage probably is due to the phenomenon of fruit senescence and sugar degradation has affected fruit quality (Cantwell, 1995).

Electrolytes leakage

The results presented in Table 2 show that the loss of electrolytes increases with increasing storage time and decreasing temperature. The stage of maturity also influenced the loss of electrolytes. In fact, the fruits harvested at the early maturity stage recorded high values compared to those harvested at mid-maturity and full maturity stages. The loss of membrane integrity in fresh-cut tomatoes is mainly affected by ripening stages, storage temperature and duration (Natalini *et al.*, 2014). These authors reported that Electrolyte leakage studied at different stages of maturity of tomato: mature green, pink (PK), fully ripe and two different storage temperatures: 4 and 15 °C shown that the tomato slices of PK stage stored at 4°C did not show changes for this parameter, while significant increase in membrane leakage was observed at 15°C, especially after 24 h of storage. The enzymes showed a simultaneous increase in their activities with a rise in electrolyte leakage after 7 d of storage.

Chilling injury

The physiological and pathological disorders manifested on the fruits were evaluated after cold storage and during 5 d of exposure to ambient temperature (20°C). The results obtained after 15 d of storage showed that only the temperature of 4°C could induce cold damage on the fruits. This slight damage occurred only in fruits harvested at mid-mature and early maturity stages. The values of the chilling index were 0.1 and 0.2 respectively (Figure 2). This damage is associated with an increase in electrolyte loss with relatively higher values in fruits stored at 4°C (32 and 41.9%) compared to those stored at 8°C (26.9 and 35.8%) for mid-maturity and full maturity respectively (Figure 8). These results are in line with those assigned by Chessa *et al.* (1992) who reported the development of cold damage

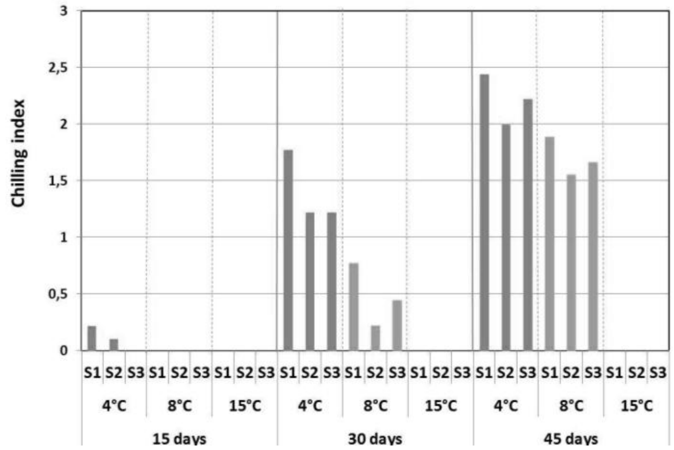

Figure 2. Chilling injury in cactus fruits (cv. Aissa) harvested at three maturity stages (S1, S2, S3) and stored for 45 d 4, 8, and 15°C.

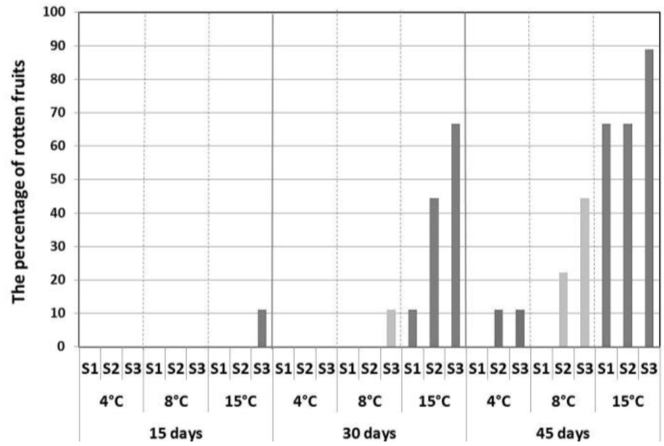

Figure 3. The percentage of rotten fruits harvested at three maturity stages (S1, S2, S3) and stored for 45 d at 4, 8, and 15°C.

Figure 4. Fruits assessment after 30 d of cold storage.

in *Opuntia ficus-indica* fruits after two weeks of storage at 6°C.

Fungal diseases including rots were considered the main pathological sources that cause considerable damage to post-harvest fruits. The main pathogens that invade cactus fruits are *Fusarium* spp, *Alternaria* spp, *Chlamydomyces* spp, and *Penicillium* spp. The intensity of the damage increases with the increase of the duration of exposure of the fruits at temperatures of 20 to 25°C. The results obtained after 15 d of storage showed no sign of rot on the fruits stored at 4 and 8°C. On the other hand, fruits stored at 15°C showed slight decay spots and the percentage of infected fruits was 11%, particularly fruits harvested at full maturity (Figure 3). Storage for 30 d at 4°C showed a significant development of cold damage on the fruits. The evaluation of the symptoms expressed by the severity index showed that these fruits recorded significant chilling indices (IC) which varied between 1.22 and 1.78 with more pronounced damage in the fruits at the beginning of maturity by other stages (Figure 2). Ripe fruits showed less severe cold damage compared to fruits from other stages. These results are in line with those reported by Gorini *et al.* (1993) and Schirra *et al.* (1999a). For the same duration of storage, Al-Qurashi & Awad (2012) found values close to IC = 2 for fruits stored at 2°C.

Fruits stored at 8°C for 30 d showed only slight signs of cold damage especially for medium-ripened fruits (Figure 2 and 4). Thus, the severity indices recorded were 0.78; 0.22 and 0.44 for the early, mid-mature and full-maturity stages respectively. These results are close to those of Schirra *et al.* (1999a) who reported that *O. ficus-indica* cv. 'Gialla' stored for 5 weeks at 6°C followed by 3 d at 20°C develop very light cold damage with the IC value of 0.8. Similar results were reported by Cantwell (1995) who recommended that cactus fruit be stored at 8°C for 3-4 weeks. The ionic leakage rates for cold damage are in the range of 48.46 to 67.57% in fruits stored at 4°C and 43.41 to 54.80% for fruits stored at 8°C (Table 2). The fruits stored at 15°C were healthy since they showed no symptoms of cold damage. However, they developed rots due to fungal attack (Figure 3). The percentage of fruit reached is 11 to 66% depending on the stage of maturity. For fruits stored at 4°C, no evidence of rot development was observed. Storage at 8°C also showed only very slight signs of rotting in the order of 11% in fruit harvested at the yellow-orange stage (S3).

Cold damage is accentuated after 45 d of storage to reach 90 to 100% and 77 to 90%, respectively, for fruits stored at 4°C and 8°C (Figure 2). Thus, the severity index varied between 2 and 2.44 (medium to severe state) after storage at 4°C, and from 1.56 to 1.89 (average state) after storage at 8°C. The ionic leakage rate recorded is 60.6 to 77.88% after storage at 4°C and 56.90 to 72.24% after storage at 8°C (Table 2). Fruits stored at 15°C showed no signs of cold damage. However, a significant development of rots has been observed in fruits at different stages of maturity and with percentages of fruits reaching 66 to 88% (Figure 3).

Conclusion

The storage at 8°C of medium-ripened fruits allowed to extend the shelf life up to 30 d without any adverse effects on the fruits with very low and economically tolerated rates of cold and rot damage. In addition, storage at 4°C has been shown to be effective in reducing rot, but limits storage time to less than 15 d because of the development of cold damage. Storage at 15°C showed no evidence of cold damage to the fruit throughout the storage period but resulted in a high rate of decay, limiting its use to less than 15 d. Good overall study validating the use of cold storage in cactus fruits. Would be good to see further suggestions as to how the work may be developed – for example using the paper as a standard to assess additional varieties. Might enriching the diversity amongst any plantations alter the flowering period slightly due to the surrounding species ethylene levels, fruits at an alternative period, changing the supply/demand issue which depreciates value. Sustainable/circular economies linking protection of the cactus pear from predators with sales might also bear hope for production.

Acknowledgements

The authors thank the support staff Mr. Said Boubih, Mr. Mohammed Haddouche Mrs Meryem Lahlali, and Mr. Abdelhamid el Mousadik for their contribution to the realization of this experimentation.

References

Agrotech, Association Agrotechnologies du Sous Massa Draa (2010) http://www.agrotech.ma/index.php?option=com_content&view=article&id=31&Itemid=4.

Al-Qurashi AD, Awad MA (2012) Postharvest salicylic acid treatment reduces chilling injury of 'Taify' cactus pear fruit during cold storage. J. Food Agric. Environ. **10**: 120-124.

Alvarado y Sosa L (1978) Fisiología y bioquímica del desarrollo del fruto del nopaltunero (Opuntia amyclaea Tenore). Tesis de Maestría. Colegio de Postgraduados, Chapingo, México.

Basile F, Foti VT (1996) Economic features of cactus pear production in Italy. Acta Hortic. **438**: 139-145.

Cabrera RM, Saltveit ME, Owens K (1992) Cucumber cultivars differ in their responses to chilling temperatures. J. Am. Soc. Hortic. Sci. **117(5)**: 802-807.

Cantwell M, Montiel-Rodriguez S, Vega-Flores AY, Ayala-Lizarraga S (1985) Cambios fisico-quimicos durante la madura-cion y almacenamiento de tunas de selecciones de Opuntia amyclaea. Abstract #133. I Congreso Nacional de Horticultura, Hermosillo, Sonora.

Cantwell M (1986) Postharvest aspects of prickly pear fruits and vegetable clalodes. Perishable Handling (Univ. California, Davis) No. **59**:6-9.

Cantwell M (1991) Quality and postharvest physiology of ‘nopalitos’ and ‘tunas’. Proc.Second Annual Texas Prickly Pear Conference, Texas Prickly Pear Council, McAllen, Texas: pp. 50-66.

Cantwell M (1995) Postharvest manage-ment of fruits and vegetable stems. In: G Barbera, P Inglese & E Pimienta-Barrios (eds) Agroecology, Cultivation and Uses of Cactus Pear, FAO Plant Production and Protection Paper No. 132, Rome, pp. 120-143.

Chessa I, Cossu QA, D’Aquino S (1992) Surface characteristics of prickly pear (Opuntia ficus-indica Mill.) fruit during development. In: Proc. II Congreso Internacional de Tuna y Cochinilla, 22-25 September 1992, Santiago del Chile, Univ. de Chile Publ., Chile, pp. 86-92.

Cohen E, Shapiro B, Shalom Y, Klein JD (1994) Water loss: a non-destructive indicator of enhanced cell membrane permeability of chilling-injured citrus fruit. J. Am. Soc. Hort. Sci. **119(5)**: 983–986.

Corbo MR, Campaniello D, D’amato D, Bevilacqua A, Sinigaglia M (2005) Behavior of Listeria monocytogenes and Escherichia coli O157:H7 in fresh-sliced cactus-pear fruit. J. Food Saf. **25(3)**: 157–172.

Corrales-García J, Andrade-Rodríguez J, Bernabé-Cruz E (1997) Response of six cultivars of tuna fruits to cold storage. J. Prof. Assoc. Cactus Dev. **2**: 160-168.

Couey HM (1982) Chilling injury of crops of tropical origin. HortScience **17**: 162-165.

Domínguez T (1992) Efecto de la incidencia de daños por frío sobre la fisiología y calidad de frutos de tuna (Opuntia amyclaea T.). Tesis de Maestría. Colegio de Postgraduados, Postgraduate College, Montecillo Campus, Fruit cultivation center, Mexique.

Gorini F, Testoni A, Cazzola R, Lovati F, Bianco MG, Chessa I, Schirra M, Budroni M, Barbera G (1993) Aspetti tecnologici: Conservazione e qualita Á di fico d'india e avocado. L'Informatore Agrario **XLIX(1)**: 89-92.

Hebert JP (1995) Identification and determination of common parameters in Mediterranean fruit and vegetable products. Document du cours de formation, Programme ‛MED-CAMPUS C057’. Septembre 1995, Italie.

Inglese P, Basile F, Schirra M (2002) Cactus pear fruit production. In: P Nobel (ed) Cacti: Biology and Use. University of California Press, pp. 163-183.

Kuti JO (1992) Growth and compositional changes during the development of prickly pearfruit. J. Hort. Sci. **67(6)**: 861-868.

Lurie S, Romen R, Meier S (1994) Determing chilling injury induction in green peppers using non destructive pulse amplitude modulated (PAM) fluometry. J. Am. Soc. Hortic. Sci. **119(1)**: 59-62.

Lyons JM, Breidenbach RW (1987) Chilling injury. In: J Weichman (ed) Postharvest Physiology of vegetables. Marcel Dekker Inc., New-York, p. 305.

Mayberry KS, Hartz TK (1992) Extension of muskmelon storage life through the use of hot water treatment and polyethylene wraps. Hortscience **27(4)**: 324-326.

McGuire RG (1992) Reporting of objective color measurements. HortScience **27(12)**: 1254-1255.

Mondragón-Jacobo C, Bordelon BB (1996) Cactus pear (Opuntia spp. Cactaceae) breeding for fruit production. J. Prof. Assoc. Cactus Dev. **1**: 19-35.

Natalini A, Vanesa MD, Ferrante A, Pardossi A (2014) Effect of temperature and ripening stages on membrane integrity of fresh-cut tomatoes. Acta Physiol. Plant. **36**: 191-198.

Rodriguez S, Caso´ liba RM, Questa AG, Felker P (2005) Hot water treatment to reduce chilling injury and fungal development and improve visual quality of two Opuntia ficus-indica fruit clones. J. Arid Environ. **63**: 366-378.

Rodríguez-Félix A. (2002) Postharvest physiology and technology of cactus pear fruits and cactus leaves. Acta Hortic. **581**: 191-199.

Rodríguez-Félix A, González-Salas MI, Soto-Valdez H, Silveira-Gramont MI (1992) Effects of postharvest treatments on the quality of ``tuna″ during storage. Proc. 3rd AnnualTexas Prickly Pear Conference, Texas Prickly Pear Council, McAllen, TX. pp. 9-21.

Saenz C (2000) Processing technologies: an alternative for cactus pear (Opuntia spp.) fruits and cladodes. J. Arid Environ. **46**: 209–225.

Saenz-Hernandez C (1995) Food manufacture and by-products. In: G Barbera, P Inglese & E Pimienta-Barrios, (eds) Agro-ecology, cultivation and uses of cactus pear. FAO Plant Production and Protection Paper 132. FAO, Rome. p. 216.

Schirra M, D’hallewin G, Inglese P, La Mantia T (1999a) Epicuticular changes and storage potential of cactus pear [Opuntia ficus-indica Miller (L.)] fruit following gibberellic acid preharvest sprays and postharvest heat treatment. Postharvest Biol. Technol. **17**: 79-88.

Schirra M, Inglese P, La Mantia T (1999b) Quality of cactus pear [Opuntia ficus-indica (L.) Mill.] fruit in relation to ripening time, $CaCl_2$ pre-harvest sprays and storage conditions. Sci. Hort. **81**:425-436.

Schirra M, Barbera G, D'Aquino S, La Mantia T, McDonald RE (1996) Hot dips and high temperature conditioning to improve shelf quality of late-crop cactus pear fruit [Opuntia ficus-indica (L.) Mill.]. Trop. Sci. **36**: 159-165.

Serek M, Tamari G, Sisler EC, Borochov A (1995) Inhibition of ethylene-induced cellular senescence symptoms by 1-aminocyclopropane , a new inhibitor of ethylene action. Physiol. Plant. **94**: 229-232.

Tucker GA (1993) Introduction. In: GB Seymour, JE Taylor & GA Tucker (eds) Biochemistry of fruit ripening. Chapman and hall, London. pp. 1-51.

Wang CY (1994) Combined treatment of heat shock and low temperature conditioning reduces chilling injury in zucchini squash. Postharvest Biol. Technol. **4**: 65-73.