Marketability of ready-to-eat cactus pear as affected by temperature and modified atmosphere

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Abstract In order to increase the diffusion of cactus pear fruits, in this study, the proper maturity index for peeling and processing them as ready-to-eat product was evaluated and characterized. Thereafter, the effects of different storage temperatures and modified atmosphere conditions on the marketability of ready-to-eat cactus pear were studied. The storage of ready-to-eat fruits at 4 °C in both passive (air) and semi-active (10 kPa O₂ and 10 kPa CO₂) modified atmosphere improved the marketability by 30%, whereas the storage at 8 °C caused a dangerous reduction in O₂ partial pressure inside modified atmosphere packages, due to fruits' increased metabolic activity. A very low level of initial microbial growth was detected, while a severe increase in mesophilic and psychrophilic bacteria was shown in control samples at both temperatures during storage; an inhibitory effect of modified atmosphere on microbial growth was also observed. In conclusion, modified atmosphere improved only the marketability of fruits stored at 4 °C; whereas the storage at 8 °C resulted in deleterious effects on the ready-to-eat fruits, whether stored in air or in modified atmosphere.

Keywords Cold storage · Spoilage · Maturity stage · Fresh-cut · *Opuntia ficus-indica* [L.] Mill

Introduction

Cactus pear (*Opuntia ficus-indica* [L.] Mill.) is a fruit belonging to the *Cactaceae* family characterized by an oval

or elongated fleshy and juicy berry of approximately 100–200 g, which is composed of a thick peel, corresponding to 30–40% of overall weight, surrounding a succulent pulp which contains many hard-coated seeds (5–10% of the pulp weight). Recently, an increasing interest in the health improving capacity of cactus-pear consumption, mainly due to its reported nutritional and functional significance (Stintzing et al. 2001; Piga et al. 2003; Piga 2004; Tesoriere et al. 2004).

One of the reasons that this fruit is not widely commercialized and consumed in international and local markets is the presence of residual glochids on the fruit surface (Flores-Valdez et al. 1995). Therefore, the availability on the market of ready-to-eat (RTE) cactus pear could be an opportunity to increase its consumption and diffusion. Generally, peeling accelerates fruit deterioration, which could be minimized by the use of cold temperature combined with packaging in a passive or active modified atmosphere (Zagory and Kader 1988; Gunes and Lee 1997). It has been widely reported that modified atmosphere packaging preserves quality during the storage of fruits and vegetables (Kader 2002; Santos et al. 2006; Rico et al. 2007; Sandya 2010) by maintaining freshness (Gorny 1997), thus extending the shelf life of fresh-cut products. Microbial spoilage is one of the major causes of quality loss in fresh fruits and vegetables; cactus pear fruit is very susceptible to microbial spoilage, so that its storage life in the fresh state is limited (Corbo et al. 2004).

In order to preserve the RTE fruits' initial quality, and to extend the marketability, it is important to select the proper maturity index for processing (Watada and Qi 1999). In cactus pear fruits, the main external maturity indices are fruit size and changes in peel colour that are well correlated with internal quality attributes (Cantwell 1995).

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Generally, fresh cactus pear fruits of marketable size are edible at every ripening stage, each one characterized by a different peel colour (from green to orange).

Although there are many publications about postharvest aspects of cactus pear intact fruits, there is very little information published about the postharvest performance of the RTE product. Piga et al. (2003) found that minimally processed cactus pear harvested at full green stage can be stored for 9 days in passive modified atmosphere. In addition, Añorve Morga et al. (2006), reported that chemical and sensory attributes remained nearly as good as they were at harvest, for 9 days and 12 days of storage in air at 4 °C and 2 °C, respectively. Usually a temperature over 10 °C reduces the general quality of fresh-cut cactus pear, and this is associated with changes in the main chemical, microbiological and sensorial parameters (Piga et al. 2003; Añorve Morga et al. 2006).

As for modified atmosphere, some authors (Piga et al. 2000, 2003; Brito Primo et al. 2009) have reported that passive modified atmosphere packaging limited decay and increased the marketability of peeled cactus pear, as long as fruits were stored at low temperature; whereas, Corbo et al. (2004) found that storage in 5% O₂ and 30% CO₂ caused a selective suppression of the growth of different microbial populations.

In this work, the proper maturity stage for peeling cactus pear in order to process it as RTE was investigated. Thereafter, the effects of storage temperature and modified atmosphere treatments on qualitative and microbiological traits of minimally processed cactus pear collected at the most suitable maturity stage for processing were studied.

Materials and methods

Raw material

Cactus pears (*Opuntia ficus-indica* [L.] Mill.), cv Gialla were harvested in August and September 2009, from a commercial farm located in Monopoli (BA), and quickly transferred to the Postharvest Laboratory of the Institute of Sciences of Food Production-CNR.

For the initial characterization of quality and to establish the proper maturity stage for processing, in August, based on visual peel colour, fruits were sorted into three maturity stages, designated *full green*, *green-yellow* and *yellow-orange*. Thirty fruits of each maturity stage were divided into 10 trays, each one containing 3 fruits and analysed as hereby described.

The proper maturity stage for peeling and processing was evaluated on a subjective 5 to 1 scale, with 5=high peelability, 4=good peelability, 3=moderate peelability, 2=low peelability, 1=no peelability. In addition fruits were

also analysed for peel colour and firmness, and after peeling they were analysed for pulp colour, pulp firmness, pH and soluble solid content (SSC). Cactus pear fruits harvested at the *green-yellow* maturity stage, which resulted in the most suitable to be peeled and processed as RTE products, were used in the next experimental trial (Table 1).

Packaging and experiment set-up

In September, fruits collected at the *green-yellow* stage were washed in tap water, sanitized by immersion in 200 mg kg⁻¹ of sodium hypochlorite for 5 min, and left to dry at room temperature. To obtain RTE products, approximately 0.5 cm of fruit was removed from each distal end by cutting with a sharp knife, and the peel was then carefully removed along the longitudinal axis. Work surfaces and cutting tools were washed with 200 mg kg⁻¹ of sodium hypochlorite before and during processing. After washing and drying, three peeled fruits (about 300 g) for each replication were set in polyethylene terephthalate (PET) trays (model C250/50 Carton Pack, Italy) and sealed (model Boxer50 Lavezzini Vacuum Packaging System, Italy) in 20×25 cm polyamide/polyethylene (PA/PE) plastic bags (PO₂ 40 cm³m²d⁻¹ bar⁻¹, 140 µm thick, Orved, Italy), with either semi-active (10 kPa O₂ and 10 kPa CO₂) or

Table 1 Quality parameters of cactus pear fruits collected at three different ripening stages

Quality parameters	Ripening stages		
	Full green	Green-yellow	Yellow-orange
Peel colour			
<i>L</i> *	54.1 b	59.0 a	51.9 b
<i>a</i> *	-11.2 c	2.3 b	20.8 a
<i>b</i> *	28.2 b	33.5 a	28.3 b
<i>hue angle</i> (°)	111.8 a	86.2 b	53.5 c
Pulp colour			
<i>L</i> *	66.0 a	61.3 b	44.2 c
<i>a</i> *	-5.7 c	1.4 b	16.7 a
<i>b</i> *	46.8 b	55.7 a	43.2 b
<i>hue angle</i> (°)	97.2 a	89.0 b	68.9 c
Peelability score (5-1)	2.3 b	4.3 a	2.1 b
Firmness (N cm ⁻²)			
<i>Peel</i>	62.8 a	50.6 b	34.4 c
<i>Pulp</i>	16.7 a	14.1 a	9.0 b
SSC (°Brix)	13.1 b	14.6 a	15.2 a
pH	5.9 b	6.2 a	5.7 b

Peelability score: 5=high peelability, 4=good peelability, 3=moderate peelability, 2=low peelability, 1=no peelability

Mean values of 30 fruit for each ripening stages. For each factor mean values followed by different letter are significantly different ($P<0.05$) according to Student-Newman-Keuls (SNK) test

passive (closed in air, 20 kPa O₂ and 0.03 kPa CO₂) modified atmosphere (aMA and pMA). Unpackaged triplicate samples (i.e. trays in unsealed plastic bags) were used as a control. All samples were stored at two different temperatures (4 and 8 °C) for 13 days. For each modified atmosphere treatment (aMA, pMA and control) and storage temperature (4 and 8 °C), 12 packages (3 replications for 4 storage periods—3, 6, 9 and 13 days) were prepared. Initially, and after each storage period, samples were taken (1 package from each replication) and analysed for qualitative traits (pulp colour, appearance score, pH, SSC and pulp firmness) as hereby described. Microbiological analysis was performed initially and after 6, 9, and 13 days, whereas the atmosphere composition inside packages was measured initially and after 9, 24, 48, 72, 144, 168, 240 and 312 h, as following reported.

Atmosphere analysis

Oxygen and carbon dioxide partial pressures inside packages were monitored by using an infrared (CO₂) and paramagnetic (O₂) gas analyser (CheckPoint, PBI Dansensor). A needle was inserted into the package through a rubber seal placed onto the film.

Quality fruit determinations

Hunter colour parameters L^* (brightness), a^* (redness) and b^* (yellowness) were measured on 3 random points on peel and pulp with a colorimeter (CR-400, Konica Minolta, Osaka, Japan) in the reflectance mode and in the CIE $L^* a^* b^*$ colour scale. Hue angle ($h^\circ = \arctg b^*/a^*$) and saturation ($Chroma = \sqrt{a^{*2} + b^{*2}}$) were then calculated from primary L^* , a^* and b^* readings. The colorimeter was calibrated with a standard reference having values of L^* , a^* and b^* corresponding to 97.55, 1.32 and 1.41, respectively.

Appearance was evaluated on a subjective 5 to 1 scale, with 5=excellent, no defects, 4=very good, minor defects, 3=fair, moderate defects, 2=poor, major defects, 1=inedible. A score of 3 was considered to be the limit of marketability and a score of 2 the limit of edibility (Amodio et al. 2007).

A selected group of 6 assessors, (composed by 3 female and 3 male; aged between 24 and 50 years old), previously involved as member of trained descriptive analysis for tropical fruits, were trained to describe the appearance quality of fresh market cactus pear. During the training sessions, a variety of cactus pear samples from different ripening stages were presented to the panel group and discussion were conducted from the panel leader in order to develop along with the panelists a list of descriptor attributes. The panel reached a consensus on the following five attributes: 5=excellent, no defects, 4=very good,

minor defects, 3=fair, moderate defects, 2=poor, major defects, 1=inedible. The assessments were performed at each storing days in a room under controlled conditions (23 °C and 60–70 % relative humidity) and diffuse daylight. Prior to evaluated the cactus pear, all fruit samples coming from each modified atmosphere treatments, were presented separately to the panelists so they could evaluate their purchasing preference.

Total soluble solid content (SSC), expressed in °Brix, was measured using a refractometer (model DBR35, XS instruments, Italy) on a liquid extract obtained by whisking (1 min; 0.78 G) in a blender (Sterilmixer lab, International PBI, Milan, Italy), 3 fruits from each replication and then filtering the juice.

The pH of the juice was measured with a pH meter (Acorn pH 6 M, Oakton Instruments, Vernon Hills, IL).

Texture (firmness) was measured on whole fruits with peel (peel firmness) and without peel (pulp firmness) using a machine texture analyser (Zwicki Line Z0.5, Zwick/Roell, Ulm, Germany). For the maturity stage selection, firmness was measured by using a puncture method, determined as the force needed to pierce the fruits up to 10 mm by using a probe 1 cm in diameter, and is expressed as N cm⁻². In the experimental trial, firmness was measured as the relative deformation of the peeled fruits up to a 10 N load (deformation method), by using a plate of 100 mm of diameter, and is expressed in percentage.

Microbiological analysis

For each replication 30 g of fruit was transferred aseptically into a Stomacher bag containing 90 mL of sterile saline solution (9 mg kg⁻¹ NaCl), homogenized for 1 min using a Stomacher machine (BagMixer, Interscience, St Nom, France), and plated on Plate Count Agar (PCA) (Oxoid S.p.A., Italy) and on Potato Dextrose Agar (Oxoid S.p.A., Italy) for total mesophilic and psychrophilic bacteria and yeast and moulds counts, respectively. The appropriate dilutions of juice samples were plated in triplicate. Mesophilic and psychrophilic bacteria were counted after 24 h and 7 days of growth at 30 °C and 7 °C, respectively; whereas yeast and moulds were counted after 72 h at 25 °C.

Statistical analysis

The effect of the maturity stage was tested performing a one-way ANOVA, with data means arranged in a completely randomized design. For the experimental trial, a multifactor ANOVA for modified atmosphere treatments, storage temperature and storage duration (fixed factors) was performed. Mean values for modified atmosphere treatments were separated using the Student-Newman-Keuls (SNK) test, while standard deviation (SD) was also calculated for data

after each storage period. In the experimental trials three replication were used.

Results and discussions

Effect of maturity stage on cactus pear initial quality attributes

Significant differences were found among cactus pear ripening stages (Table 1). In particular, the ripening stages were well differentiated by measuring colour parameters (L^* , a^* , b^* , h°) and the main quality traits (peelability score, firmness, SSC and pH). As showed by data of h° value, a higher presence of the green component was detected in *full-green* fruits in comparison with the other maturity stages (Table 1). The yellow characterized *green-yellow* peel and pulp samples, whereas yellow and red were the main colour components detected in *yellow-orange* fruits (Table 1). As for the suitability to be peeled and processed, fruits belonging to *green-yellow* ripening stage were scored high peelable in comparison with samples coming from the other stages (Table 1), according to other authors (Brito Primo et al. 2009; Silva et al. 2009). As the cactus pear fruit develops and ripens, the peel decreases in thickness and becomes easier to remove (Wessels 1988). Fruits collected at the *full-green* stage were difficult to peel due to the thickness of the skin, which affected the fruits' suitability for peeling. Both the thinning and the softening of the peel shown in *yellow-orange* samples may contribute to the fruits' increased susceptibility to physical damage during handling (Cantwell 1995), which is why this stage was also considered unsuitable for peeling (Table 1). On the other hand, *green-yellow* fruits were at a stage of intermediate peel thickness and pulp softness, which was scored by the panellist particularly suited to peel and consequently process cactus pear as RTE fruits (Table 1). Our results on peelability agreed with data obtained by Harker et al. (2011) on kiwifruits. These authors found that the ease of skin detachment was closely related to the ripening process. They indicated at least two ways in which ripening of flesh can have an impact on peelability of fruits. Firstly, it reduces the adhesion between the skin and the underlying flesh, and secondly it allows a discontinuity to develop between the soft flesh and the tougher skin (Harker et al. 2011). Besides, these authors found a correlation between firmness and peelability, for which softer fruit peeled better than firmer fruit. Similarly we found that *green-yellow* fruits, which result more softer than the *full-green* ones, were easier to peel (Table 1). Firmness analysis showed *full-green* fruits to have a mean peel firmness 19% and 45% higher than *green-yellow* and *yellow-orange* samples, respectively. Moreover, *yellow-orange* samples were shown to have a mean pulp firmness

roughly 53% lower than the other two categories. Therefore, *green-yellow* fruits resulted suitable to peel and softer than the *full-green* samples.

For SSC determination, *full-green* cactus pears showed a significantly lower mean value than *green-yellow* and *yellow-orange* fruits (Table 1). The highest content in SSC detected in *yellow-orange* samples might be associated with the transformation of pectin substances and starch hydrolysis (Carrillo et al. 2003; Nath et al. 2011). Lastly, for pH measurement, *green-yellow* samples showed a mean value 7% higher than the other two ripening stages (Table 1). Based on these data, the *green-yellow* maturity stage yielded the most suitable fruit, both for ease of peeling and for marketable fruit appearance, meaning full pulp colour and optimal firmness in comparison with the other maturity stages.

Effect of modified atmosphere and storage temperature on RTE cactus pear quality

Atmosphere analysis

Once the cactus pear packages were closed, no further control of the inside atmosphere was exercised, and the composition changed due to produce respiration and film permeability to gases (Sivertsvik et al. 2002). In particular, fruits stored at 4 °C in pMA showed severe changes in O_2 and CO_2 partial pressures, reaching after 13 days of storage the values of 4.5 kPa (± 1.1) and 12.1 kPa (± 2.3) respectively. When, samples were packed in semi-active modified atmosphere, the O_2 content decreased by about 60% after 7 days and remained unchanged by the end of the experiment. In addition, a slight increase in CO_2 was observed, with final values of 14.0 kPa (± 0.3) (Fig. 1a).

When fruits were exposed to an higher temperature (8 °C), a faster gas change was registered, since temperature, could affect gas permeability and the fruit respiration rate (Kader 2002). Inside the bags stored at 8 °C in pMA, O_2 levels were less than 5 kPa after about 3 days of storage and practically nil at the end of the trial; in these conditions CO_2 increased faster, to final values of 18.6 kPa (± 0.4). In bags packaged in aMA, a rapid reduction in O_2 level was observed after only 48 h, to near zero at the end of the experiment. On the other hand, CO_2 content increased to 19.8 kPa (± 0.7) after a week, and these values remained roughly unchanged for the remaining storage period (Fig. 1b). In both storage temperatures, the equilibrium in gas composition after 7 days was reached. Generally, factors affecting establishment of optimal modified atmospheres are the rate of gas permeation through plastic film and the product respiration rate. The first depends on characteristics of film (material, thickness, and area), on gradient between external and internal atmosphere (driving force) and on temperature, which could affect gas

Fig. 1 Gas levels into ready-to-eat cactus pears packages stored at 4 °C (a) and 8 °C (b) in semi-active modified atmosphere (aMA) and passive modified atmosphere (pMA) ($n=3$)

permeability. Product respiration rate depends on the commodity, on its quantity, on gas composition inside package, and on temperature (Del-Valle et al. 2009).

Quality fruit determinations

The effects of modified atmosphere treatments, storage duration, temperature and their interactions on qualitative attributes of RTE cactus pears are reported in Table 2. Significant mean differences among the three types of atmosphere treatments were detected for pH and h° colour parameter (Table 3). Unpackaged samples reported a higher mean value for pH, in comparison with samples packaged in both modified atmosphere treatments. The same significant differences were reported for hue angle, meaning that air samples had a slightly higher presence of red component than fruits stored in MA. During storage, samples from all

treatments showed a decrease in appearance score (Fig. 2). At 4 °C, low appearance scores were given to control samples, which were considered still marketable (score 3) after only 6 days in storage, but were scored below the limit of edibility (score 2) after 9 days of storage, and designated inedible at the end of the experiment. Samples packed in both modified atmospheres reached the limit of marketability after 9 days. However, at the end of the experiment, samples stored in pMA reached a mean score of about 2, whereas fruits stored in aMA reached this value two days sooner (Fig. 2a). In control samples, low appearance scores were attributed to a reduction in turgidity due to the well-known high transpiration and consequent high deterioration rate of fresh-cut fruits stored in air (Cantwell and Suslow 2002) and to an enzymatic browning process on the pulp surface, resulting in an undesirable colour (Swailam et al. 2007) shown by colour analysis. All of these factors contributed

Table 2 Effect of modified atmosphere treatments (control, semi-active modified atmosphere and passive modified atmosphere), storage duration (3, 6, 9 and 13 days), storage temperature (4, 8 °C) on quality attributes of ready-to-eat cactus pear fruits

ANOVA factors	SSC (° Brix)	pH	Relative deformation (%)	Hue angle (°)	Overall appearance score (5–1)	Mesophilic load (Log CFU g ⁻¹)	Psychrophilic load (Log CFU g ⁻¹)
Modified atmosphere treatments (A)	ns	***	ns	*	****	****	****
Storage duration (B)	ns	****	ns	*	****	****	****
Storage temperature (C)	ns	ns	ns	ns	****	****	****
AxB	ns	ns	*	ns	****	****	****
AxC	ns	ns	**	ns	****	****	**
BxC	ns	ns	****	ns	****	****	**
AxBxC	ns	ns	ns	ns	ns	****	****

(ns) not significant; $P \leq 0.01$; (*) $P \leq 0.05$; (**) $P \leq 0.05$; (***) $P \leq 0.001$; (****) $P \leq 0.0001$

to the loss of freshness. On the other hand, the loss of quality in samples stored in MA was related to the senescence process and the qualitative changes due to development of anaerobic conditions, which occurred sooner if a high temperature was applied. In samples stored at 4 °C in both modified atmosphere conditions, the O₂ partial pressure was around 3–5 kPa at the end of storage, while CO₂ increased to 10–15 kPa. This optimal atmosphere composition was established after only few days in aMA, while it was reached after about a week in pMA packages. As a consequence, the fruits stored in MA (passive and semi-active) showed an higher marketability than the control at the same temperature. The MA with low O₂ and high CO₂ levels limited the postharvest deterioration shown in RTE cactus pear fruits stored in unsealed bags. In particular, since the O₂ is needed for browning reactions (Rojas-Graü et al. 2009), MA with low O₂ and high CO₂ levels can help to prevent browning in RTE produce. In addition, other authors used this atmosphere composition to maintain the visual appearance of several fresh-cut fruits such as peach (Palmer-Wright and Kader 1997; Gorny et al. 1999), kiwifruit (Agar et al. 1999), melon (Bai et al. 2001; Oms-Oliu et al. 2007a),

banana (Kudachikar et al. 2011) and table grape (Sabir et al. 2011).

When fruits were stored at 8 °C, higher losses in appearance quality were measured than under storage at 4 °C. Control samples showed a severe and rapid decrease

Table 3 Main effects of the storage in air (control), semi-active modified atmosphere (aMA) and passive modified atmosphere (pMA) on quality attributes of ready-to-eat cactus pears. Mean values of 12 samples (3 replicates × 4 storage duration)

Attributes	Modified atmosphere treatments		
	Control	p MA	a MA
pH	5.8 a	5.7 b	5.7 b
Hue angle (°)	72.4 b	74.7 a	75.5 a

For each factor mean values followed by different letter are significantly different ($P < 0.05$) according to Student-Newman-Keuls (SNK) test

Fig. 2 Appearance evaluation during the cold storage of ready to eat cactus pears stored at 4 °C (a) and 8 °C (b) in semi-active modified atmosphere (aMA) and passive modified atmosphere (pMA) and in unsealed packages (control) ($n=3$)

in appearance score, dropping below the limit of marketability and edibility after 6 days and 9 days of storage, respectively. A similar trend was shown in those packages where nearly anaerobic conditions developed very early (aMA). Samples stored in pMA reached the limit of marketability after 6 days of storage and the limit of edibility after 9 days; finally control and MA samples resulted inedible (score 1) after 9 and 13 days respectively (Fig. 2b).

On the other hand, the storage at 8 °C caused a higher product respiration activity, in comparison with the storage at 4 °C. As consequence anaerobic conditions were promptly reached in fruits stored in aMA. As a consequence, these samples obtained the lowest appearance scores and resulted near the marketable limit after only 3 days of storage. Whereas in samples stored in pMA, these anaerobic conditions were reached after 6 days of storage, at which time these samples also became unmarketable. Generally, the beneficial effect of MA can be attributed to a decrease of the overall metabolic activity of plant tissues. However, if O₂ partial pressure in MA decreases below the fermentation threshold limit, the tissue will initiate anaerobic respiration, with the corresponding production of off-flavours and off-odours that limit marketability (Oms-Oliu et al. 2007b).

Although Piga et al. (2000) stored intact cactus pear fruits for 8 days in air at 4 °C, we found that unpackaged samples became unmarketable after about 6 days of storage at both temperatures. Thus, peeling affected the fruit marketability as reported for fresh-cut processing (Kader 2002; Haseena et al. 2010). However, these losses in quality can be reduced by the use of MA.

As for fruit deformation, starting from an initial deformation value of 7.9% (± 0.01), no significant changes were shown among all samples stored at 4 °C, whereas a slight increase was measured among all fruits stored at 8 °C (data not shown). During this trial, no significant changes in SSC and firmness were measured in any samples stored at both temperatures. This could be attributed to the postharvest physiological traits of the cactus pear, which is classified as a non-climateric fruit. Similarly, other authors have shown low variations in these attributes during the cold storage of cactus pear fruits (Cantwell 1995).

Microbiological analysis

The aerobic mesophilic microbial load after washing was very low, while no psychrophilic load was detected. RTE cactus pears stored at 4 °C in aMA showed after 6 days in storage a slight increase in mesophilic growth, which remained stable by the end of the storage. In fruits stored in pMA and in control samples, the mesophilic load increased faster during storage, reaching the final values

of about 6 Log CFU g⁻¹ (Table 4). The psychrophilic load, after low changes measured in all treatments during the first week, increased dramatically in control samples and in pMA after 13 days, while only a slight increase was measured in aMA bags during the same period (Table 4). At 4 °C, no differences between mesophilic and psychrophilic count were measured. In addition, a low yeast and mould load (< 3 Log CFU g⁻¹) was detected initially, with no significant changes during the storage among modified atmosphere treatments and storage temperatures. According to Gounot (1986) psychrophilic or psychotropic microorganisms can grow at cold temperatures although they have a maximum growth temperature near or above 20 °C. As a consequence, we can suppose that during the trial the epiphytic bacteria able to grow at low temperature, although their optimal growth temperature is much more higher (25 °C), were counted.

The higher storage temperature (8 °C) caused a severe increase in microbial load, both mesophilic and psychrophilic. In this condition, mesophilic load increased slightly during the first week in aMA samples, after which it showed rapid growth, reaching a final value near to 9 Log CFU g⁻¹. On the other hand, fruits stored in pMA and in unpackaged bags reported a severe increase in mesophilic load until 6 days of storage, thereafter only small changes, in pMA and control respectively were detected (Table 4). The same increase pattern was observed for psychrophilic

Table 4 Mesophilic and psychrophilic bacterial growth on ready to use cactus pear stored at 4° and 8 °C in semi-active modified atmosphere (aMA) and passive modified atmosphere (pMA) and unsealed packages (control)

Modified atmosphere treatments	Storage temperature (°C)	Storage duration (days)			
		0	6	9	13
		Mesophilic load (Log CFU g ⁻¹)			
Control	4	0.7 ±0.20	2.4 ±0.70	5.3 ±0.10	6.4 ±0.10
	8	0.7 ±0.10	5.1 ±0.30	6.3 ±0.10	8.4 ±0.10
aMA	4	0.7 ±0.20	2.8 ±1.21	3.3 ±0.10	3.3 ±0.20
	8	0.7 ±0.10	2.3 ±0.20	7.3 ±0.10	9.4 ±0.10
pMA	4	0.7 ±0.20	2.0 ±0.00	3.9 ±1.52	5.6 ±0.10
	8	0.7 ±0.10	4.9 ±0.10	6.3 ±0.10	7.3 ±0.10
Psychrophilic load (Log CFU g ⁻¹)					
Control	4	ND	1.9 ±0.30	4.9 ±0.10	6.4 ±0.10
	8	ND	4.1 ±0.04	6.3 ±0.10	8.4 ±0.10
aMA	4	ND	1.2 ±0.20	3.3 ±0.10	3.5 ±0.10
	8	ND	3.3 ±0.10	6.3 ±0.10	6.3 ±0.10
pMA	4	ND	1.7 ±0.10	3.3 ±0.10	5.6 ±0.10
	8	ND	4.8 ±0.10	6.3 ±0.10	7.3 ±0.10

ND not detected

Mean values of 3 replication for each modified atmosphere treatments, storage temperature and storage duration $\pm$ standard deviation

bacterial growth when fruits were stored in aMA and pMA. In control samples, psychrophilic load increased positively, reaching a value of about 8 Log CFU g⁻¹ at the end of storage (Table 4). The increase in storage temperature caused a significant rise in microbial growth in samples stored in modified atmosphere, just after the severe reduction in O₂ partial pressure was detected inside the packages, which could be due to a change in selection from aerobic to anaerobic microflora. This might suggest an effect of atmosphere composition on microbial load in cactus pear stored at 8 °C. At 4 °C, total bacterial count during the whole storage period (13 days) remained below the legal limit (7 Log CFU g⁻¹) reported for fresh-cut product (Francis et al. 1999), in air and in both MA treatments, whereas at 8 °C, 9 days were enough for samples with all treatments to reach this limit.

Conclusion

In conclusion, it is possible to process cactus pear at the *green-yellow* ripening stage as a read-to-eat fruit and to store it for 9 days in modified atmosphere packaging (either semi-active or passive) at 4 °C. On the other hand, it was demonstrated that the storage at 8 °C caused a severe increase in bacterial counts, which contributed to the loss of fruit marketability. This research gives the opportunity to increase the diffusion and the availability of cactus pear by satisfying the increasing demand of consumers. In addition, this research could contribute to increase the ready-to-eat fruit references actually present in the market.

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