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Integrated Postharvest of Pitahaya fruits (*Hylocereus ocamponis*) stored at different temperatures

Lyzbeth Hernández-Ramos[1], María del Rosario García-Mateos[1*], Ana María Castillo-González[1], Ma Carmen Ybarra-Moncada[2]

[1]Instituto de Horticultura, Departamento de Fitotecnia, Universidad Autónoma de Chapingo.
[2]Instituto de Alimentos, Departamento de Ingeniería Agroindustrial, Universidad Autonóma Chapingo, Carretera México-Texcoco km 38.5, Chapingo, Estado de México, C.P. 56230

*Corresponding Author: rosgar08@hotmail.com

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Abstract. Pitahaya (*Hylocereus* spp.) has been placed successfully in the global fruit market due to its exotic appearance and pleasant flavor; however, its short postharvest life has limited its marketing in national and international markets. The postharvest life and final quality of fruits depend on the state of maturity in which the fruit is harvested, as well on the storage conditions. The aim of this study was to assess the postharvest behavior of pitahaya fruits (*H. ocamponis*) harvested during two states of maturity (pre-consumer and consumption maturity), stored at 6 ± 1 °C and 22 ± 3 °C for 24 d. The color, firmness, epicarp thickness, weight loss, soluble solids, total soluble sugars, betalains, phenolic compounds and antioxidant activity showed significant changes during the storage period. The preserved fruits at room temperature maintained their firmness and color of the epicarp, content of soluble solids, soluble sugars and betalains during 9 d of storage, but from the 16th d, they showed rottenness and degradation of epicarp betalains. In contrast, the stored fruits in refrigeration presented a lower weight loss, greater firmness, and epicarp thickness, reaching 24 d of shelf life. The antioxidant activity was greater in the pulp of the stored fruits at 22 °C, due to an apparent higher betalains concentration associated with greater water loss in the fruit.

Keywords: *Refrigeration, shelf life, betalains, state of maturity.*

Introduction

The Pitahaya, known as dragon fruit or tuna tasaja, is the name given to the fruits from species of the *Hylocereus* genus, which comprises approximately 16-18 cacti species native to America and most widely distributed in the Cactaceae family (García-Rubio *et al*., 2015; Mercado-Silva, 2018). Its photosynthetic crassulacean acid metabolism (CAM) allows the biomass production in arid and dry conditions, for this, its habitat is found in temperate, tropical and semi-arid regions of some countries. In Mexico, a wide diversity of species has been identified, their distribution is presented in 11 from the 14 biogeographical provinces of the country according to García-Rubio *et al*. (2015). The most produced and marketed species are *H. undatus* (red pitahaya, white pulp), *H. megalanthus* (yellow pitahaya, white pulp) and *H. polyrhizus* (red pitahaya, red pulp) (Ibrahim *et al*., 2018; Mercado-Silva, 2018). The fruit is a berry with a non-climacteric behavior, soft pulp, juicy and with abundant small, embedded seeds; the peel (epicarp) shows bracts (Nerd *et al*., 1999). The pitahaya fruit is eaten fresh due to its exotic appearance and pleasant flavor, it is used in making jam, liquor and juices (Jalgaonkar *et al.,* 2020); it has a high mineral, lipids and betalains content compared with the fruit of other cacti.

It is a source of proteins, fiber, phenolic compounds, flavonoids, phytosterols, triterpenes. The seed has an important polyunsaturated fatty acids content (Ibrahim *et al*., 2018; Hernández-Ramos *et al*., 2020); it is a fruit with potential to be considered a functional food because the current trend of consumers to purchase natural products for health benefits.

The attractive color of the epicarp and the color of the pulp of some *Hylocereus* species, is due to the presence of betalains, pigments with antioxidant activity, anti-cancer and inflammatory properties, antimicrobial and neuroprotective activities (Wu *et al*., 2006; Ibrahim *et al.,* 2018); the epicarp as an underutilized tissue could be a source of pectin and natural pigments for the agri-food industry (Jalgaonkar *et al*., 2020).

When the pigmentation of the epicarp is totally red, indicates ripeness, with the better physicochemical and sensory characteristics for the fruit consumption, but its postharvest life is lower. For this, fruits are harvested at different maturing stages, from the incipient appearance of color in the epicarp (initial maturity) to its totality (full maturity) (Nerd *et al*., 1999; Osuna-Enciso *et al.,* 2011; Freitas and Mitcham, 2013). Harvest during the correct maturity stage is a factor that influences the final physicochemical characteristics of the fruit and its shelf life (Wanitchang *et al*., 2010). According to Osuna-Enciso *et al*. (2011) and Magalhães *et al*. (2019), fruits can be harvested at different maturity stages depending on the commercial destination of the pitahaya: 1) at medium or pre-consumer (semi-ripe fruit) maturity, the fruit shows predominantly red pigmentation in the epicarp, it is the proper state of maturity for marketing in markets far from the cultivation area; 2) during the full maturity or consumption, when the fruit has an intense red pigmentation in the entire epicarp, state of maturity suitable for the marketing in neighboring markets and immediate consumption. Fruits at initial maturity stage, of some *Hylocereus* species, show a less sweet pulp and greenish epicarp, different from the two referred states of maturity (medium and full maturity) where fruits have better characteristics regarding the color of the epicarp and pigmentation, as well as other quality attributes for their marketing [total soluble solids (TSS), acidity, pH, weight, firmness, and epicarp thickness]. In the case of the fruits of *H. undatus* harvested at initial maturity, they show longer postharvest life than those at full maturity or for consumption due to the greater firmness of the pulp and lower respiration rates; but less sweet and less attractive color (Osuna-Enciso *et al.,* 2011).

An alternative to extent the postharvest life of climacteric and non-climacteric fruits is the refrigeration because it delays senescence, also, decreases or slows the deterioration factors that alters the product quality due to physiological disorders (Kader, 2007). However, there is little information about the refrigeration effect in the postharvest life of pitahaya fruits, despite being highly perishable, but susceptible to chilling injury. Some authors say that *H. undatus* and *H. polyrhizus* fruits store at a temperature less than or equal at 6 ºC can develop chilling injury (firmness loss, darkening of bracts and the outer part of the pulp, release of electrolytes, among other symptoms) (Nerd *et al*., 1999; Freitas and Mitcham, 2013; Quiroz-González *et al*., 2017). It is unclear the management and postharvest behavior, as well as the storage conditions for the fruits of some species such as *H. ocamponis* (red pitahaya with red, pink, or purple pulp), species that acquires greater relevance for its harvest due to its better characteristics (greater sweetness and attractive intense red color of the pulp, associated with its high betalains content) for its marketing. Therefore, the aim of this research was to assess the postharvest behavior of pitahaya fruits (*H. ocamponis*) harvested during two states of maturity, under two storage conditions (refrigeration and room temperature), to contribute with information about the quality characteristics of the fruit of this species during its postharvest period.

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Material and Methods

Biological material

Pitahaya fruits with red pulp (*H. ocamponis*) pest-free and without physical damages, were harvested in a commercial orchard in Molcaxac, Puebla, Mexico (18º 43' 36'' LN, 97º 54' 48'' LO, at an altitude of 1843 m and average annual rainfall of 655 mm), with a room temperature of 22 ± 2 ºC during the harvest time.

Maturity indicators of the fruit

For harvest, fruits were selected through the visual observation of the epicarp pigmentation, and were taken to the laboratory for measurement of epicarp surface color variables (fruit maturity index), in order to classify the fruits in accordance with two maturity stages (pre-consumer and consumption maturity), through the assessment of the epicarp color parameters according to the criterion of Osuna-Enciso *et al.* (2011) and Magalhães *et al*. (2019), stablished for *H. polyrhizus* and *H. undatus* fruits, respectively, who mention three states of maturity: 1) green fruits at initial maturity (≤ 50% of red pigmentation of the epicarp) and angle value (*Hue*) proximate to 120°; 2) semi-ripe fruits or at medium maturity (pre-consumer maturity), between 50 - 75% of red pigmentation in the epicarp and hue angle proximate to a 60 - 75°; and 3) mature fruits or at full maturity (consumption maturity), with more than 75% of red pigmentation and *hue* ≤ 60° in the epicarp, and a *hue* proximate to 20° when the total pigmentation of the epicarp is achieved.

Treatments, design, and experimental unit

Each group of *H. ocamponis* (60 fruits during the pre-consumer maturity and 60 fruits during the consumption maturity) was divided into two parts for its storage at different temperature (Figure 1). The four treatments were: pre-consumer maturity (30 fruits) stored at 22 ± 3 °C (T1); fruits during consumption maturity (30 fruits) stored at 22 ± 3 °C (T2); fruits during the pre-consumer maturity (30 fruits) stored at 6 ± 1 °C (T3) and fruits at consumption maturity (30 fruits) stored at 6 ± 1 °C (T4), all treatments stayed at 70% of relative humidity. The day storage began (0 d), 12 fruits from each maturity stage were sampled to develop an initial characterization. Subsequently, the assessments of the response variables were conducted periodically (1, 3, 6, 9, 12, 16, 20 and 24 d of storage) at 6 and 22 °C. The experimental design was completely random, and the experimental unit consisted of one fruit.

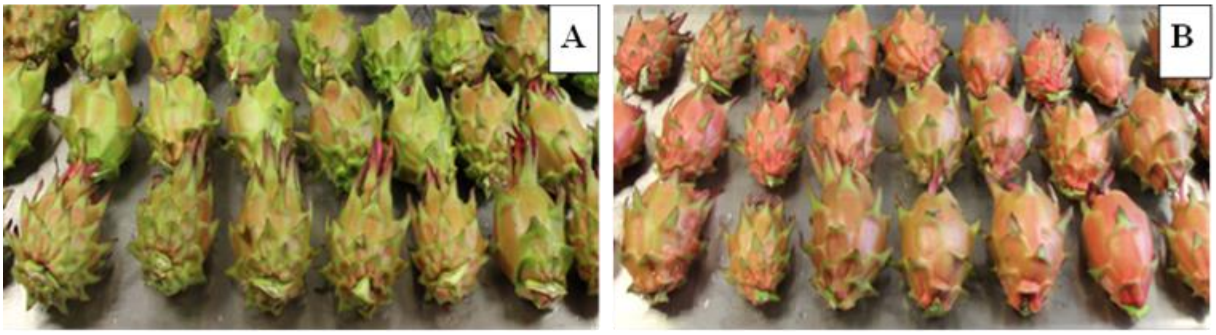

Figure 1. Pitahaya fruits (*Hylocereus ocamponis*) harvested at pre-consumer maturity (A) and consumption maturity (B).

The physical (weight loss) and chemical characterization [total soluble solids (TSS) content, total soluble sugars (AST), titratable acidity (TA), total phenolic compounds (TPC) content and antioxidant activity (AA)] was conducted in the pulp (mesocarp); in the epicarp (epicarp) the weight loss, thickness and firmness were assessed, and the determination of the betalains content and color variables (*hue*, chroma and luminosity) in the pulp and in the epicarp.

Physical characterization

The equatorial diameter (ED) and length of the fruit (L) and the epicarp thickness were determined with a digital Vernier (INOX IP54 Caliper, Grass Valley, USA), the shape index was calculated through the L/ED ratio. All fruits were weighted at the beginning of the assessment and during the subsequent sampling days, with an electronic balance (Scout Pro SP2001 Ohaus®, USA). The weight loss (%) was determined according to the initial weight. The firmness of the epicarp was assessed with a penetrometer (FT 327, QA SUPPLIES®, USA) equipped with a plunger tip of 8 mm thickness. The color of the pulp and epicarp were assessed with a portable colorimeter Color Tec-PCM® (Cole Palmer, Illinois, USA) and expressed into Luminosity (*L**), hue angle (*hue*) and color saturation index (*chroma*). The calculation was done with the following formulas: *Hue* = arc tan(b/a); *Chroma* = $(a_2 + b_2)^{½}$ (McGuire, 1992).

Chemical characterization

The total soluble solids (ºBrix) were assessed with a digital refractometer (PAL-1 ATAGO®, Japon); the total soluble sugar content through the anthrone method described by Witham *et al.* (1971) and the titratable acidity through the technique described by the Association of Official Analytical Chemists (AOAC, 2005).

Betalains content

Methanolic extract was prepared from the pulp and another with the separately epicarp according to the method described by Wu *et al*. (2006). One gram of the milled plant tissue was mixed with 20 mL of methanol 80% (v/v). Mixture was homogenized through the stirring in a vortex, and it was sonicated during 10 min at room temperature. Subsequently, the absorbance of the extract was read with a spectrophotometer (Genesys 10s). The content of total betalains, betacyanins and betaxanthins were determined with the formula: B [mg g^{-1}] = A·DF·MW·V / ε·L·W; where B = betacyanins or betaxanthins concentration, A = absorbance at 538 nm (betacyanins) or 483 nm (betaxanthins), DF = dilution factor, MW = molecular weight (550 g mol^{-1} for betanin and 308 g mol^{-1} for indicaxanthin), V = volume diluted (mL), ε = molar extinction coefficient (betanin: 60 000 L mol^{-1} cm^{-1} and indicaxanthin: 48 000 L mol^{-1} cm^{-1}), W = sample weight (g) and L = cell length (1 cm). Results are expressed as total betalains content (betacyanins + betaxanthines) for each 100 g of fresh weight.

Quantification of phenolic compounds

Phenolic compound content was determined only with the pulp (mesocarp) with seeds according to the modified method described by Singleton and Rossi (1965). To prepare the extract, one gram of the milled plant tissue was mixed with 10 mL of acetone at 80% (v/v). Mixture was homogenized through the stirring in a vortex and was sonicated for 10 min at room temperature. A mixture with 0.1 mL of the extract, 0.1 mL of the Folin-Ciocalteu (1 N) reactive, 4.5 mL of distilled water and 0.3 mL of Na_2CO_3 at 2% (w/v) was prepared. Mixture was incubated at room temperature and in darkness for 2 h. Absorbance readings of the mixture were taken at 760 nm in a spectrophotometer (Genesys 10s, Thermoscientific, USA). The phenolic compound content was determined through a standard curve of gallic acid (y = 0.0011x – 0.0084; R^2 = 0.998). Results were expressed as mg equivalent of gallic acid per 100 g of fresh sample (mg EAG 100 g^{-1} p. f.).

Quantification of the antioxidant activity

The FRAP test was carried out according to the procedure described by Benzie and Strain (1996), with some modifications. A mixture with 100 µL of the ketone extract, 3 mL of FRAP reactive [2.5 mL of acetate buffer 300 mM at pH=3.6 and 0.25 mL of a 10 mM solution of 2,4,6 Tripyridyl-s triazine (TPTZ; Sigma–Aldrich) in HCl 40 mM and 0.25 mL of $FeCl_3$ 20 mM] and 300 µL of distilled

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H_2O, was prepared. Mixture was incubated for 30 min at 37 °C. Finally, the absorbance of the mixture was read in a spectrophotometer at a wavelength of 593 nm. The antioxidant activity was calculated through a standard curve Trolox-based ($y = 0.7419x + 0.0297$; $R^2 = 0.990$). Results were expressed in µM equivalent of Trolox for each 100 g of fresh weight (µM ET 100 g^{-1} p. f.).

Statistical analysis

All data were expressed as the median ± standard error of three repetitions, except for the physical characteristics and betalains content during the harvest time, where 12 repetitions were conducted by measurement. The T-Student test was applied to differentiate the physical characteristics and betalains content (betacyanins and betaxanthins) among the fruits at the two maturity stages during the harvest time. Data from the postharvest behavior were analyzed with the SAS 9.2 (SAS Institute Inc, Cary, NC, EE. UU.) software, based on an analysis of variance (ANOVA) using a mixed model, according to the factorial design 22 and comparison of Tukey means ($P \leq 0.05$). The four treatments were considered as fixed effects and storage time as a random effects variation factor.

Results and discussion

Physical characteristics of the fruit

The fruits harvested at pre-consumer maturity and consumption maturity showed a similar shape index, weight of the fruit and epicarp thickness, only with a different firmness due to the biochemical and sensorial changes they presented at the consumption maturity phase (Table 1).

Table 1. Morphological and physical characteristics of pitahaya fruits (*Hylocereus ocamponis*) harvested at pre-consumer maturity and consumption maturity.

Characteristic	**Pitahaya (*H. ocamponis*)**	
	Pre-consumer maturity	**Consumption maturity**
Morphological attributes		
Equatorial diameter (cm)	8.09 ± 0.40 a	8.49 ± 0.30 b
Polar diameter (cm)	13.39 ± 0.69 a	14.70 ± 0.44 b
Shape index	1.66 ± 0.10 a	1.73 ± 0.07 a
Fruit weight (g)	491.92 ± 77.12 a	513.64 ± 73.96 a
Epicarp physical attributes		
Thickness (mm)	4.49 ± 0.52 a	4.79 ± 0.54 a
Firmness (N)	11.45 ± 0.76 a	7.20 ± 0.43 b

All data are expressed as the mean ± standard error considering twelve replicates. Different letters in the same row indicate statistically significant differences by the T-Student test ($P \leq 0.05$).

Seymour *et al.* (2012) point out that the ripening process is a genetically programmed and irreversible process that implies biochemical and physiological processes that result in softer fruits with different firmness, and edible with quality attributes desirable for the consumer. In this regard, Wanitchang *et al.* (2010) report a firmness decrease in immature fruits (13 N) and in mature fruits (8 N) of *H. polyrhizus* due to changes in components of the cell wall because the presence of enzymes such as polygalacturonase (PG), pectinmethylesterase (PME), xyloglucan-endo-trans-glycoslyase (XET) and the expansin protein (EXPs), component of the cell wall. Consequently, an increased enzymatic activity associated with medium layer degradation results in decreased cell adhesion (Paniagua *et al.,* 2014).

However, the temperature was a factor that modified the physical properties of fruits, which stored at 22 °C at pre-consumer maturity and consumption maturity showed a superior weight loss rate (0.99 and 0.80% per day, respectively) compared to those stored at 6 °C (0.52 and 0.40%,

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respectively), possibly to a greater biomass loss due to greater respiratory activity. The same reducing effect at room temperature was observed in the epicarp thickness (Figure 2). These results are similar to those reported by Osuna-Enciso *et al.* (2011) in the *H. undatus* fruits with a total weight loss of 5% and bract wilt after 10 d of storage 20 ± 2 °C. Pitahaya fruit is sensible to the water loss after its harvest, for this, it is recommended to store at high values of relative humidity, between 80 to 95% (Chandran, 2010; Freitas and Mitcham, 2013), in this study, fruits were stored at lower relative humidity (70%) in all treatments, thus, the vapor pressure deficit could cause a greater transport of water from the interior of the fruit to the environment, which could explain the weight loss.

On the other side, after 16 d, fruits stored at room temperature were more vulnerable to mechanical damages with a decrease in the epicarp thickness and firmness of the fruits, bract wilting, less glossy epicarp, and less turgid appearance, decreasing their shelf life and favoring the incidence of postharvest pathologies (rots caused by fungi) during storage. In contrast, fruits at the two states of maturity maintained in refrigeration at 6 °C, from the 16 d of storage, showed an increase in the firmness of the epicarp (Figure 2) that inhibited its softening, possibly: 1) to a decrease in enzyme activity (Ben-Arie *et al.*, 1989); and 2) to a greater water loss through transpiration that accelerated the wilting of the shell. Consequently, the fruits stored in refrigeration were less vulnerable to mechanical damages and showed less incidence of postharvest pathologies (rots caused mainly by fungi).

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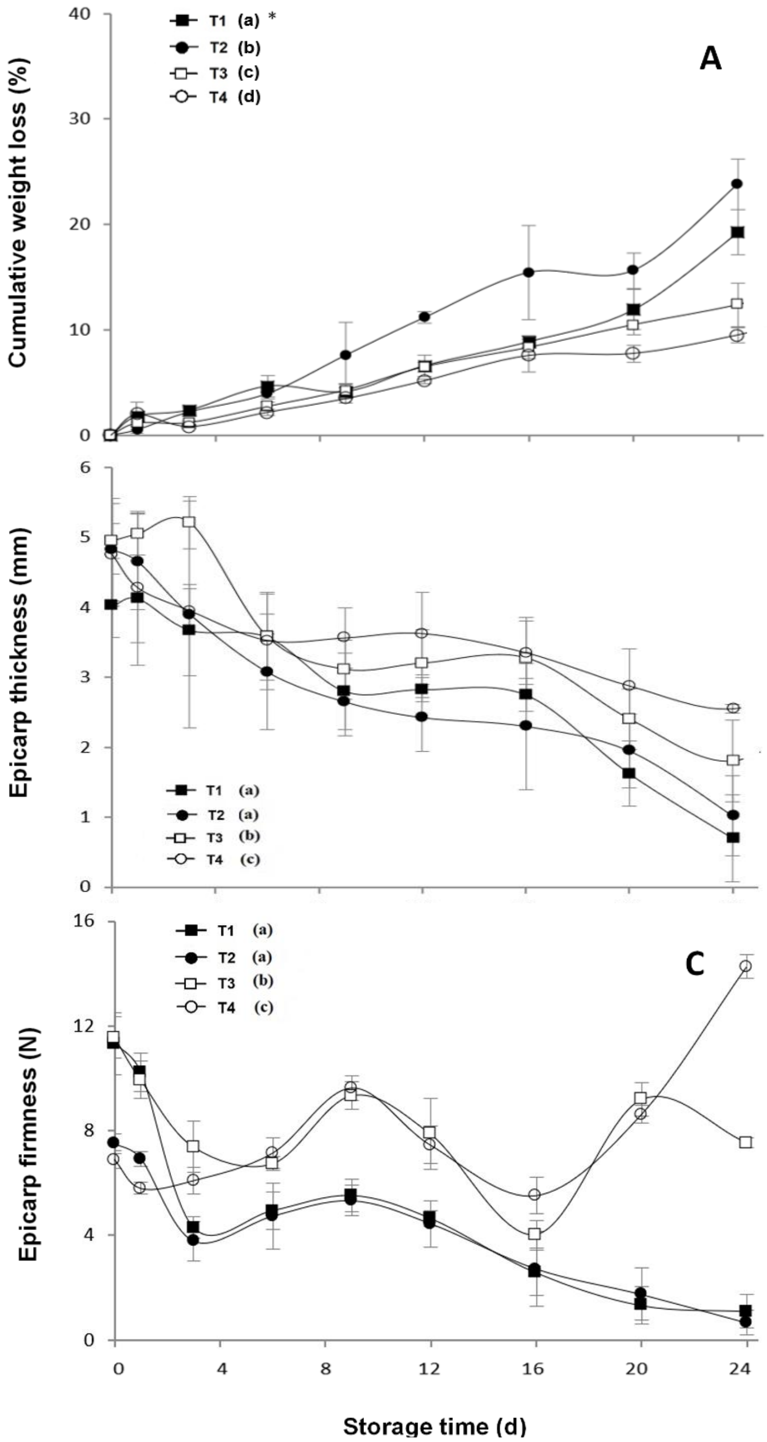

T1: fruit at pre-consumer maturity, stored at 22 °C
T2: fruits at consumption maturity, stored at 22 °C
T3: fruit at pre-consumer maturity, stored at 6 °C
T4: fruits at consumption maturity, stored at 6 °C

Figure 2. Cumulative weight loss (A), thickness (B) and epicarp firmness (C) of pitahaya fruit (*H. ocamponis*) harvested at two stages of maturity and storage during 24 d at 6 °C and 22 °C. Error bars correspond to standard deviation. *Different letters between treatments indicate a significant difference at 24 d of storage (Tukey, P ≤ 0.05).

Chemical characteristics of the fruit

The total soluble solids (TSS) and total soluble sugars (AST) did not show differences between both states of maturity; as it was reported by Osuna-Enciso *et al.* (2011), where similar TSS values were found in medium maturity (11.6-13.6 °Bx) and full maturity (11.3-12.4 °Bx) *H. undatus* fruits. However, in this study there were only variations of TSS and AST during storage between 6 and 22 °C (Figure 3). Fruits stored at 22 °C showed a marked decrease (30 %) in the TSS and AST concentration at 24 d of storage, possibly due to the maintenance of respiratory activity, associated with increased transpiration and consequently the oxidative degradation of sugars (Moreno Velázquez *et al*., 2013). In contrast, fruits stored at 6 °C (T3 and T4) showed an increase in TSS and AST after 16 d of storage (Figure 3). Similar increases were reported by Balois-Morales *et al.* (2013) and Quiroz-González *et al.* (2017) in *H. undatus* fruits stored between 2 and 3 °C, because fruits of some cacti species accumulate sugars and TSS as a tolerance mechanism to low temperatures and sometimes chilling injury.

On the other side, the acidity is a quality parameter that determines the flavor of the fruit, because of the balance between organic acids and sugars (TSS/TA ratio). *H. ocamponis* fruits are known because their sweet flavor with low values of titratable acidity (TA ≤ 0.20 %). In the harvested fruits at different states of maturity and stored at different temperature (Figure 3) there were no meaningful differences in the TA.

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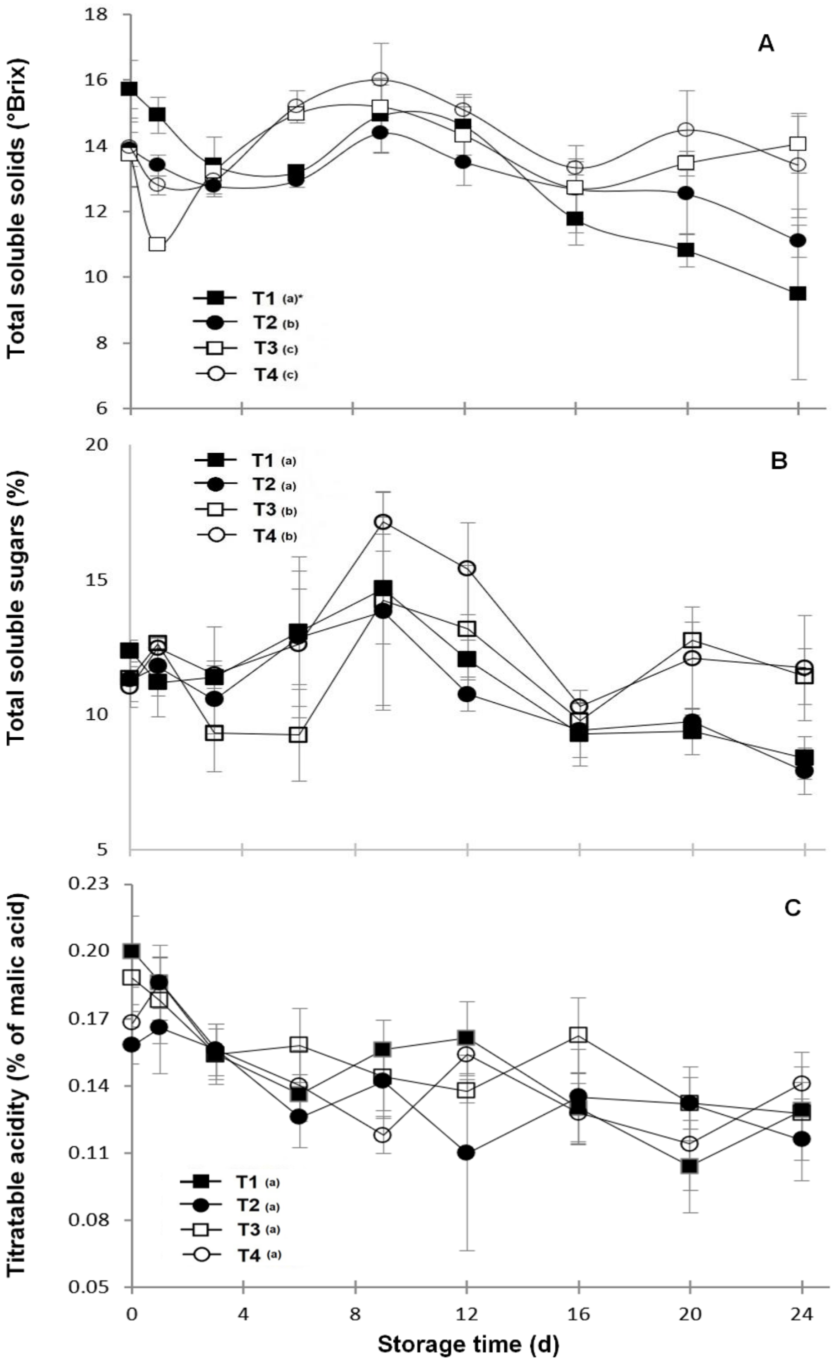

T1: fruit at pre-consumer maturity, stored at 22 °C
T2: fruits at consumption maturity, stored at 22 °C
T3: fruit at pre-consumer maturity, stored at 6 °C
T4: fruits at consumption maturity, stored at 6 °C

Figure 3. Behavior of total soluble solids (A), total soluble sugars (B) and titratable acidity (C) of the pulp of pitahaya fruit (*Hylocereus ocamponis*) harvested at two stages of maturity and storage during 24 d at 6 and 22 °C. Error bars correspond to standard deviation. *Different letters between treatments indicate a significant difference at 24 d of storage (Tukey, P ≤ 0.05).

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Color and betalains parameters

Betalains biosynthetically derive from the betalamic acid, these compounds grouped into betacyanins and betaxanthins, which impart red-purple and yellow-orange color of the pulp and epicarp of these fruits, respectively (Zrÿd and Christinet, 2004; Stintzing and Carle, 2007). The color is a distinctive characteristic of *H. ocamponis* due to the high betacyanins content in the pulp and epicarp, metabolites responsible for pigmentation (Hernández-Ramos *et al*., 2020). As it was pointed out in the methodology, the pigmentation level is an indicator of the maturity level of the fruit (Figure 4), due to the degradation of chlorophyll and the betalains synthesis in both tissues.

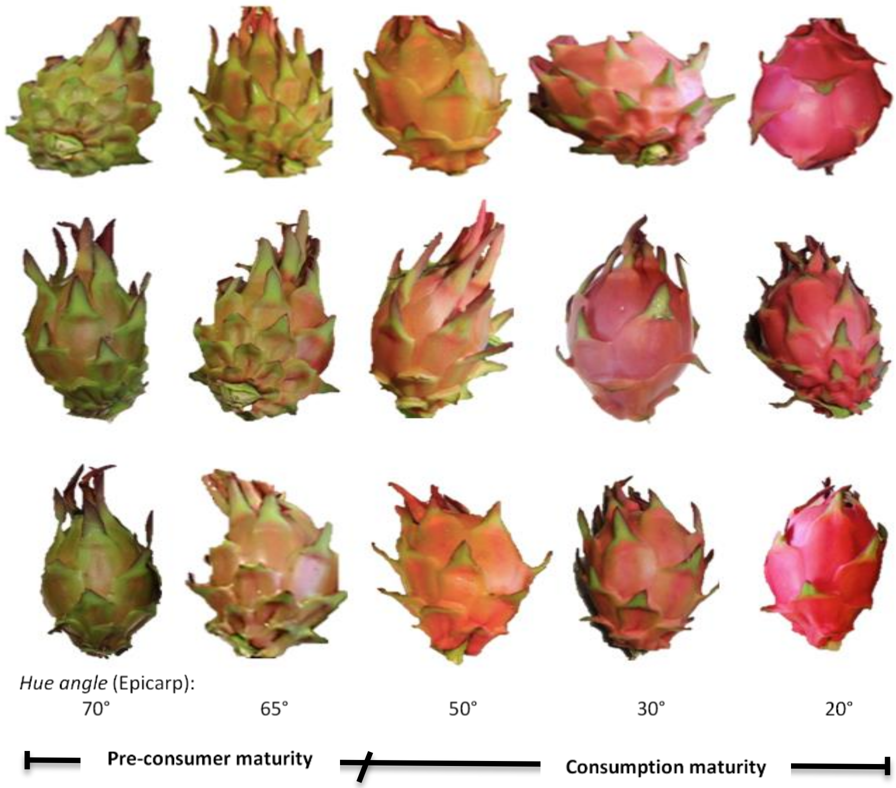


Figure 4. Hue angle in the epicarp of pitahaya fruits (*Hylocereus ocamponis*) harvested at pre-consumer maturity and consumption maturity.

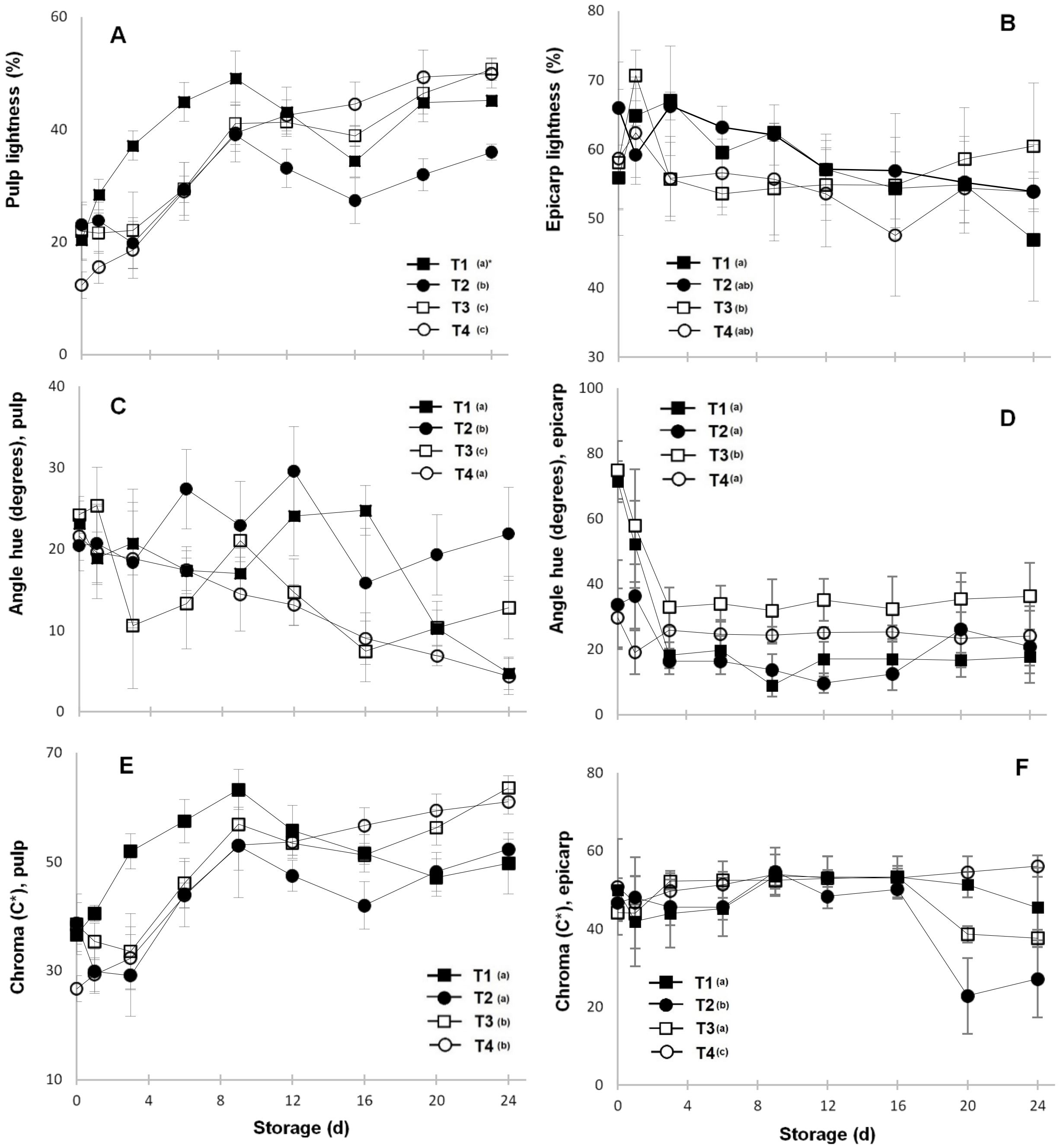
The epicarp and pulp at consumption maturity showed lower hue values (more red fruits) compared to the fruits at pre-consumer maturity, due to an increased betalains synthesis (Table 2 and Figure 4); however, the epicarp of the fruits at both states of maturity showed greater hue values, which means a lower pigmentation compared to the pulp (less betalains content), which matched with what was reported in *H. polyrhizus*, where pigmentation also started first in the pulp (28 d after anthesis) and then in the epicarp (34 d after anthesis) (Magalhães *et al.*, 2019; Wu *et al*., 2019). There were not differences statistically meaningful in the color parameters *L** and chroma of the fruits harvested at both states of maturity (Table 2).

Table 2. Color attributes and betalains content of pitahaya fruits (*Hylocereus ocamponis*) harvested at pre-consumer maturity and consumption maturity.

Characteristic	**Pitahaya (*H. ocamponis*)** Pre-consumer maturity	Consumption maturity
Epicarp attributes		
L:* Lightness (%)	57.59 ± 6.99 a	62.28 ± 8.97 a
Hue angle (degrees)	73.19 ± 6.84 a	35.99 ± 8.59 b
Chroma	47.06 ± 4.44 a	48.77 ± 13.45 a
Betacyanins (mg 100 g^{-1})	7.34 ± 1.60 a	12.62 ± 3.17 b
Betaxanthins (mg 100 g^{-1})	2.44 ± 0.42 a	2.53 ± 1.10 a
Mesocarp attributes		
*L**: Lightness (%)	21.16 ± 3.85 a	17.71 ± 6.16 a
Hue angle (degrees)	23.66 ± 2.25 a	20.98 ± 2.63 b
Chroma	37.56 ± 3.96 a	32.69 ± 6.82 a
Betacyanins (mg 100 g^{-1})	9.34 ± 0.79 a	9.81 ± 2.53 a
Betaxanthins (mg 100 g^{-1})	3.67 ± 0.68 a	3.27 ± 0.72 a

All data are expressed as the mean ± standard error considering twelve replicates. Different letters in the same row indicate statistically significant differences by the T-Student test ($P \leq 0.05$).

However, pitahaya fruits showed meaningful changes regarding lightness, *hue* and *chroma* in the four treatments at two temperatures (Figure 5), which is reflected in color changes in the pulp and epicarp due to the betalains content (Figures 6 and 7). The pulp of the fruits stored at 22 °C showed an apparent higher concentration of pigments, which increased after 24 d of storage associated to the greater water loss compared to the pulp of the fruits stored at 6° C (Figure 6); behavior seen in Figure 7, where fruits of the treatments T1 and T2 are less turgid. By contrast, fruits stored at 6 °C showed an opposite variation (higher *L** and *chroma* values and lower *hue* values), preserving a pigment content close to that reported at the time of harvest. Yong *et al*. (2018) point out that the storage at low temperatures is great for preserving betalains in the pitahaya fruits (*H. polyrhizus*), because at room temperature its degradation is produced due to the action of peroxidases and polyphenol oxidases.



T1: fruit at pre-consumer maturity, stored at 22 °C
T2: fruits at consumption maturity, stored at 22 °C
T3: fruit at pre-consumer maturity, stored at 6 °C
T4: fruits at consumption maturity, stored at 6 °C

Figure 5. Color attributes of the pulp of pitahaya fruits (*Hylocereus ocamponis*) harvested at two stages of maturity and storage during 24 d at 6 °C and 22 °C. Error bars correspond to standard deviation. * Different letters between treatments indicate a significant difference at 24 d of storage (Tukey, P ≤ 0.05).

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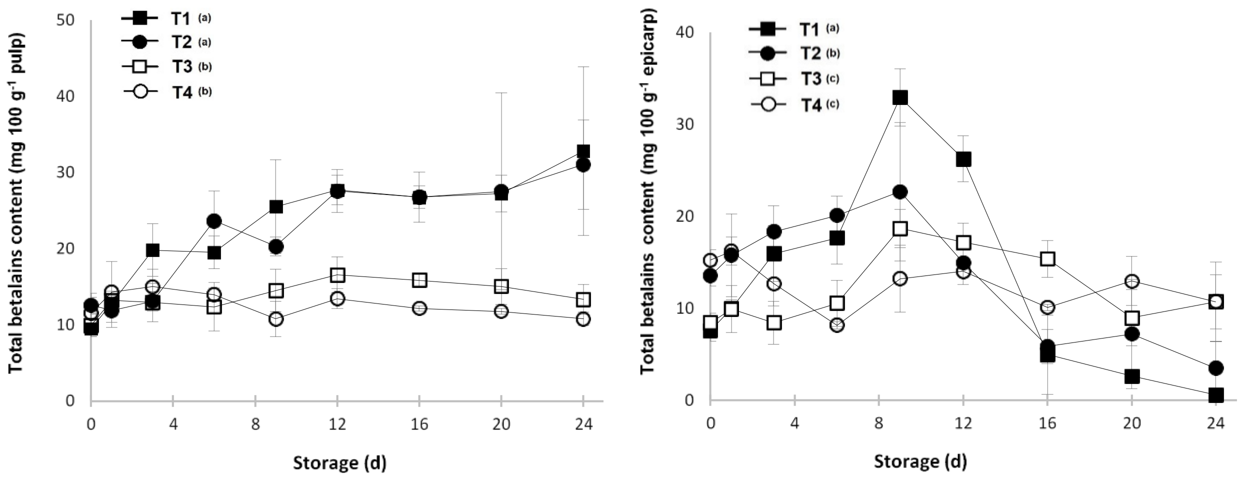

T1: fruit at pre-consumer maturity, stored at 22 °C T2: fruits at consumption maturity, stored at 22 °C
T3: fruit at pre-consumer maturity, stored at 6 °C T4: fruits at consumption maturity, stored at 6 °C

Figure 6. Betalains content in the pulp and epicarp of pitahaya fruits (*Hylocereus ocamponis*) harvested at two stages of maturity and storage during 24 d at 6 °C and 22 °C. Error bars correspond to standard deviation. *Different letters between treatments indicate a significant difference at 24 d of storage (Tukey, P ≤ 0.05).

Regarding the epicarp, values of *L** gradually decreased only based on storage time with respect to the values recorded on the day of harvest, while *hue* and *chroma* values in the epicarp were significantly affected by the temperature and storage time. The epicarp of fruits stored at 22 °C showed lower *chroma* values (loss of color purity, Figure 5) and decrease of the betalains concentration (Figure 6) after 24 d, possibly due to the presence of rottenness and necrosis as it can be seen in Figure 7; an opposite effect was observed in the epicarp of fruits stored at 6 °C, where less variation in its pigmentation was found, a desirable characteristic for the product purchasing by the consumer.

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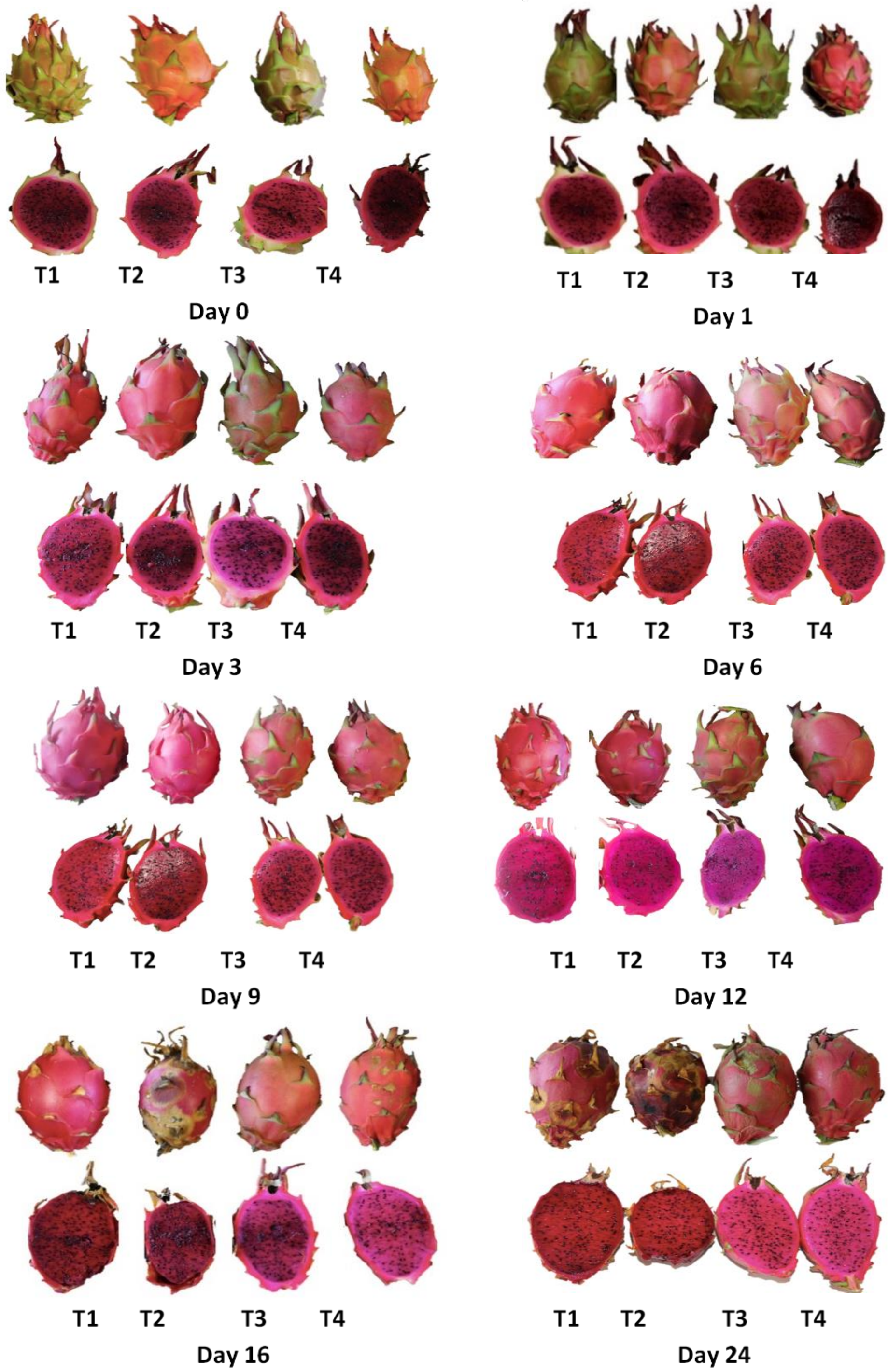

Figure 7. Color changes in pitahaya fruits (*Hylocereus ocamponis*) harvested at two stages of maturity and stored at different temperatures: T1: fruit at pre-consumer maturity, stored at 22 °C; T2: fruits at consumption maturity, stored at 22 °C; T3: fruits at pre-consumer maturity, stored at 6 °C and T4: fruits at consumption maturity, stored at 6 °C.

Phenolic compounds content

The total soluble phenolic compounds (TPC) content in the pulp of fruits was only affected during the storage time (Figure 8A). In general, in all treatments, concentrations of these metabolites decreased after the 12 d of storage, possibly because the oxidative metabolism caused by the increase in the activity of enzymes such as polyphenol oxidase and peroxidase, involved in the degradation of phenolic compounds due to stress conditions (Tomás-Barberán and Espín, 2001).

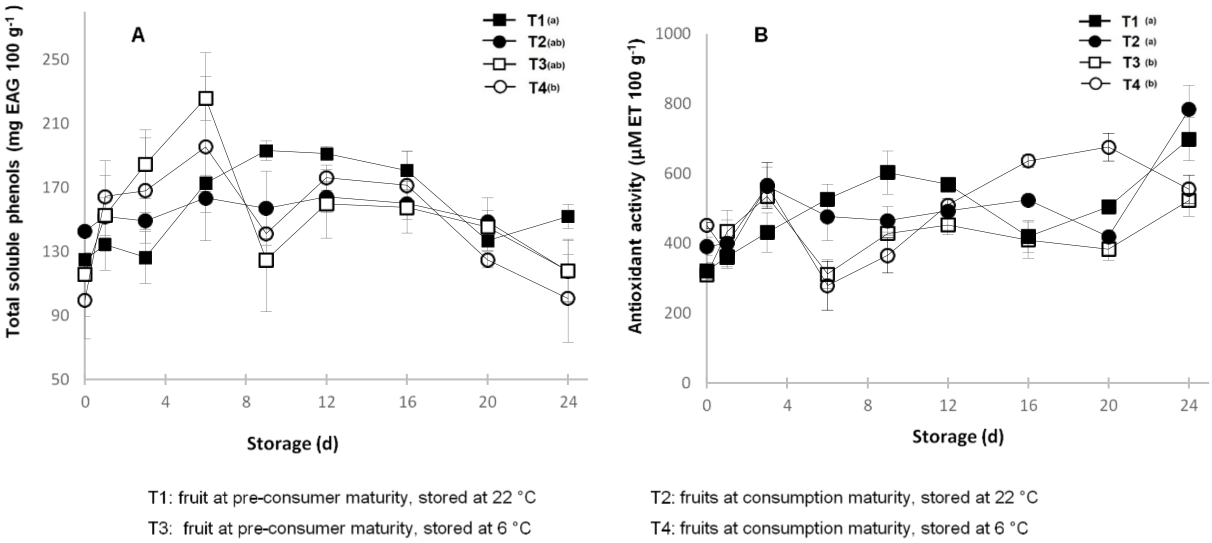

Figure 8. Total soluble phenols content (A) and antioxidant activity (B) of pulp and epicarp of pitahaya fruit (*Hylocereus ocamponis*) harvested at two stages of maturity and storage during 24 d at 6°C and 22 °C. Error bars correspond to standard deviation. *Different letters between treatments indicate a significant difference at 24 d of storage (Tukey, $P \leq 0.05$).

Antioxidant activity

Fruits at two states of maturity stored at a 22 °C showed a slight increase of the antioxidant activity in the pulp, different from the fruits stored at a lower temperature (6 °C) after 24 d (Figure 8B). The AA increase in the fruits stored at room temperature could be due to the apparent increase of the betalains concentration at the end of the storage period.

Conclusion

The Pitahaya fruits stored at 6 °C, regardless of the state of maturity, showed longer shelf life (24 d) due to their quality characteristics (TSS, AST, greater firmness and epicarp thickness, and lower weight loss), they also preserved the concentration of antioxidant pigments close to what was observed at the time of harvest. However, the sensitivity to chilling injury of the fruits was not evaluated after the end of the storage period. In contrast, fruits stored at 22 °C showed 9 d of shelf life, lower TSS and AST content, rottenness, necrosis and betalains degradation in the epicarp; although the concentration of these pigments in the pulp increased until the 24 d of storage associated with greater water loss compared to fruits stored at 6 °C.

ETHICS STATEMENT

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF SUPPORTING DATA

All data generated or analyzed during this study are included in this published article.

COMPETING INTERESTS

The authors declare that they have no competing interests.

FUNDING

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AUTHOR CONTRIBUTIONS

All authors contributed jointly to all aspects of the work reported in the manuscript. All authors have read and approved the final manuscript.

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