Journal of Applied Botany and Food Quality 93, 197 - 203 (2020), DOI:10.5073/JABFQ.2020.093.024

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Fruits of the pitahaya *Hylocereus undatus* and *H. ocamponis*: nutritional components and antioxidants

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(Submitted: May 2, 2020; Accepted: September 15, 2020)

Summary

The pitahaya (*Hylocereus* spp.) is a cactus native to America. Despite the great diversity of species located in Mexico, there are few studies on the nutritional and nutraceutical value of its exotic fruits, ancestrally consumed in the Mayan culture. An evaluation was made regarding the physical-chemical characteristics, the nutritional components and the antioxidants of the fruits of *H. ocamponis* (mesocarp or red pulp) and *H. undatus* (white pulp), species of great commercial importance. The pulp of the fruits presented nutritional and nutraceutical differences between both species. The red pulp of *H. ocamponis* presented the highest content of betalains (15.94 mg 100 g^{-1}), ascorbic acid (10.13 AAE mg 100 g^{-1}) and antioxidant activity (2009.58 μM TE 100 g^{-1}) compared to that of *H. undatus*. The seeds of both species had a higher content of linoleic acid (ω^{-6}) compared to other fatty acids. The underused skin (epicarp) of the white pulp pitahaya presented a higher content of betalains (19.83 mg 100 g^{-1}) than that found in the pulp and the red skin of the other species (13.21 mg 100 g^{-1}). The red pitahaya that is for regional consumption presented a better functional quality. The skin of both species could be a source of pigments in the food industry.

Keywords: *Hylocereus ocamponis*, *Hylocereus undatus*, linolenic acid, phenolic compounds, betalains and antioxidant activity.

Introduction

In Mexico there are located approximately nine of the eighteen species identified so far of the genus *Hylocereus* Britton & Rose (Cálix De Dios, 2004). It is one of the most wide y distributed genera of the family *Cactaceae*. It is characterized by a *crassulacean acid metabolism* (CAM) photosynthetic metabolism, which allows the production of biomass in arid and dry conditions according to its habitat (Mercado-Silva, 2018). However, these hemiepiphytic plants respond to stressful situations, grow in temperate, tropical and semi-arid areas of Mexico, in wild or cultivated conditions, in varying annual precipitation (400 to 4000 mm), at altitudes from 0 to 2500 m above sea level (García-Rubio et al., 2015) and survive at temperatures above 38-40 °C. Mexico, Central America and northern South America could be considered the center of origin of the genus *Hylocereus* due to the number of species located in those regions. The great adaptability of these cacti has allowed their cultivation in various countries (India, Thailand, China, Australia, Taiwan, Malaysia, the Philippines, Vietnam, Cambodia, Indonesia, Israel, the United States) among others (García-Rubio et al., 2015; Ibrahim et al., 2018).

The non-climacteric fruit of the pitahaya is a globose or subglobose berry, with a sweet and juicy pulp (mesocarp) with small seeds, commonly known as dragon fruit because of the presence in the epicarp of bracts. In addition, it is important to point out that "pitaya" and "pitahaya" have been used incorrectly as synonyms (Ibrahim et al., 2018; Le Bellec et al., 2006). "Pitaya" corresponds to the genus *Stenocereus* (Quiroz-González et al., 2018), while "pitahaya" corresponds to the genus *Hylocereus* (Wu et al., 2006). Research on pitahaya was done in this study.

The fruit of *H. ocamponis* (Salm-Dyck) Britton & Rose, known as pitahaya solferina (red epicarp, red, pink or purple mesocarp) is a native species of Mexico (García-Rubio et al., 2015), little documented, underused and of low commercial demand. It has recently caught the attention of consumers due to the pigmentation of the pulp because of its betalain content (Ibrahim et al., 2018). The species *H. undatus* (Haw.) Britton & Rose (red or pink epicarp, white mesocarp) is the most economically important, cultivated and exported one. Finally, another underutilized species is *H. megalanthus* (K. Schumann ex Vaupel) Ralf Baue (yellow epicarp, white mesocarp) of regional consumption, which is cultivated in backyards in different regions of Mexico; it is a native species of Colombia, one of the important producing countries worldwide (Mercado-Silva, 2018).

Currently, the consumption of these exotic fruits is increasing, due to their nutritional, mineral, but mainly functional attributes. Studies report that depending on the species (*H. monacanthus*, *H. megalanthus*, *H. polyrhizus* and *H. undatus*), the fruit is a source of carbohydrates (pectin, simple sugars, hemicellulose), protein, high fiber content, minerals (mainly potassium, magnesium, calcium, phosphorus in a lower concentration, zinc, iron), antioxidant compounds (phenolic acids, flavonoids), pigments (betalains), vitamins C and B, triterpenoids (cholesterol, campesterol, stigmasterol, and β-sitosterol) (Ibrahim et al., 2018; Lim et al., 2010; Mercado-Silva, 2018), some volatile components (flavor components) and a high content of functional lipids present in the seeds (palmitic, oleic and linoleic acids) (Akram and Mushtaq, 2019). However, the nutritional and nutraceutical properties of *H. ocamponis* are little known as well as the inhibitory effect of betanin against steatohepatitis in mice (Lugo-Radillo et al., 2020). Few studies on this species were carried out in other countries (Wybraniec et al., 2007),

These ingredients provide health benefits, which include the prevention and treatment of illnesses (Wildman and Kelley, 2007) and aid in preventing some health problems of this century such as obesity, cardiovascular disorders (Badimon et al., 2010), cancer, osteoporosis, arthritis, diabetes and cholesterol among others (Das et al., 2012). Recent epidemiological studies have shown that the frequent consumption of fruits and vegetables is positively associated with a lower risk of chronic diseases including type 2 diabetes mellitus and obesity. A high consumption of fruits and vegetables ensures an intake of appropriate amounts of nutrients, dietary fibers, and non-nutrient phytochemicals. Mercado-Silva (2018) have pointed out the nutritional composition of *H. undatus* (dietary fiber, soluble fiber, insoluble fiber, and protein), the contents of calcium, phosphorus, iron and antioxidants (phenolic compounds and vitamin C) cultivated in Mexico. However, the characteristics of *H. ocamponis* are unknown.

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In addition, WYBRANIEC et al. (2007) showed the presence of betacyanins in the peel and flesh of fruits of *H. ocamponis* and betacyanins in the peel of *H. undatus*. These metabolites possess various biological activities from which their antioxidant activity, anticancer properties and antimicrobial activity stand out (WU et al., 2006; GENGATHARAN et al., 2015). Betalains are nutraceutical components of restricted distribution, mainly in the family of the order Caryophyllales. These pigments are biosynthetically derived from the bethalamic acid, and are grouped into betacyanins (red pigments) and betaxanthines (yellow pigments). They are responsible for the color of the pulp and the skin of cacti fruits such as the pitaya, the prickly pear, the xoconostle and the pitahaya (QUIROZ-GONZÁLEZ et al., 2018; LÓPEZ et al., 2015).

Currently, the identification of these metabolites justifies some of the medicinal properties of the different parts of the plant, ancestrally used in the Mayan culture (WYBRANIEC and MIZRAHI, 2002). To the fruit, it is attributed anti-diabetic, anti-cancer, hepatoprotective, anti-inflammatory, prebiotic, hypolesterolemic properties and the reduction of blood pressure (IBRAHIM et al., 2018). Flower infusions are consumed as a diuretic and as a hypoglycemic. Regarding those with a skin, for the treatment of some chronic degenerative diseases, mainly due to the presence of some nutraceutical and antioxidant components (betalains, phenolic compounds and flavonoids) (IBRAHIM et al., 2018).

In recent decades, research on the antioxidant properties of cacti fruits have intensified due to the growing interest of the consumer in eating foods with nutraceutical quality that contribute to the improvement of health and the prevention of diseases (IBRAHIM et al., 2018). There are reports of the chemical components in the fruits of some species grown in other countries, but it must be considered that the different edaphoclimatic conditions can mainly modify their nutraceutical quality and consequently their medicinal properties (AKRAM and MUSHTAQ, 2019; IBRAHIM et al., 2018). In Mexico, despite the great diversity and as a greater center of origin of cacti (NOVOA et al., 2015) there is little information on the nutritional and nutraceutical quality of most of them. The contribution of this paper focuses on providing information on the physical and chemical characterization as well as the nutritional and nutraceutical quality of the *H. ocamponis* fruits grown in Mexico, information that is not reported. These properties of the *H ocamponis* fruits were compared with those of *H. undatus*. Both species were cultivated in the same study area. The few studies that have been carried out on these species correspond to fruits grown in the American continent. Therefore, the objective was to determine the nutritional characteristics and the content of antioxidant components of the fruits of the red pulp pitahaya (*Hylocereus ocamponis*) and the white pulp pitahaya (*H. undatus*) cultivated in Mexico, in order to contribute with information on its nutraceutical potential, mainly concerning the red pulp dragon fruit with a higher degree of pigmentation.

Materials and methods

Vegetal material

The fruits of two species of pitahaya (*Hylocereus undatus* and *H. ocamponis*) were obtained from a commercial produce farm in Molcaxac, Puebla, Mexico (18º43'36" N and 97°54'48" W at an altitude of 1843 m above sea level), with a precipitation of 655 mm and a mean annual temperature of 19.2 °C. The fruits were harvested at commercial maturity during the second fruition of the plant, free of pests and physical damage.

Physical characterization

The evaluated variables were the equatorial diameter (ED), length (L), skin thickness, width of bracts and length of the apical bracts using a digital vernier (INOX IP54 Caliper, Grass Valley, USA). The relationship between L/ED was considered to determine the roundness index. Also, the number of bracts and seeds per fruit of each species was counted. The weight of the fruit, pulp, seeds, skin and the proportionality of pulp, seeds and skin were determined using an electronic scale (Scout Pro SP2001 Ohaus®, USA). The skin firmness was evaluated with a penetrometer (FT 327, QA SUPPLIES®, USA) equipped with an 8 mm thick plunger tip. In addition, the color was evaluated with a Color Tec-PCM® portable colorimeter (Cole Palmer, Illinois, USA) and was expressed in luminosity (*L**), hue angle (*Hue*) and color saturation index (*Chroma*).

Chemical characterization

The evaluated chemical parameters were the pH using a potentiometer (HI2221 Hanna Instruments, Woonsocket, USA), the titratable acidity using the technique described by the Association of Official Analytical Chemists (AOAC, 2005), the total soluble solids (ºBrix) using a digital refractometer (PAL-1 ATAGO®, Japan), as well as the content of total soluble sugars by the anthrone method described by WITHAM et al. (1971).

Proximate analysis

The pulp with seeds was dried in an oven at 65 °C and ground in a Thomas-Wiley Mill (Model 4, Thomas Scientific, USA). Percentages of moisture, lipids, crude fiber, ash and carbohydrates were determined using the methods described by the AOAC (2005).

Mineral quantification

The contents of P, K, Ca, Mg, S, Na, Fe, Zn, Mn, Cu, B, Mo and Ni were quantified by an inductively coupled plasma optical emission spectrometry (ICP-OES, model 725-ES, Agilent®), prior to a multielement acid digestion in microwaves. The total nitrogen content was determined by the Dumas combustion method (AOAC, 2005).

Fatty acid analysis

Three batches of about 4 kg (8-9 fruits) of fresh pitahaya per batch were processed in order to obtain 70 g seed/batch. The seeds were dried to constant weight in a circulation stove with forced air at 60 °C. The dried pitahaya seeds of both species were crushed separately in a mortar. The extraction of the oil was carried out using the Soxhlet method with hexane for 3 hours. The fatty acids were converted into their methyl esters using the method proposed by AOAC (2012). The identification and quantification of the fatty acids were performed using a gas chromatograph (HP Hewlett Packard Model 6890 GC System, USA) coupled to a flame ionization detector. The separation was carried out using a capillary column (60 m × 0.25 mm × 0.20 μm), helium as a carrier gas at a constant flow rate of 0.73 mL min^{-1}. The temperature-time conditions of the injector and the detector were adjusted to 250 °C for 19.66 min.

Nutraceutical quantification

Preparation of the extract

For the quantification of total phenolic compounds, flavonoids and antioxidant activity by ABTS and FRAP, an extract of acetone was prepared. The content of the nutraceutical components was determined separately in the skin and in the pulp with seeds according to what is described by WU et al. (2006), with some modifications. For the preparation of the extract, 1 g of the ground vegetable tissue was mixed with 10 mL of 80% (v/v) acetone. The mixture was homogenized by stirring in a vortex, sonicated for 10 min at room temperature and the extraction was carried out twice with the same residue. The extract was kept refrigerated until analysis.

Quantification of total soluble phenolic compounds

The quantification of these metabolites was carried out according to the method described by Singleton and Rossi (1965). It was mixed 0.1 mL of the previously prepared acetone extract, 0.1 mL of the Folin-Ciocalteu reagent (1 N), 4.5 mL of distilled water and 0.3 mL of 2% (w/v) Na_2CO_3. The mixture was incubated at room temperature and in the dark for 2 h. The absorbance of the mixture was read at 760 nm on a spectrophotometer (Genesys 10s, Thermoscientific, USA). The content of total phenolic compounds was determined using a standard gallic acid curve ($y = 0.0011x - 0.0084$; $R^2 = 0.998$). The results were expressed as mg gallic acid equivalent per 100 g of fresh sample (mg GAE 100 g^{-1}fresh weight).

Flavonoid quantification

A mixture was prepared with 0.5 mL of previously prepared acetone extract, 1.5 mL of 95% (v/v) ethanol, 0.1 mL of 10% (w/v) $AlCl_3$ solution, 0.1 mL of CH_3COOK (1 M) solution, and 2.8 mL of distilled water, and then incubated for 30 min. Subsequently, the absorbance was determined at 415 nm in a spectrophotometer. The flavonoid concentration was determined from a standard quercetin curve ($y = 0.006x - 0.0026$; $R^2 = 0.996$). Results were expressed in mg quercetin equivalents per 100 g of fresh weight (mg QE 100 g^{-1} fresh weight).

Betalains quantification

The extraction of betalains from the skin and from the pulp was performed separately with 80% (v/v) methanol. For the preparation of the extract, 1 g of the ground vegetable tissue was mixed with 15 mL of 80% (v/v) methanol. The mixture was homogenized by stirring in a vortex, sonicated for 10 min at room temperature, and the extraction was carried out twice with the same residue. Subsequently, the absorbance of the extracts was read on a spectrophotometer (Genesys 10 s). The content of total betalains, betacyanins and betaxanthines was determined according to the method described by Wu et al. (2006) using the formula: $B\ [mg\ g^{-1}] = A \cdot DF \cdot MW \cdot V / \varepsilon \cdot L \cdot W$; where B = concentration of betacyanins or betaxanthines, A = absorbance at 538 nm (betacyanins) or 483 nm (betaxanthines), DF = dilution factor, MW = molecular weight (550 g mol^{-1} for betanin and 308 g mol^{-1} for indicaxanthin), V = gauging volume (mL), ε = molar extinction coefficient (betanin: 60,000 L mol^{-1} cm^{-1} and indicaxanthin: 48,000 L mol^{-1} cm^{-1}), W = weight of the sample (g) and L = cell length (1 cm). The results were expressed as content of total betalains (betacyanins + betaxanthines) for every 100 g of fresh sample.

Ascorbic acid quantification

The ascorbic acid (vitamin C) content was determined by iodometric titration using the method proposed by Suntornsuk et al. (2002), with modifications. An extract was prepared with 20 g of ground pitahaya pulp and 25 mL of 2N sulfuric acid. The solution was filtered and mixed with 100 mL of distilled water and 3 mL of 1% (w/v) starch as an indicator. The solution was titrated with 0.1N iodine previously standardized with a 0.1N sodium thiosulfate solution. Each mL of iodine (0.1 N) was equivalent to 8.806 mg of ascorbic acid.

Quantification of antioxidant activity

ABTS method. A 7 mM solution of ABTS (2,2'-azino-bis(3-ethylbenzothiazolin-6-sulfonic acid), Sigma-Aldrich) in distilled water and another 2.45 mM potassium persulfate solution were prepared. Both were combined at a 1:1 ratio. The mixture was left to stand for 16 h in the dark, to allow the generation of the free radical, and was diluted with anhydrous ethanol until obtaining an absorbance of 0.7 ± 0.01 at a wavelength of 734 nm (Wu et al., 2006). To determine the antioxidant capacity, 30 µL of the previously prepared acetone extract per species and 3 mL of the $ABTS^{\cdot+}$ radical were placed. The mixture was incubated in the dark for 30 min. Finally, the absorbance reading of the mixture at a wavelength of 734 nm was taken on a spectrophotometer. The antioxidant activity was quantified using a standard trolox curve (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, Sigma-Aldrich) ($y = 29.599x + 9.238$; $R^2 = 0.988$). Results were expressed in µM trolox equivalents per 100 g of fresh weight (mg TE 100 g^{-1}fresh weight).

FRAP method

The FRAP test was carried out according to the procedure described by Benzie and Strain (1996), with some modifications. It was mixed 100 µL of the previously prepared acetone extract, 3 mL of the FRAP reagent (2.5 mL of 300 mM acetate buffer at pH = 3.6, 0.25 mL of 10 mM solution of 2,4,6-Tripyridyl-s-triazine (TPTZ; Sigma-Aldrich) in 40 mM HCl and 0.25 mL of 20 mM $FeCl_3$) and 300 µL of H_2O. The mixture was incubated for 30 min at 37 °C. Subsequently, its absorbance was read from the mixture at a wavelength of 593 nm on a spectrophotometer. The antioxidant activity was calculated using a trolox-based standard curve ($y = 0.7419x + 0.0297$; $R^2 = 0.990$). Results were expressed in µM trolox equivalents per 100 g of fresh weight (mg TE 100 g^{-1} fresh weight).

Statistical analysis

All data was expressed as the mean ± standard error of six repetitions, except for the physical characteristics of the fruit (twenty repetitions). The experimental unit was three pitahaya fruits. A Student's t-test was applied to differentiate the physical, chemical, nutritional characteristics and the fatty acid profile between the two pitahaya species. For the analysis of the data of the nutraceutical components and the antioxidant activity, it was performed an analysis of variance and a Tukey comparison of means ($P \leq 0.05$) using the SAS software version 9.2.

Results and discussion

Physical characteristics of the fruits

The two pitahaya species presented differences in their fruits' morphological characteristics (shape, color of the epicarp or skin, and quantity and shape of their bracts) (Fig. 1). The fruits of *H. ocamponis* (mesocarp or red pulp) were characterized by their elongated shape with an abundant number of thin bracts compared to the fruits of

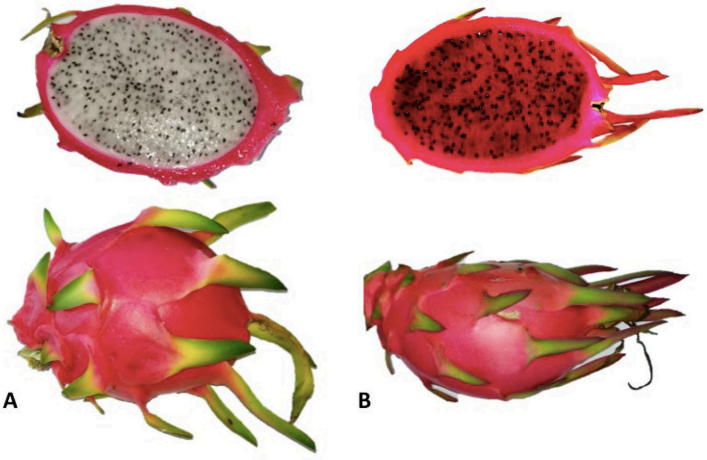

Fig. 1: Pitahaya: A) White pulp fruit (*Hylocereus undatus*); B) Red pulp fruit (*Hylocereus ocamponis*).

H. undatus (mesocarp or white pulp). It is a description similar to that reported by Le Bellec et al. (2006) for *H. ocamponis*, who pointed out that the fruits with red pulp, oblong shape and length between 10 and 15 cm were similar to those of *H. purpusii*. However, in thisresearch, the fruits of *H. ocamponis* presented thin acicular bracts in their skins, which differentiates them from *H. purpusii*. Color was the most distinctive attribute of the mesocarp of the pitahaya fruit, ranging between red shades (*hue*) (lower values) for the red pulp of *H. ocamponis* than in those of *H. undatus* (Tab. 1). However, the pulp of *H. undatus* presented a higher luminosity (*L**) and a low color purity (low *chroma* values), which translates into a light gray pulp that is not very attractive to the consumer when compared to the red tone pulp of *H. ocamponis*. Vaillant et al. (2005) reported a positive correlation between *chroma* and the concentration of betacyanins, which are pigments that provide red colorations. In this research, the pulp of *H. undatus* presented a very low concentration of betalains when compared to the pulp of *H. ocamponis*. The skin of *H. undatus* presented a lower *hue* value when compared to that of *H. ocamponis*, which means that the skin of the first species has a redder coloration. *Hue*, *chroma* and luminosity (*L**) values in the epicarp were close to those reported by Ortiz and Takahashi (2015). The red coloration in the pulp and in the skin of the pitahaya (*Hylocereus* spp.) is the result of the synthesis and accumulation of betalain pigments. Betalains assist in the prevention of cancer and prevent the oxidation of lipid membranes due to their antioxidant properties. They do not show toxic effects in humans when consumed in fruits in comparison with synthetic pigments and are used in the food, pharmaceutical and cosmetic industries (Ibrahim et al., 2018; Quiroz-González et al., 2018).

The fruits of both species presented an average weight of 478.9 g, with the pulp being the most abundant part of the fruit (62.5%), followed by the skin (34.2%). The two species presented high firmness values (55 to 70 N), higher than that reported by other authors on pitahaya fruits (*H. undatus*) cultivated in Mexico (4.2-7.1 N) (Osuna Enciso et al., 2011) as well as in other cacti fruits like the pitaya (*Stenocereus pruinosus* and *S. stellatus*) and the prickly pear (*Opuntia megacantha*) (1.59-2.45 and 14.9 ± 5.2 N, respectively) (García-Cruz et al., 2016; Ríos-Alegría et al., 2018), which is a property that provides a longer shelf life to the fruits of *Hylocereus* spp. compared to those of *Stenocereus* spp. It is important to note that the two species of pitahaya studied were found cultivated in a highly calcareous soil (40.02% $CaCO_3$) which could explain the high firmness values. These results indicated that the pitahaya is a fruit with a hard consistency, making it less susceptible to mechanical damage during its post-harvest handling. Awang et al. (2011) reported that the calcium in the pitahaya fruits (*H. polyrhizus*) treated with $CaCl_2$ increased its firmness from 19.2 to 23.6 N because this element has an important role in the functionality and integrity of the cell membrane when binding to the polar headof phospholipids. Abd El-Rahman et al. (2019) pointed out that the Ca^{+2} maintains the integrity of the middle lamella of the cell wall due to its union with the pectic acid and the formation of calcium pectates which generates a lower weight loss and a higher firmness.

Tab. 1: Physical and chemical characterization of pitahaya fruits with white (*Hylocereus undatus*) and red pulp (*H. ocamponis*).

Variable	*H. undatus*	*H. ocamponis*
Morphological characteristics		
Equatorial diameter (cm)	8.60 ± 0.12 a	8.50 ± 0.15 a
Length (cm)	12.28 ± 0.21 a	13.56 ± 0.21 b
Shape index	1.43 ± 0.02 a	1.60 ± 0.02 b
Fruit weight (g)	466.94 ± 18.81 a	490.82 ± 22.21 a
Mesocarp weight (g fruit $^{-1}$)	278.26 ± 16.65 a	325.51 ± 28.69 a
Epicarp weight (g fruit^{-1})	167.60 ± 7.86 a	153.87 ± 9.53 a
Seed weight (g fruit^{-1})	10.26 ± 0.36 a	7.95 ± 0.41 b
Number of seeds (seeds fruit $^{-1}$)	6571 ± 652 a	5282 ± 232 a
Mesocarp (%)	60.84 ± 2.32 a	64.09 ± 2.79 a
Epicarp (%)	36.86 ± 1.04 a	31.57 ± 0.72 b
Seeds (%)	2.20 ± 0.08 a	1.62 ± 0.08 b
Number of bracts	18.00 ± 0.56 a	31.20 ± 1.02 b
Width of bracts (cm)	4.14 ± 0.15 a	2.94 ± 0.07 b
Apical bracts length (cm)	6.43 ± 0.83 a	6.08 ± 0.84 a
Epicarp physical attributes		
Thickness (mm)	5.45 ± 0.18 a	4.44 ± 0.18 b
Firmness (N)	57.86 ± 2.97 a	65.13 ± 4.63 a
Lightness (L*)	36.08 ± 2.25 a	35.69 ± 1.34 a
Hue angle (*Hue*)	19.08 ± 2.50 a	26.44 ± 1.91 b
Chroma	41.18 ± 2.14 a	42.94 ± 2.45 a
Pulp physical attributes		
Lightness (L*)	55.71 ± 2.83 a	21.66 ± 2.71 b
Hue angle (*Hue*)	48.37 ± 6.56 a	16.73 ± 2.11 b
Chroma	4.09 ± 0.70 a	36.70 ± 2.71 b
Chemical characterization		
pH	4.60 ± 0.11 a	5.00 ± 0.02 b
Titratable acidity (TA, % malic acid)	0.33 ± 0.02 a	0.15 ± 0.01 b
Total soluble solids (TSS, ºBrix)	14.41 ± 0.26 a	15.63 ± 0.40 b
TSS / TA ratio	51.92 ± 3.09 a	106.36 ± 5.05 b
Total soluble sugars (%)	11.06 ± 0.63 a	13.14 ± 0.63 b

Data are expressed as mean ± standard error of six repetitions, except for the physical characteristics of the fruit (twenty repetitions). Different letters in the same row indicate significant statistical differences by T-Student test ($P \leq 0.05$). TSS: total soluble solids, TA: titratable acidity.

Chemical characteristics of the fruits

The white pitahaya presented lower values of pH, soluble solids and total soluble sugars compared to those of the red pitahaya (Tab. 1). The observed differences are possibly due to the variability between species or due to its CAM metabolism, where the CO_2 fixation is carried out by the enzyme phosphoenolpyruvate carboxylase (PEP) and the accumulation in vacuoles of some organic acids (malic acid) in the cacti fruits. These values coincided with those reported by Ortiz and Takahashi (2015) in the fruits of *H. undatus* (pH = 4.6; 12.2 ºBx and 0.27% of titratable acidity). Flavor is a parameter that determines the quality of a fruit, a result of the relationship between organic acids and sugars (TSS/TA). In this research, the TSS/TA value (55.5 TSS/TA) indicated that the fruits of *H. undatus* had a more acidic flavor compared to those of *H. ocamponis* (Tab. 1). Van To et al. (2002) indicated that Vietnamese consumers of white pitahaya (*H. undatus*) preferred less sweet fruits when the TSS/TA ratio was 40. However, it is important to consider that the best evaluation of the taste of a fruit is obtained through a sensory evaluation, which allows to have a knowledge regarding consumer preferences.

Nutritional components of the fruits

The proximate and mineral analysis did not show significant differences in the content of moisture, carbohydrates, crude fiber, Na and S between the fruits of the two species (Tab. 2). Mercado-Silva (2018) reported values of moisture (83-89 %), ash (0.4-0.68%), P (16-19 mg 100 g^{-1}), Fe (0.30-0.65 mg 100 g^{-1}) and Ca^{+2} (6.0-10 mg 100 g^{-1}), in the fruits of the *H. megalanthus* and the *H. undatus* species, which are similar to those found in this research. The fruits of the white pitahaya (*H. undatus*) presented a higher nutritional

Tab. 2: Nutritional components in pitahaya fruits with white (*Hylocereus undatus*) and red pulp (*H. ocamponis*).

Variable	*H. undatus*	*H. ocamponis*
Proximate analysis		
Moisture (%)	86.12 ± 0.59 a	86.67 ± 0.53 a
Carbohydrates (%)	11.05 ± 0.37 a	11.47 ± 0.51 a
Protein (%)	0.93 ± 0.03 a	0.76 ± 0.02 b
Lipids (%)	0.67 ± 0.02 a	0.39 ± 0.01 b
Crude fiber (%)	0.27 ± 0.02 a	0.32 ± 0.01 a
Ash (%)	0.71 ± 0.03 a	0.43 ± 0.01 b
Energetic value (Kcal 100 g^{-1})	53.89 ± 1.60 a	52.38 ± 2.03 a
Mineral content (mg 100 g^{-1} fw)		
N	140.18 ± 7.30 a	110.62 ± 5.43 b
P	19.43 ± 1.01 a	14.66 ± 0.72 b
K	294.23 ± 8.63 a	175.93 ± 8.63 b
Ca	8.33 ± 0.43 a	6.66 ± 0.33 b
Mg	33.31 ± 1.74 a	23.99 ± 1.18 b
S	13.88 ± 0.72 a	14.66 ± 0.72 a
Na	0.00 ± 0.00 a	0.00 ± 0.00 a
Ni	0.00 ± 0.00 a	0.00 ± 0.00 b
Fe	0. 20 ± 0.01 a	0.36 ± 0.02 b
Zn	0.28 ± 0.02 a	0.16 ± 0.01 b
Mn	0.08 ± 0.00 a	0.05 ± 0.00 b
Cu	0.02 ± 0.00 a	0.02 ± 0.00 b
B	0.15 ± 0.01 a	0.13 ± 0.01 b
Mo	0.00 ± 0.00 a	0.00 ± 0.00 b

Data are expressed as mean ± standard error of six repetitions. Values reported in fresh weight (fw). Different letters in the same row indicate significant statistical differences by T-Student test ($P \leq 0.05$).

value compared to the fruits of *H. ocamponis*. An exception was the content of Fe and Cu (Tab. 2). The differences in mineral levels between these species were probably due to the differential expression of the absorption capacity, transport and accumulation of minerals, because both were grown in a produce farm with the same chemical characteristics in the soil (Gupta et al., 2016).

On the other hand, in the fruits of both species the predominant mineral was potassium, which had the highest concentration in the white pitahaya, but no Na was found. The intake of a white pitahaya fruit could contribute with 20% of the potassium daily requirements (4.5-4.7 g day^{-1}) in persons between 9 and 70 years of age (Brown, 2011), contributing to a decrease in blood pressure and in the risk of suffering a cerebrovascular accident by consumers (Soto, 2018).

In general, the fruits of the white and red pitahaya had a higher content of carbohydrates, lipids, P, K, Ca and Mg compared to that reported in other cactifruits such as the pitaya (*S. pruinosus*) (8.5-10.2%, 0.10- 0.12%, 0.61-0.63%, 3.4-3.6 mg kg^{-1}, 1.1-1.2 mg kg^{-1}, 0.90-0.95 mg kg^{-1} and 2.15-2.35 mg kg^{-1}, respectively) (García-Cruz et al., 2013) and with the carbohydrate, protein and lipid content in the xoconostle fruits (*Opuntia* spp.) (4.64-7.25%, 0.14-0.39% and 0.08-0.32%, respectively) (López et al. 2015).

Fatty acid profile of the pitahaya seed

Oil content such as that of polyunsaturated fatty acids in the seeds of *H. undatus* (25.49% dry weight) was higher than that found in *H. ocamponis* (18.11% dry weight), but similar to that reported in *H. undatus* (28.37% dry weight) by Lim et al. (2010). In the seeds of both species, the linoleic acid (Omega-6) was the one with the highest concentration (Tab. 3). Lim et al. (2010) reported higher palmitic, linolenic and linoleic acid values than those found in this

Tab. 3: Fatty acid compositions (%) of pitahaya seed oil white (*Hylocereus undatus*) and red pulp (*H. ocamponis*).

Variable	*H. undatus*	*H. ocamponis*
Saturated fatty acid	18.68 ± 0.22 a	21.37 ± 0.27 b
Monounsaturated fatty acid	28.85 ± 0.35 a	34.07 ± 0.42 b
Polyunsaturated fatty acid	52.50 ± 0.63 a	44.94 ± 0.56 b
Palmitic acid (C16:0)	12.22 ± 0.15 a	13.90 ± 0.17 b
Stearic acid (C18:0)	7.17 ± 0.09 a	8.06 ± 0.10 b
Oleic acid (C18:1)	27.50 ± 0.33 a	32.68 ± 0.41 b
Linoleic acid (C18:2)	50.77 ± 0.65 a	44.88 ± 0.56 b
Linolenic acid (C18:3)	0.36 ± 0.00 a	0.43 ± 0.01 b

Data are expressed as mean ± standard error of three repetitions. Different letters in the same row indicate significant statistical differences by T-Student test ($P \leq 0.05$).

research, possibly due to genetic factors, edaphoclimatic factors, sample storage times and oil extraction techniques (Akram and Mushtaq, 2019). The pitahaya fruit is consumed with seed, which leads to the consumption of fatty acids that are mainly unsaturated and which play an important role in human nutrition and which are associated with a reduced risk of pathologies such as coronary heart and cardiovascular disease (Mensink and Katan, 1992).

Nutraceutical content

The pulp of the red pitahaya (*H. ocamponis*) presented the highest levels of betalains and ascorbic acid, as well as the highest antioxidant activity (Tab. 4). However, the skin of the white pitahaya had a higher content of betalains than that of the red pitahaya. Furthermore, there were no differences in the antioxidant activity in this tissue between both species. The differences in the concentration between species and tissues are possibly due to genetic variability. When Felker et al. (2008) were carrying out research on prickly pear fruits (*Opuntia ficus-indica*) of different pigmentation, they did not find differences in the genomic DNA, which is why they pointed out that the absence or presence of pigmentation in this cactus could be due to a defect in the transcription factor associated with the main enzymes involved in the biosynthesis of betalains.

The concentrations of betacyanins found in this study were similar to those reported by WU et al. (2006) in the pulp of *H. polyrhizus* (10.3 ± 0.22 mg 100 g^{-1} fresh weight). Wybraniec and Mizrahi (2002) reported higher concentrations in eight species and hybrids of *H. polyrhizus*, *H. purpusii*, *H. costaricensis* and *H. undatus* cultivated in Israel (23 to 39 mg betanin equivalent 100 g^{-1} of fresh pulp) perhaps due to either analysis methods or differences between species or edaphoclimatic conditions. It is important to note that there are no reports of the levels of betaxanthines (yellow color pigments) in the skin of the pitahaya. The consumption of fruits with these pigments could assist in the prevention of cancer. These pigments also prevent the oxidation of membrane lipids due to their antioxidant properties (Livrea and Tesoriere, 2006) and do not present toxic effects in humans as some synthetic pigments. These underused resources could be a source of dyes for use in the food and pharmaceutical industries, since these pigments are more stable to changes in pH than the anthocyanins found mainly in strawberries (Tanaka et al., 2008).

In the present study, the content of phenolic compounds in the tissues of the two species (Tab. 4) was similar and higher than that reported by WU et al. (2006) in the pulp and skin of the pitahaya *H. polyrhizus* (42.4 ± 0.04 and 39.7 ± 5.39 mg GAE 100 g^{-1}). In contrast, the highest flavonoid content was detected in the skin of both species when compared to the pulp. These metabolites have

Tab. 4: Nutraceutical components and antioxidant activity (AA) in pulp and epicarp of pitahaya fruits with white (*Hylocereus undatus*) and red (*H. ocamponis*).

Variable	*Hylocereus undatus*		*Hylocereus ocamponis*	
	Pulp	Epicarp	Pulp	Epicarp
Total betalains (mg 100 g^{-1})	0.02 ± 0.00 c	19.83 ± 5.06 a	15.94 ± 2.89 ab	13.21 ± 2.19 b
Betacyanins (mg 100 g^{-1})	0.01 ± 0.00 c	14.66 ± 3.76 a	11.98 ± 2.03 ab	9.65 ± 1.67 b
Betaxanthins (mg 100 g^{-1})	0.01 ± 0.00 c	5.17 ± 1.40 a	3.97 ± 0.88 ab	3.55 ± 0.53 b
Total soluble phenolic (mg GAE 100 g^{-1})	126.03 ± 29.71 a	139.39 ± 36.47 a	132.47 ± 21.58 a	127.88 ± 12.88 a
Flavonoids (mg QE 100 g^{-1})	4.82 ± 0.52 b	22.57 ± 2.91 a	5.32 ± 0.29 b	25.68 ± 2.08 a
Ascorbic acid (mg AAE 100 g^{-1})	8.50 ± 0.23 b	ND	10.13 ± 1.18 a	ND
AA by ABTS (mM TE 100 g^{-1})	1118.20 ± 102.71 b	812.60 ± 80.32 b	2009.58 ± 159.66 a	817.35 ± 27.28 b
AA by FRAP (mM TE 100 g^{-1})	506.55 ± 38.48 b	500.24 ± 47.41 b	1164.47 ± 111.91 a	365.69 ± 41.48 b

Data are expressed as mean ± standard error of six repetitions. Values reported in fresh weight. Different letters in the same row indicate significant statistical differences by Tukey's test ($P \leq 0.05$). GAE: gallic acid equivalents, QE: quercetin equivalents, AAE: ascorbic acid equivalents, TE: trolox equivalents, ND: variable not detected

been reported mainly in higher concentrations in the flowers of the family Cactaceae (Iwashina, 2015). These are particular synthesis sites, as protective metabolites against biotic and abiotic stress and as part of the plant resistance mechanism against diseases (Panche et al., 2016). Phenolic compounds, due to their diversity and wide distribution, are the most important group of natural antioxidant metabolites. There are epidemiological evidences that show the health benefits and the contribution of these compounds in the prevention of some degenerative diseases (Soto-Hernández et al., 2017). These metabolites are compounds with the ability to chelate heavy metals, modulate some enzymes and neutralize free radicals (reactive oxygen species produced by oxidative stress in the organism, affecting lipoproteins, lipids of blood plasma and other biomolecules) (Soto-Hernández et al., 2017).

On the other hand, the ascorbic acid is another important constituent of food, which possesses a high antioxidant activity (Naidu, 2003). In the present study, the content of ascorbic acid found in both species was lower than the concentration reported by Vaillant et al. (2005) in three varieties of *Hylocereus* sp. cultivated in Nicaragua (12.3 to 17.1 mg AAE 100 g^{-1} fresh weight), probably because the CAM metabolism in the fruits of *Hylocereus* favors the formation of malic acid compared to that of other organic acids.

The pulp of both species showed a higher antioxidant activity than in the skin, but in the pulp of *H. undatus,* it could be associated with a synergistic effect of different metabolites. These results indicated that the pitahaya fruits had a higher antioxidant potential than the fruits of some cacti such as the prickly pear (*Opuntia ficus-indica*) from yellow, red and white cultivars (531, 420 and 430 µM TE 100 g^{-1} fresh weight, respectively) (Butera et al., 2002) and that of the red pulp pitaya (*Stenocereus stellatus*) (921 µM TE 100 g^{-1} of pulp fresh weight) (García-Cruz et al., 2016). Pearson's correlation coefficient showed a positive correlation between betalains (0.49) and the antioxidant activity in the pulp of the red pitahaya (*H. ocamponis*). In contrast, the correlation was positive between flavonoids (0.87) and phenolic compounds (0.45) with the antioxidant activity in the pulp of the white pitahaya (*H. undatus*).

Conclusions

The white pulp pitahaya fruit of *H. undatus* presented a higher nutritional value than the red pulp fruit of *H. ocamponis* due to a higher content of protein, lipids, N, P, K, Ca, Mg, B in the mesocarp, and oleic acid along with linoleic acid in the seeds. In contrast, the red pulp of *H. ocamponis* presented the highest nutraceutical potential given the higher betalain content and antioxidant activity, despite being a fruit of lower commercial demand and consumption. On the other hand, the skin of *H. undatus* is an underused resource, which could be a source of antioxidant components associated to the presence of betalains, to be used agroindustrially to obtain natural pigments in the food industry.

Conflict of interest

No potential conflict of interest was reported by the authors.

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