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Physicochemical characterization of four varieties of prickly pear (*Opuntia* spp.)

Alemán-Villa, Diana M.[1]; Torres-Aquino, Margarita[1]; Peredo-Rivera, Ernesto[1]; Tovar-Robles, Clara L.[2*]; Delgado-Alvarado, Adriana[3*]

[1] Colegio de Postgraduados, Campus San Luis Potosí, Salinas de Hidalgo, San Luis Potosí, México, C. P. 78622.
[2] Universidad Autónoma de Aguascalientes, Aguascalientes, Aguascalientes, México, C. P. 20131.
[3] Colegio de Postgraduados, Campus Puebla, Puebla, Puebla, México, C. P. 72760.
* Correspondence: adah@colpos.mx

ABSTRACT

Objective: To characterize the physicochemical properties of the pulp from four varieties of prickly pear collected in three localities from the municipality of Salinas, San Luis Potosí.

Design/Methodology/Approach: The following characteristics were recorded in 15 fruits of each variety: fruit size (equatorial and polar diameter), fresh biomass of total fruit, peel, and locule. Nine fruits per replicate were used (one fruit equals one replicate) to analyze moisture, ash content, total soluble solids, pH, titratable acidity, and total soluble sugars.

Results: The physical differences of the fruits, total fresh weight, and equatorial and polar diameter match the typical characteristics of each variety. The largest fruits were (in descending order): Cristalina, Fafayuca, Naranjona, and Cardona. The highest moisture percentage (87.34%) was reported in Cristalina. Varieties such as Fafayuca from La Reforma and Naranjona from Salinas de Hidalgo had the highest and lowest concentration of total soluble sugars (25.84 and 11.46 g 100 g^{-1} FW, respectively). The fruits had a titratable acidity from 0.01 to 0.03% citric acid, while total soluble solids ranged from 11.60 to 15.84 °Brix.

Study Limitations/Implications: Harvesting was based on the visual parameters established by the farmers.

Findings/Conclusions: Fruits harvested from backyard orchards (<500 m^2) had fruits of greater weight, which are used for self-consumption. The amount of total soluble solids and total soluble sugars per variety was different between localities, indicating that farmers from different localities have different harvesting criteria.

Key words: sugars, chemical characteristics, backyard orchards, fruit morphology, prickly pear.

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INTRODUCTION

The Altiplano Potosino is characterized by a great diversity of prickly pear cactus species, which can be found both in wild populations and in backyard orchards. In recent decades, a great deal of attention has been paid to the benefits of the *Opuntia* genus, because all of its parts (including cladode, pulp and peel of the fruits, and seeds) have shown potential to treat several diseases (Abbas *et al.*, 2022). As a fresh product and living tissue, pricky pears are susceptible to physical, chemical, and biological modifications between harvest and consumption, affecting its quality and reducing its postharvest life, which is approximately

10-15 days (Sandoval-Trujillo *et al.*, 2019). These issues limit their long-term storage and worldwide distribution (Feugang *et al.*, 2006). Prickly pear is an oval or cylindrical fleshy berry, 5 cm to 10 cm long and 4 cm to 8 cm wide. Its total weight generally ranges from 80 to 200 g (Martins *et al.*, 2023a), which are divided into three components: peel (30-40%), pulp (60-70%), and seeds (2-10%). Fruit weight can vary greatly depending on cultivar, cladode load, and environmental conditions. They can sometimes reach a weight of up to 250 g. However, a commercial fruit should not weigh less than 120 g (Cabrera, 2021), although wild fruits have recorded less than 60 g (Reyes-Agüero *et al.*, 2009). Prickly pear consumption in the agri-food sector has increased due to its organoleptic properties, nutritional value, and health benefits (Silva *et al.*, 2021). The objective of the study was to assess the physicochemical properties of pulp in four varieties of prickly pear from three localities in the municipality of Salinas, San Luis Potosí, Mexico.

MATERIALS AND METHODS

Collection of plant material

Opuntia fruit (prickly pear) varieties such as Cardona (*Opuntia streptacantha*), Naranjona (*O. megacantha*), Cristalina, and Fafayuca (*O. albicarpa*) were harvested at consumption maturity from June to August 2022, according to the visual parameters (size and fullness of fruits) established by the producers.

The four prickly pear varieties were harvested in La Reforma, Diego Martin and Salinas de Hidalgo in the municipality of Salinas, San Luis Potosi, in self-consumption backyard orchards (<500 m^2), as well as in commercial backyard orchards (>1 ha) (Figure 1, Table 1).

Fruit size (polar and equatorial diameter): The polar diameter of the fruit (base to apex) and the equatorial diameter (middle zone) of 15 fruits of each variety were measured using a digital vernier caliper (Karlen®, Mexico) with 0.01 mm accuracy.

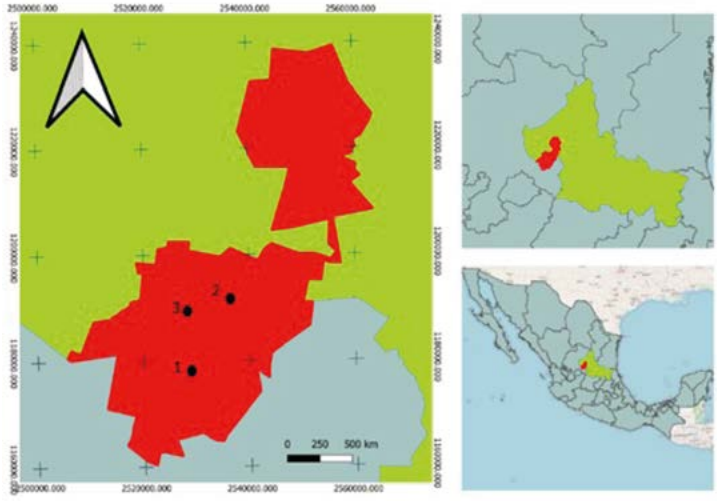

Figure 1. Geographical location of the three localities of the Altiplano Potosino, Mexico where prickly pear varieties were harvested: 1) Salinas de Hidalgo, 2) La Reforma, 3) Diego Martín. Figure developed by the authors.

Table 1. Prickly pear varieties harvested in three localities of the municipality of Salinas, San Luis Potosí, backyard area, and geographical location of harvesting sites.

Variety	Locality	Area	Longitude	Latitude	Altitude (masl)
Cardona Naranjona Cristalina Fafayuca	Salinas de Hidalgo	>1 ha	22.63078° N	101.73632° W	2082
	La Reforma	<500 m^2	22.75623° N	101.64686° W	2080
	Diego Martín	<500 m^2	22.73049° N	101.71960° W	2040

Total fresh weight: A Velab™ VE-1000 analytical electronic balance was used to determine the individual weight of the fruit, peel, and locule (pulp and seeds).

Chemical characteristics of four varieties of prickly pear

Nine fruits per variety were used to determine moisture, ash content, total soluble solids, pH, titratable acidity, and total soluble sugars.

Moisture. A 0.5 g sample of prickly pear fruit pulp was weighed with an OHAUS™ MB45 moisture analyzer to determine the moisture percentage, expressing the results as a percentage.

Ash content. The ash content was determined according to the NMX-F-066-S-1978 standard. Five g of the sample were weighted in a porcelain crucible, previously brought to constant weight for 12 h at 75 °C and slowly pre-incinerated until it stopped smoking. Subsequently, the crucible was placed in a muffle at 550 °C for 5 h to be fully burned and then allowed to cool in a desiccator to record the weight of the crucible with the ashes.

Total Soluble Solids. An Atago 2311 digital refractometer (Master Professional) was used to determine the total soluble solids of the pulp, expressed in °Brix at 20 °C.

pH. pH was determined with a PH 700 pH Meter Kit (Apera Instruments). Two grams of pulp were mixed in 20 mL of distilled water; this mixture was filtered before determining the pH.

Titratable acidity. The pH was measured to analyze the titratable acidity. Three grams of pulp were homogenized in 30 mL of distilled water. The mixture was titrated with NaOH (Macron Fine Chemicals) 0.01 N, until a pH of 8 was reached, with the help of an Orion Star™ A25 potentiometer (Thermo Scientific).

Total soluble sugars. Total soluble sugars were quantified according to the Anthrone method (Montreuil *et al.*, 1997).

Statistical Analysis

The morphological and physicochemical characteristics were subjected to an analysis of variance (ANOVA) by variety between collection sites. The difference between means per sample was assessed with Tukey's test (α=0.05) using STATISTICA version 7.0 and Minitab version 18.0.

RESULTS

Total fresh weight of the fruit (TFWF). The results showed that the TFWF and polar fruit diameter (PFD) of Cardona (*O. streptacantha*) were significantly higher in La

Reforma than in Salinas de Hidalgo and Diego Martin (Table 2), indicating that fruit from orchards with an area of less than 500 m^2 in La Reforma may be more suitable for the production of Cardona fruit. Meanwhile, the TFWF of the Naranjona variety was significantly higher in La Reforma than in the other two locations assessed; however, its equatorial (EFD) and polar (PFD) diameters were the same in La Reforma and Diego Martín. For the Cristalina variety, the heaviest fruits with the highest EFD and PFD were located at Diego Martín. Finally, for the Fafayuca variety, the heaviest and biggest fruits were recorded in La Reforma. According to Patil and Dagadkhair (2019), a TFWF between 67 and 216 g per fruit (depending on the species) has been reported in the genus *Opuntia*. Meanwhile, a TFWF from 23.5 to 116.4 and 29.8 to 256.4 g has been reported in *O. streptacantha* and *O. megacantha*, respectively (Reyes-Agüero *et al.*, 2009). These values are similar to those found in this work for the same species.

Moisture content. While the Cardona variety harvested in La Reforma had a higher moisture content than the fruit from Diego Martín and a similar percentage than commercial use fruit (Salinas de Hidalgo), the moisture content of the Naranjona, Cristalina, and Fafayuca varieties did not show significant differences (Table 3) in the three studied localities. Among the species analyzed and those reported in other research works (Zenteno-Ramírez, 2016; Cabrera, 2021), the moisture percentage ranges from 80 to 90% in cultivated and wild varieties.

Ash content. The ash percentage of the Cardona variety was statistically equal in the three locations, with 0.29 to 0.33% less ash content than those recorded by Martins *et al.* (2023b). Orange varieties reported 0.35% (Paucara and Del Castillo, 2021) and 0.37% (Díaz *et al.*, 2007). These values were similar to those determined for the Naranjona variety (0.35 to 0.40%) and no significant difference was detected between locations (Table 3). Regarding

Table 2. Analysis of physical characteristics of four prickly pear varieties in three localities of the municipality of Salinas, San Luis Potosí.

Variety	Locality	TFWF (g)	PFD (cm)	EFD (cm)
Cardona	Salinas de Hidalgo	$51.94^{b}\pm1.69$	$4.71^{b}\pm0.04$	$4.23^{b}\pm0.07$
	La Reforma	$73.22^{a}\pm3.95$	$5.59^{a}\pm0.14$	$4.80^{a}\pm0.14$
	Diego Martín	$56.44^{b}\pm3.86$	$4.88^{b}\pm0.22$	$4.48^{ab}\pm0.13$
Naranjona	Salinas de Hidalgo	$70.06^{c}\pm6.14$	$6.91^{b}\pm0.17$	$4.57^{b}\pm0.16$
	La Reforma	$126.57^{b}\pm6.74$	$7.75^{a}\pm0.27$	$5.73^{a}\pm0.16$
	Diego Martín	$160.55^{a}\pm8.18$	$7.56^{ab}\pm0.25$	$6.09^{a}\pm0.12$
Cristalina	Salinas de Hidalgo	$120.59^{c}\pm7.03$	$7.29^{c}\pm0.16$	$5.41^{b}\pm0.14$
	La Reforma	$142.30^{b}\pm6.03$	$8.06^{b}\pm0.48$	$5.80^{b}\pm0.23$
	Diego Martín	$185.46^{a}\pm7.75$	$9.56^{a}\pm0.30$	$6.14^{a}\pm0.12$
Fayayuca	Salinas de Hidalgo	$124.72^{b}\pm4.53$	$7.72^{a}\pm0.22$	$5.44^{ab}\pm0.11$
	La Reforma	$148.41^{a}\pm7.38$	$7.90^{a}\pm0.26$	$5.78^{a}\pm0.12$
	Diego Martín	$86.72^{c}\pm3.01$	$7.61^{a}\pm0.14$	$4.69^{b}\pm0.05$

TFWF=total fresh weight of fruit; PFD=polar fruit diameter; EFD=equatorial fruit diameter; ±=accuracy of an approximation; S.E.=standard error. For each variable, means per variety between locations that do not share a letter are significantly different according to Tukey (α=0.05).

the varieties with green pulp (Cristalina and Fafayuca), the percentages ranged from 0.18 to 0.26%; these figures are lower than the 0.40% value reported by Díaz *et al.* (2007).

Total Soluble Solids (TSS). The results showed that the TSS of the Cardona prickly pear was similar in the three locations, with an average of 14.27 °Brix. In Salinas de Hidalgo, Naranjona prickly pear had the highest TSS content, while lower TSS contents were recorded in La Reforma and Diego Martin, with no significant differences between locations (Table 3). The Cristalina prickly pear had a significantly higher TSS content in Salinas de Hidalgo and Diego Martín than in La Reforma. Fafayuca prickly pear did not show significant differences between locations (Table 3).

Overall, the results of this study suggest that the TSS content of the prickly pear varieties assessed is adequate for fresh consumption. However, the Naranjona prickly pear from La Reforma could be a more attractive option for the market, as it statistically showed the highest TSS of the three locations. Prickly pear has a higher TSS content than other widely consumed fruits, such as peaches, apples, plums, apricots, cherries, and melons, which have values of 7.5 to 11.0 °Brix (Corrales-García, 2011).

Potential Hydrogen (pH). Table 3 shows that the pH of pulp from the prickly pear varieties assessed had a very narrow range (6.11-6.88) (Table 3), which falls within the range (5.3-6.6) reported for prickly pears by other researchers (Feugang *et al.*, 2006). This result confirms that prickly pear has lower acid level (pH>4.5) than citrus fruits (orange, lemon, etc.); however, it is more vulnerable to microbiological deterioration (Lamia *et al.*, 2018).

Titratable acidity (TA). The titratable acidity of the assessed varieties is lower than the acidity of raspberry (1.05%), strawberry (3.63%), grapefruit (1.41%), Mexican plum

Table 3. Analysis of the chemical characteristics of the pulp of four varieties of prickly pear from three localities in the municipality of Salinas, San Luis Potosí.

Variety	Locality	Moisture (%)	Ashes (%)	TSS (°Brix)	pH	TA (% citric acid)	TSS (g 100 g^{-1} FW)
Cardona	Salinas de Hidalgo	85.48^{ab}±0.28	0.28^{a}±0.01	14.34^{a}±0.19	6.15^{a}±0.06	0.02^{b}±0.01	17.13^{b}±0.63
	La Reforma	86.50^{a}±1.03	0.34^{a}±0.02	14.00^{a}±0.29	6.11^{a}±0.05	0.03^{a}±0.01	16.68^{b}±0.65
	Diego Martín	84.58^{b}±0.29	0.32^{a}±0.02	14.36^{a}±0.28	6.16^{a}±0.09	0.03^{a}±0.01	19.47^{a}±0.58
Naranjona	Salinas de Hidalgo	85.73^{a}±0.36	0.40^{a}±0.03	14.04^{b}±0.19	6.59^{b}±0.02	0.02^{a}±0.01	11.46^{c}±0.47
	La Reforma	83.50^{a}±0.75	0.39^{a}±0.02	15.84^{a}±0.34	6.87^{a}±0.03	0.03^{a}±0.01	18.51^{a}±0.75
	Diego Martín	85.26^{a}±0.56	0.35^{a}±0.02	12.73^{b}±0.74	6.88^{a}±0.05	0.01^{b}±0.01	14.65^{b}±0.40
Cristalina	Salinas de Hidalgo	87.34^{a}±1.09	0.18^{b}±0.01	12.76^{a}±0.23	6.43^{a}±0.03	0.02^{a}±0.01	19.57^{ab}±0.89
	La Reforma	85.18^{a}±0.53	0.22^{a}±0.01	11.60^{b}±0.53	6.27^{b}±0.01	0.02^{a}±0.01	16.52^{b}±0.83
	Diego Martín	87.08^{a}±1.06	0.26^{a}±0.02	12.60^{a}±0.37	6.16^{b}±0.02	0.01^{b}±0.01	22.99^{a}±1.70
Fayayuca	Salinas de Hidalgo	85.51^{a}±0.37	0.01^{a}±0.24	14.87^{a}±0.31	6.42^{b}±0.02	0.03^{a}±0.01	17.19^{c}±0.50
	La Reforma	85.07^{a}±0.38	0.02^{a}±0.23	14.33^{a}±0.21	6.54^{b}±0.05	0.02^{b}±0.01	25.84^{a}±0.93
	Diego Martín	84.97^{a}±1.44	0.02^{a}±0.23	14.09^{a}±0.38	6.86^{a}±0.03	0.02^{b}±0.01	20.06^{b}±0.47

TSS=total soluble solids; pH=potential hydrogen; TA=titratable acidity; TSS=total soluble sugars; ±=accuracy of an approximation; S.E.=standard error. Means that do not share a letter are significantly different according to Tukey (α=0.05). The variety between locations was the point of comparison.

(4.05%), and other fruits (Rubio-Ochoa *et al*., 2019; Villarreal-Fuentes *et al*., 2019). The low percentage of acidity in Naranjona and Cristalina varieties (0.01% to 0.03% citric acid) influences consumer preference; therefore, acidity is an important factor to determine the most suitable processing conditions for any fruit (Sáenz, 2000).

Total soluble sugars (TSS). The green to white crystalline fruits showed a high TSS concentration, particularly the Cristalina variety (22.99 g 100 g^{-1} FW) of Diego Martín and the Fafayuca variety (25.84 g 100 g^{-1} FW) of La Reforma. The TSS concentration in the four varieties varied significantly between locations, showing remarkably higher contents in La Reforma and Diego Martin. The difference in sugar concentration may be caused by the level of fruit ripening (Zenteno-Ramírez *et al*., 2015). The low amount of total soluble sugars in the pulp of *Opuntia* fruits is due to the high temperatures (>30 °C) to which they are exposed, resulting in the reduction of their third phenological stage, corresponding to the development of the fruit (Inglese *et al*., 2017; Nassrallah *et al*., 2021).

These results are possibly the consequence of less competition for water, soil, and light resources in the backyard orchards than in commercial orchards, which have a higher density of plants per unit area. Climatic factors (temperature and precipitation) possibly had a lesser influence on these characteristics, given the closeness between locations.

CONCLUSIONS

The fruits of four varieties destined for commercialization (Salinas de Hidalgo) had the following physical characteristics: lower total fresh weight and smaller size.

The results of the four varieties of *Opuntia* fruits grown in the municipality of Salinas, San Luis Potosí, have variable physicochemical characteristics. Therefore, the harvesting practices adopted by farmers do not seem to be uniform, since the location of the fruit in the cladode of the prickly pear cactus is important for its harvesting.

Overall, the Cristalina and Fafayuca varieties of the *Opuntia albicarpa* species had larger fruits (length, diameter, and weight), as well as a high content of total soluble solids and total soluble sugars. These characteristics could contribute to consumer preference.

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