



Nutritional components and anti-oxidant capacity of ten cultivars and lines of cactus pear fruit (*Opuntia* spp.)

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ABSTRACT

Cactus pear fruit (*Opuntia*) are harvested from various species of the genus *Opuntia* of the cactus family (Cactaceae), and are produced and consumed in several countries. We have characterized the nutritional content and antioxidant capacity (AC) of the fruit of ten cultivars/lines of distinct pulp colors. 'Camuesa' had the highest betalains, total carotenoids, β -carotene, ascorbic acid, and was one of the highest in total phenolic compounds, but its AC did not demonstrate outstanding differences with some other cultivars/lines that were not as rich in these compounds. 'Roja Pelota' had high AC when measured with the DPPH assay, but had low total carotenoids, β -carotene and total phenolic content. 'Reyna' had slightly low AC as measured by the FRAP assay, practically no betalains, and low vitamin C, tocopherols, β -carotene, and total phenolic content.

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1. Introduction

Cactus pear or prickly pear, a member of the *Cactaceae* family, which is widely distributed in Mexico, has the widest germplasm variability as well as the highest number of uses, and also grows in several other parts of the world such as Africa, Australia, the Mediterranean basin, and some parts of Asia. Cactus pear (*Opuntia ficus-indica*) is an emergent fruit crop, which evolved commercially during the second half of the 20th century. It was dispersed around the globe during the two centuries after the arrival of Christopher Colon to the Americas in the late 15th century. Nowadays it can be found in North and South Africa, the Near East and as far as inland China. There are close to 50,000 ha associated to a gross production of about 300,000 MT a year of cultivated cactus pear for fresh consumption in Mexico alone (ASERCA, 1999). In Europe for example, it is firmly established as a regular fruit crop in Sicily, from where it is exported to the rest of Europe. In some countries such as Morocco, Tunisia, Ethiopia, Eritrea, Yemen, and Turkey, the fruit in summer is more important in volume than some common fruits such as oranges or bananas (Arba, 2006; Bekir, 2006; Mondragon & Tegegne, 2006).

There have been a number of studies on the chemical and nutritional composition of cactus pears (Butera et al., 2002; Saenz, 2006; Stintzing, Schieber, & Carle, 2001) commonly done on varieties readily available, some of them unidentified. The fruit is generally characterized by high sugar content and low acidity (Joubert, 1993; Muñoz de Chavez, Chavez,

Valles, & Roldan, 1995; Sepúlveda & Sáenz, 1990). However, cactus pear diversity and variability in different parts of the world, especially in Mexico, is very big, and so is the diversity in fruit contents. Variability is expressed in all parts of the plant, fruits included. Features like skin and pulp color, pulp texture, sugar content, and juice acidity are directly related to the presence, intensity and activity of nutritional and functional compounds.

Fruits and vegetables contain a wide range of substances that are suggested to be important for health (Yahia, 2010). In addition to the major food constituents such as proteins, fats, carbohydrates and micronutrients such as vitamins, minerals and trace elements, fruits and vegetables contain other components that may have a positive effect on human health. These phytochemicals include carotenoids, flavonoids and other phenolic compounds, glucosinolates, allylic sulfides, isothiocyanates, dietary fibers, phytosterols and monoterpenes, among others (Yahia, 2010). Cactus pear fruit is a fleshy berry, varying in shape, size, and color and has a consistent number of hard seeds. It is characterized by a high sugar content (12 to 17%) and low acidity (0.03 to 0.12%). It has higher vitamin C content than apple, pear, grape and banana, and is rich in potassium, calcium and phosphorous and low in sodium (Sáenz-Hernández, 1995). The fruit of some types of cactus pear contain 2 betalain pigments, the purple-red betanin and the yellow indicaxanthin, both with radical-scavenging and reducing properties (Castellanos-Santiago & Yahia, 2008; Gandía-Herrero, Jiménez-Atiñzar, Cabanes, García-Carmona, & Escribano, 2010; Stintzing et al., 2005). Morales, Sáenz, and Robert (2008) reported lower amounts of carotenoids in purple and orange cactus pear pulp. The nutritional and health benefits of cactus fruit are associated with their antioxidant properties related to

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Table 1
Main traits of the genotypes included in this study.

Entry	Taxonomical classification	Actual status	Destination	Pulp texture
Naranjona	<i>O. megacantha</i>	Commercial variety	NM	Juicy
Reyna	<i>O. albi-carpa</i>	Commercial variety	NM	Juicy
Roja Lisa	<i>O. ficus-indica</i>	Commercial variety	NM, E	Intermediate
Liria	<i>O. ficus-indica</i>	Emergent variety	WRM	Intermediate
Roja Pelota	<i>O. robusta</i>	Emergent variety	WRM	Juicy
Cardona	<i>O. streptacantha</i>	Wild species	WRM	Intermediate
Camuesa	<i>O. robusta</i>	Semi-domesticated backyard orchard	WRM	Juicy
2-6-51	<i>O. ficus-indica</i>	Experimental selection	NC	Juicy
2-14-2	<i>O. ficus-indica</i>	Experimental selection	NC	Juicy
2-14-41	<i>O. ficus-indica</i>	Experimental selection	NC	Juicy

WRM: wild fruit for regional market NM: national market, E: export market; NC: not commercial yet.

ascorbic acid, phenolic compounds, and a mixture of yellow betaxanthin and red betacyanin pigments (Magloire, Konarski, Zou, Stintzing, & Zou, 2006). The cactus pear's total antioxidant activity was found to be 2-fold higher compared with that of pear, apple, tomato and grape and similar to that of red grape raisin, orange and grapefruit (Livrea & Tesoriere, 2006). Total antioxidant activities of differently colored cactus fruit measured by different assays were highly correlated among each other and also with total phenolics, betalains and ascorbic acid concentrations (Corral-Aguayo, Yahia, Carrillo-Lopez, & Gonzalez-Aguilar, 2008; Stintzing et al., 2005).

This study presents the analysis of the fruits of a cactus pear collection, which includes three species; five commercial varieties, three selections, one semi-domesticated entry as well as one subjected to recollection from wild plants (Table 1 and Fig. 1). They cover an array of effect of domestication, fruit colors, pulp texture, sugar content and juice acidity, traits that are associated with consumer preferences, and with the availability and activity of functional compounds, and therefore with potential positive effects on human nutrition and health.

2. Materials and methods

2.1. Reagents

HPLC-grade methanol, acetone, *n*-hexane, toluene, methyl tert-butyl ether (MTBE), methylene chloride, acetonitrile, and ethanol

were purchased from J.T. Baker (Baker Mallinckrodt, Mexico). All other solvents were ACS grade. Standard purity was $\geq 97\%$ for β -carotene, and ≥ 95 for α -, β -, γ - and δ -tocopherol. HPLC-grade water was prepared by a Milli-Qplus purification system (Millipore Corp., Bedford, MA).

2.2. Samples

Fully ripe cactus pear fruits were collected from the experimental fields and the germplasm bank of the National Institute for Agricultural, Forestry and Livestock Research (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, INIFAP) in San Luis de la Paz, Guanajuato, Mexico, grown under rain-fed conditions. The genotypes included in the study (Table 1 and Fig. 1) represent an array of fruits that cover a range of domestication status, fruit colors, and market preferences, representative of the Mexican cactus pear germplasm. Mexico is recognized as the center of domestication of cactus pear and has the largest diversity. 'Reyna' (*O. albi-carpa*), 'Naranjona' (*O. megacantha*), and 'Roja Lisa' (*O. ficus-indica* L.) are the most important Mexican cactus pear cultivars for the local and export markets, while 'Liria' (*Opuntia* sp.) and 'Roja Pelota' (*O. ficus-indica* L., Mill.) are slowly increasing in the national market due to their attractive color. 'Cardona' (*Opuntia streptacantha*) and 'Camuesa' (*Opuntia robusta* Wendl.) are two well accepted genotypes subjected to recollection from wild stocks. The experimental selections '2-6-51', '2-14-2' and '2-14-41' were obtained by the breeding program of INIFAP according to features favored by the export market; with colorful, large and juicy fruits (Table 1 and Fig. 1). The ten cultivars and lines used in this study are characterized with fruits of purple, red, orange, yellow, and white pulp colors.

2.3. Initial quality evaluation

Initial quality of fruits was assessed by measuring total soluble solids (TSS) and color. TSS ($^{\circ}$ Brix) was measured in the juice obtained from a representative portion of each fruit, using a temperature adjusted hand refractometer (ATAGO, Co. Ltd., Osaka, Japan). Flesh (internal) color (L° , a° and b°) was measured with a CM-2002 Minolta spectrophotometer operating with the spectraQC 7.2 software (Minolta, Co. Ltd., Osaka, Japan), which was calibrated with the white pattern during each sampling time, and hue (h°) and chroma (C°) were calculated.

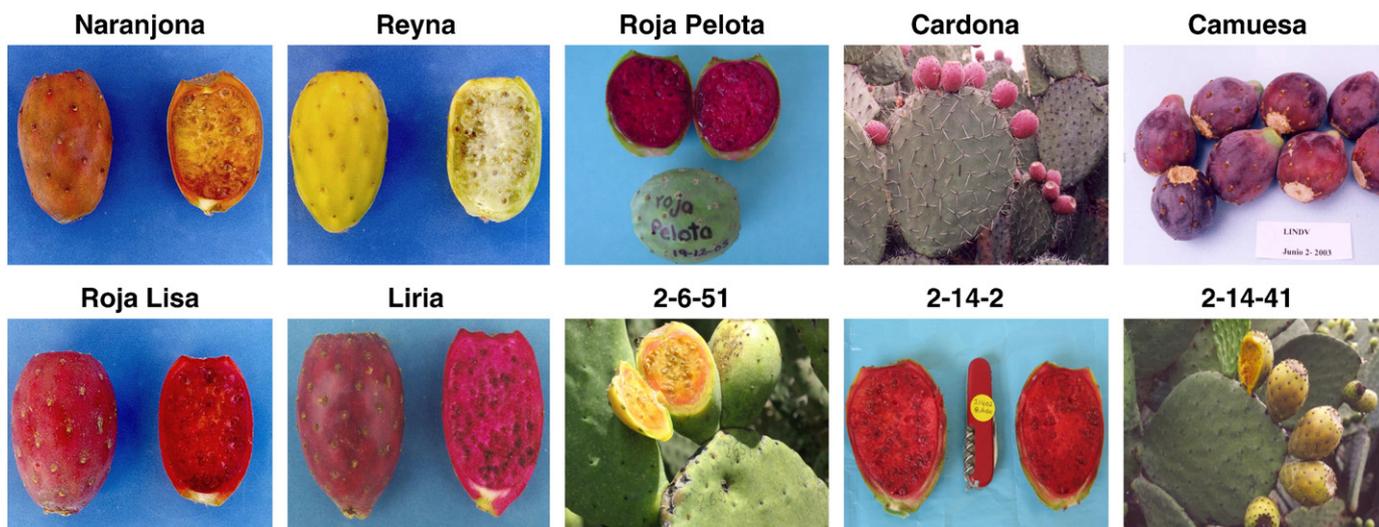


Fig. 1. Cactus pear fruit from the selected genotypes used in the study.

2.4. Extract preparation and analysis

For analysis of bioactive compounds and antioxidant capacity (AC), fruits were peeled and seeds were removed, fruit pulp was freeze-dried, and the resulting dried powder was stored in the dark at -20°C until analysis.

2.4.1. Pigments

For chlorophyll extraction, freeze-dried fruit tissue was stirred for 10 min in darkness in 10 mL of MTBE and 1% BTH, MeOH (9:1) or hexane-acetone-EtOH (2:1:1) as solvents. After they were stirred, the samples were centrifuged at 12000 g for 15 min. Supernatants were filtered through a 0.45 μm pore size white nylon filter, and the extracts obtained were analyzed spectrophotometrically. The absorbance was measured at 642.5 and 660 nm, using a UV/Vis DU-65 Spectrophotometer (Beckman Coulter, Inc., Fullerton, CA). Chlorophyll content was calculated in mg/L using the equations: chlorophyll a = $(9.93 \times A_{660}) - (0.777 \times A_{642.5})$, chlorophyll b = $(17.6 \times A_{642.5}) - (2.81 \times A_{660})$, and total chlorophyll = $(7.12 \times A_{660}) + (16.8 \times A_{642.5})$ (Yahia, Soto-Zamora, Brecht, & Gardea, 2007).

Betalains were extracted and analyzed as reported earlier (Castellanos-Santiago & Yahia, 2008). Dry fruit tissue (100 mg) was stirred for 10 min in darkness in a citrate-phosphate buffer (pH 6.5) or water (20 mL) as solvents. After they were stirred, the samples were centrifuged at 12000 \times g at 15°C for 15 min in a Z323K Hermle centrifuge (Wehingen, Germany). Supernatants were filtered through a 0.45 μm nylon filter (Millipore Corp., Bedford, MA), and the extracts obtained were analyzed spectrophotometrically. Betanin used for the partial synthesis of betaxanthin standards was extracted from the fresh roots of red beet (*Beta vulgaris* L. ssp. Var. Pablo) (Stintzing, Schieber, & Carle, 2002). Beet roots were washed, peeled and sliced before being freeze-dried. The dried powder was extracted using water as a solvent. Crude magenta colored extract was transferred to a Sephadex LH-20 column (10 g), and separated by elution with water, and this procedure was done three times for each 2 mL portion of extract. Betacyanins (red-violet fractions) which showed maximum absorbance at 535 nm, were collected and then freeze-dried to obtain partially purified betalains powder. All determinations were performed on a UV/Vis spectrophotometer (Beckman, USA) equipped with UVWinLab V 2.85.04 software. The UV/Vis absorption spectra were recorded from 200 nm to 700 nm to obtain absorption values of $0.9 \leq A \leq 1.1$ at their respective absorption maxima. Measurements were performed in triplicate, and the betanin content (BC) was calculated according to Castellanos-Santiago and Yahia (2008).

$$\text{BC}[\text{mg/g}] = [(A(\text{DF})(\text{MW})\text{Vd} / \epsilon \text{LWd})]$$

where A is the absorption value at the absorption maximum of 535 nm and 483 nm for betacyanins and betaxanthins, respectively, DF is the dilution factor, Vd is the dried pulp solution volume (mL), Wd is the dried pulp weight (g) and L is the path-length (1 cm) of the cuvette. The molecular weight (MW) and molar extinction coefficient (ϵ) of betanin [MW = 550 g/mol; ϵ = 60,000 L/(mol cm) in H_2O] were applied in order to quantify the betacyanins. Quantitative equivalents of the major betaxanthins (Bx) were determined by applying the mean molar extinction coefficient [ϵ = 48,000 L/(mol cm) in H_2O]. In all cases, water extracted the highest level of pigments.

Total carotenoids (TC) and β -carotene extractions were performed using the AOAC method (2000) with some modifications (Corral-Aguayo et al., 2008; Soto-Zamora, Yahia, Brecht, & Gardea, 2005; Yahia, Ornelas-Paz, & Gardea, 2006). Samples of 0.5 g of freeze-dried powder were mixed with 15 mL of hexane:acetone:toluene:ethanol (10:7:7:6, v/v/v/v) solution and homogenized for 2 min. Then we added 1 mL of 40% KOH in methanol; stirred at 56°C for 20 min and cooled with faucet water, and 10 mL of 10% Na_2SO_4 was added, stirred

and incubated in the dark until phase separation (approx. 10 min). The top phase was separated and used for analysis. TC quantification was measured on top phase aliquots in a Beckman DU-65 spectrophotometer at 450 nm. A calibration curve was established using β -carotene in hexane as standard and hexane as blank. For β -carotene quantification, one top-phase aliquot was filtered through 0.45 μm nylon membrane (Pall Co., Michigan, USA) and injected (10 μL) to the HPLC, equipped with a diode-array detector. A 150 mm \times 4.6 mm i.d., 3.5 μm , Symmetry C18 column (Waters Co., Milford, USA) was used. Acetonitrile-methanol-dichloromethane (82:10:8, v/v/v) was employed as mobile phase at a flow rate of 2 mL/min. Analysis was monitored using HP ChemStation software version A.06.03 (Hewlett Packard/Agilent Technologies Co., Palo Alto, USA). A calibration curve (from 0 to 10 $\mu\text{g/mL}$) was prepared with β -carotene, and measurements were done in triplicate.

2.4.2. Total soluble phenols (TSP)

TSP were extracted as described by Wolfe, Xianzhong, and Liu (2003) with some modifications. This method measures a sample's reducing capacity and can be considered as another (electron transfer) antioxidant capacity assay (Huang, Ou, & Prior, 2005; Prior, Wu, & Schaich, 2005). Briefly, 1 g of lyophilized sample was homogenized in 15 mL of 80% acetone using an Ultra Turrax model T25 basic homogenizer (IKA Works, Willmington, NC) at ambient temperature. The homogenate was sonicated for 5 min in a Bransonic 2510 (Bransonic Ultrasonic Co., Danbury, CT) and centrifuged at 13500 g for 15 min at 2°C in a Hermle Z323K centrifuge (Labortechnik, Wehingen, Germany). The supernatant was collected, and an additional extraction was done in the sediment following the same procedure. Both supernatants were mixed and evaporated at 40°C using a rotary evaporator (Buchi R-205, Labortechnik, Switzerland). The residue was reconstituted in 25 mL of methanol and taken to 50 mL with HPLC water. An aliquot was filtered through a 0.45 μm membrane for analysis. Extractions were performed in triplicate. For TSP quantification, 30 μL -aliquots were diluted with HPLC water (1:10) and was placed in 96-well plates. Then, 150 μL of Folin-Ciocalteu reagent (dilution 1:10) and 120 μL of 7.5% Na_2CO_3 were added. The plates were incubated for 2 h protected from light, and absorbance was measured at 630 nm using a Dynex MRX microplate reader (Dynex Technol., Chantilly, VA). Results were expressed as milligrams of gallic acid equivalents (GAE)/100 g FW.

2.4.3. Ascorbic acids

Vitamin C (ascorbic and dihydroascorbic acids) determination was carried out as reported by Corral-Aguayo et al. (2008) with some modifications. Samples of 0.5 g of freeze-dried powder were homogenized in 10 mL extraction solution (0.1 M citric acid; 0.05% EDTA, pH 2.35–2.40) using an IKA T25 basic homogenizer (IKA Works, Willmington, USA). Then the homogenate was centrifuged at 15,000 \times g for 10 min at 2°C . The supernatant was separated and filtered through Sep-Pak C18 Vac 3 μL cartridge (Waters Co., Milford, USA). The first 5 mL was discarded and the next 3 mL was analyzed. The cartridge had been previously conditioned with 10 mL ethanol and then with 10 mL HPLC-grade water. The residual water was expelled with air. Three mL of the sample was collected and 1 mL (0.832 mg/mL) 1,2-phenylenediamine prepared in methanol/water (5:95 v/v) was added. The samples were incubated for 37 min in the dark and filtered through 0.45 μm nylon membrane. Aliquots of 40 μL were injected in a HP 1100 Series HPLC (Hewlett Packard/Agilent Technologies Co., Palo Alto, USA). A 300 mm \times 3.9 mm i.d., 10 μm , μ Bondapak C18 column and a 20 mm \times 3.9 mm i.d., 10 μm C18 guard column (Waters Co., Milford, USA) were used. The mobile phase consisted of 5 mM hexadecyltrimethylammonium bromide (cetrimide) and 50 mM KH_2PO_4 in methanol-water (1:99 v/v) at pH 4.6. The flow rate was 1.5 mL/min. Ascorbic acid was monitored at 261 nm and dehydroascorbic

acid at 348 nm. Calibration curves were prepared from standards and used for quantification.

2.4.4. Tocopherols

Vitamin E (tocopherol) was determined as reported by Corral-Aguayo et al. (2008). Samples of 0.5 g of freeze-dried powder were homogenized in 10 mL of HPLC-grade methanol, stirred at 55 rpm in a water bath at 30 °C for 15 min and centrifuged at 5000×g for 10 min. The supernatant was filtered through 0.45 µm nylon membrane, and 20 µL of filtered sample was injected to the HPLC. A 150 mm×4.6 mm i.d., 3.5 µm, Symmetry C18 column (Waters Co., Milford) was used. HPLC-grade methanol (100%) was employed as a mobile phase at a flow rate of 0.8 mL/min. For quantification, a model FLD G1321A fluorescence detector (Agilent Technologies Co., Palo Alto, USA) at excitation wavelength of 294 nm and emissions of 325 nm was used. Calibration curves for quantification were prepared using standards.

2.4.5. Antioxidant capacity (AC)

AC was determined by the FRAP (ferric ion reducing antioxidant power) and the DPPH (2,2-difenil-1-picril-hidrazil) assays. Lipophilic extracts (LPE) and hydrophilic extracts (HPE) were obtained as reported (Wu, Beecher, et al., 2004), with some modifications. Samples of 1 g of freeze-dried powder were homogenized in 10 mL of hexane/dichloromethane (1:1, v/v) using an Ultra Turrax model T25 Basic Homogenizer (IKA Works, Willmington, NC). The homogenate was sonicated for 5 min in a Bransonic 2510 sonicator (Bransonic Ultrasonic Co., Danbury, CT) and then centrifuged at 15,000 g for 10 min at 4 °C. The supernatant was collected, and the residue was again subjected to the same extraction process. Both supernatants were mixed and dried at 40 °C and low pressure. The dried extract was re-suspended in 10 mL of HPLC-grade acetone, filtered through a 0.45 µm nylon membrane, and designated as LPE. The residue, after the second extraction process, was dried with nitrogen, and the dried residue was homogenized in 20 mL of acetone/water/acetic acid (70:29.5:0.5, v/v/v), then sonicated and centrifuged as previously described for LPE. The supernatant was collected, and the extraction process was repeated with the pellet. Both supernatants were mixed and designated as HPE. Both LPE and HPE were used for AC analysis. DPPH assay was performed as reported (Kim, Lee, Lee, & Lee, 2002), with some modifications, using a microplate reader. Aliquots of 280 µL of 100 µM DPPH/methanol solution per well were placed in the same row of a 96-well plate, and then, 20 µL of extracts, diluted to different concentrations, was added to each well to complete 300 µL. Aliquots of 300 µL of methanol were placed in the first row as a blank. The plates were incubated for 30 min in the dark, and measurements were taken at 490 nm in an MRX microplate reader (Dynex Technology, Chantilly, VA). For the FRAP assay (Benzie & Strain, 1996), aliquots of 280 µL of FRAP reagent were placed in 96-well plates, and 20 µL of extracts, diluted to different concentrations, was added in each well. The plates were incubated for 30 min in the dark and read using a filter of 630 nm in a MRX microplate reader. FRAP reagent was

prepared with 50 mL of 300 mM acetate buffer (pH 3.6), 5 mL of 10 mM 2,4,6-tripyridyl-2-triazine (TPTZ) in 40 mM of HCl, and 5 mL of 20 mM Fe Cl₃.

2.5. Data analysis

Results are presented as means of at least three replications and standard error of the mean. All data analyses were performed using Sigma Plot 10.0 (Systat Software Inc, San Jose, CA).

3. Results and discussion

The TSS content of the cactus pear varied from 11.6 to 15.3 °Brix (Table 2). The highest TSS content was observed in 'Cardona' (15.3 °Brix) followed by 'Liria' (14 °Brix), 'Naranjona' and 'Roja Lisa' (13.86 °Brix) (Table 2). 'Camuesa' and '2-14-2' had the lowest TSS with 11.6 and 11.9 °Brix, respectively. These values are in agreement with those reported recently in other cactus pear fruit cultivar produced in Mexico (Chavez-Santoscoy, Gutierrez-Urbe, & Serna-Saldivar, 2009).

The ten cultivars/lines used in our study varied in color from white to purple (Table 2 and Fig. 1). 'Naranjona', 'Reyna', '2-6-51' and '2-14-41', which have a yellow-green coloration, showed the highest hue (h°) and b° values. 'Reyna' had a relatively high lightness (L°) and b° values. As expected, the purple and the orange-red colored fruits had the highest a° values and the lowest L° values.

Fig. 2A shows the betalains content of the different cactus pear fruit studied. 'Camuesa' had the highest betacyanins and betaxanthins content followed by 'Roja Pelota' and 'Roja Lisa'. Although these varieties contained high amounts of betaxanthins, the color exerted by the red violet betalains predominated in this and other purple pigmented fruits. Butera et al. (2002) reported that cactus pear fruits are considered a rich source of the yellow-orange betaxanthins and the red-violet betacyanins. Similar results were obtained in the present study. However, there were wide differences in terms of betaxanthins and betacyanins content in the cultivars/lines studied. Chavez-Santoscoy et al. (2009) observed that the lesser the color of juices obtained from different cactus pear fruit the lower the betacyanin content. The color of cactus pear fruit appears to be more related to this group of pigments than to phenols and carotenoids.

Chlorophylls (Fig. 2B) were very low in the pulp of all the cultivars/lines used, with 'Camuesa', 'Roja Pelota', '2-6-51', 'Roja Lisa', and 'Reyna' having higher amounts, and 'Liria' and '2-14-41' having the lowest amounts. Chlorophyll a is much higher than chlorophyll b in all the cultivars/lines.

The fruit pulp of all cultivars/lines have relatively low amounts of total carotenoids (Fig. 2C), with 'Camuesa' having the highest amount of about 2.5 µg/g dw, and 'Liria' and '2-14-2' having the lowest amounts of about 1 µg/g dw.

The highest ascorbic acid content was observed in 'Camuesa', followed by 'Cardona' with 4000 and 2100 µg/100 g FW, respectively (Fig. 3A). A lower ascorbic acid content was observed in '2-6-51', 'Naranjona', and '2-14-2' with levels ranging between 1200 and

Table 2
Total soluble solids (TSS) and internal (flesh) color components (a°, b°, L°, h°, C°) of the different cactus pear cultivars and lines used in the study. Values are means ± standard deviation.

Cultivar/line	TSS	a°	b°	L°	h°	C°
Camuesa	11.60 ± 0.40	22.85 ± 3.31	0.10 ± 1.04	23.88 ± 2.50	204.3 ± 78.59	22.87 ± 3.32
Cardona	15.30 ± 0.61	22.50 ± 4.33	1.11 ± 0.88	24.79 ± 2.54	327.07 ± 98.09	22.56 ± 4.30
Liria	14.00 ± 0.00	34.93 ± 3.06	3.95 ± 1.52	34.54 ± 4.14	353.61 ± 2.19	35.18 ± 3.14
Naranjona	13.86 ± 0.23	22.21 ± 3.68	23.70 ± 5.58	41.31 ± 5.12	46.42 ± 9.19	32.88 ± 4.24
Reina	13.33 ± 1.01	0.22 ± 1.77	14.63 ± 2.2	58.00 ± 4.03	14.67 ± 2.20	14.67 ± 2.20
Roja Lisa	13.86 ± 0.23	29.54 ± 4.52	9.83 ± 4.54	34.23 ± 2.97	17.48 ± 6.36	31.30 ± 5.49
Roja Pelota	13.50 ± 0.61	29.44 ± 4.17	2.07 ± 1.18	30.19 ± 4.34	11.30 ± 50.87	29.53 ± 4.21
2-6-51	13.80 ± 0.11	19.71 ± 5.49	14.69 ± 4.25	43.38 ± 7.31	37.34 ± 11.23	25.02 ± 5.16
2-14-2	11.86 ± 0.46	29.89 ± 5.70	6.36 ± 3.17	33.30 ± 3.75	11.34 ± 3.90	30.63 ± 6.20
2-14-41	12.00 ± 0.00	19.24 ± 2.17	28.89 ± 5.23	43.23 ± 4.21	55.82 ± 6.10	34.89 ± 4.39

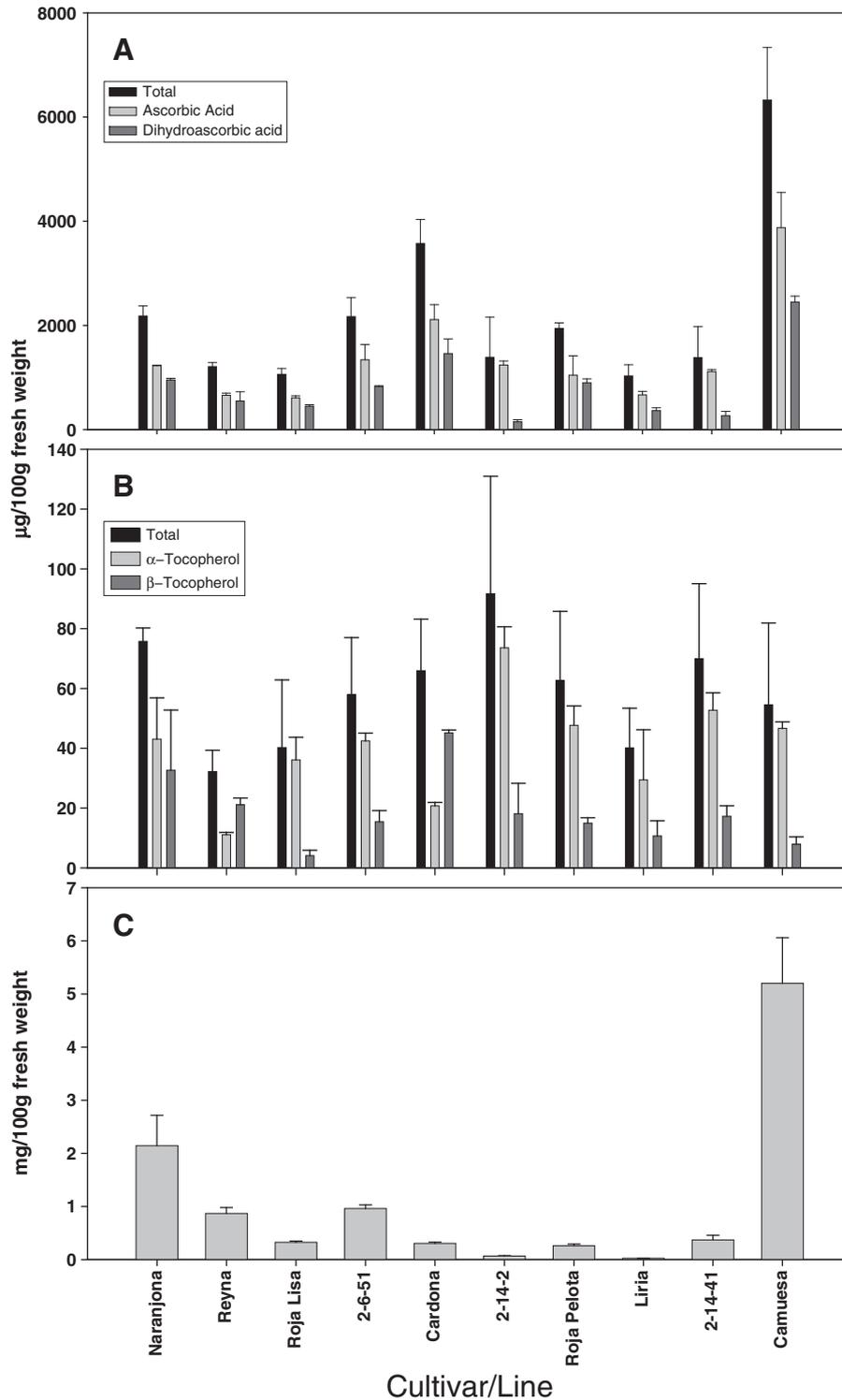


Fig. 2. Pigment contents in fruits of the cultivars/lines used in the study. (A) Betalains (betacyanins, betaxanthins, and total), (B) chlorophylls (total, a and b); and (C) total carotenoids. Vertical bars indicate standard errors of the means.

1400 µg/100 g FW. The rest of cultivars/lines had lower and similar content among them. Dihydro ascorbic acid had a similar pattern in all the cultivars/lines studied.

Very low amounts of tocopherols have been found in the cultivars and line studies, in addition there were no major differences between them (Fig. 3B). α-tocopherol was higher than δ-tocopherol in all the cultivars/lines (about 2:1). The highest relative α-tocopherol and total tocopherol contents were found in '2-14-2' (about 74 µg/100 g FW) and 'Cardona' followed by 'Naranjona', and the lowest amount was found in

'Reyna' (about 11 µg/100 g FW). The content of δ-tocopherol in all studied cultivars/lines ranged from 5 to 20 µg/g FW. The highest δ-tocopherol was found in 'Cardona' (about 45 µg/100 g FW), and the minimum amount (about 0.3 µg/100 g FW) was found in 'Cardona'. The highest amount of the total tocopherols (α- plus δ-tocopherol) of about 92 µg/100 g FW, was found in '2-14-2'. We have not detected any β- and γ-tocopherol.

'Camuesa' and 'Naranjona' had the highest β-carotene content of all cactus pear fruit cultivars/lines analyzed, with 5 and 2 µg/g FW,

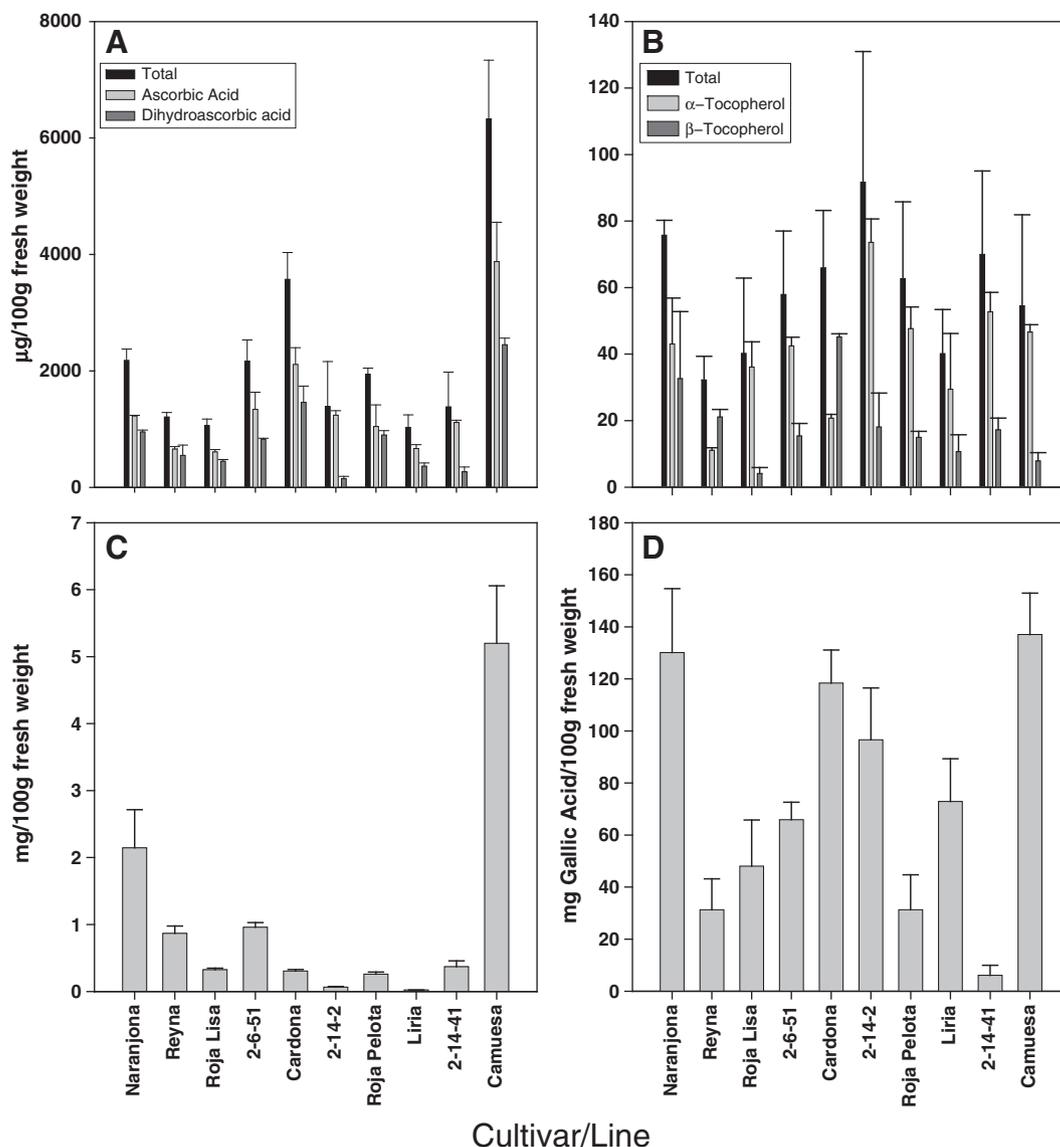


Fig. 3. The content of some important antioxidant components in the cultivars/lines used in the study. A) vitamin C (ascorbic acid, dihydro ascorbic acid, and their total), B) tocopherols (α , δ and their total), C) β -carotene, and D) total phenolic content. Vertical bars indicate standard errors of the means.

respectively (Fig. 3C). 'Reyna' and '2-6-51' had about 1 $\mu\text{g/g}$ FW of β -carotene and the rest of the cultivars/lines had lower than 0.5 $\mu\text{g/g}$ FW. Fruits with the highest β -carotene content possessed yellow and red colors, as observed in Fig. 1. However, it does not necessarily signify that yellow fruits have the highest β -carotene content, because other pigments such as betalains present in prickly pear fruit can mask the yellow color that carotenoids commonly confer (Yahia & Ornelas-Paz, 2010).

'Naranjona' and 'Camuesa' possessed the highest total phenolic content of about 130 mg gallic acid/g FW (Fig. 3D). The lowest phenolic content was found in '2-14-41' with only 10 mg gallic acid/g FW. An intermediate phenolic content was found in 'Cardona' and '2-14-2', followed by the rest of the cultivars/lines having a content ranging from 10 to 70 mg gallic acid/g FW. Kuti (2004) analyzed different types of cactus pears and concluded that purple skinned fruits contained the highest amounts of flavonoids. In general, cultivars that contained the highest vitamin C levels had the highest content of phenols and β -carotene. Phenolic compounds provide several advantages to different fruits (such as color and sensory attributes) and are of good nutritional and health value (Babbar, Oberoi, Harinder, Dewinder, & Patil, 2011; Wootton-Beard, Moran, & Ryan, 2011). The apparent relationship between total phenolic

content and color within the cactus pear fruits studied here appears to depend mainly on the species. Tesoriere, Butera, Pintaudi, Allegra, and Livrea (2004) found that the pulp of cactus pears contained phenolic compounds and other antioxidants such as biothiols and concluded that they had a positive effect in the redox balance of humans mainly due to reduced LDL hydroperoxide levels. The nutraceutical benefits have been attributed to the synergistic effects of betalains and flavonoids (Stintzing et al., 2005). Flavonoids, such as kaempferol-3-O-rutinoside; isorhamnetin-3-O-rutinoside and isorhamnetin-3-O-glucoside have been identified in juices extracted by pressing whole prickly pears of *O. ficus-indica*, and quercetin was the predominant flavonol quantified as aglycone (Kuti, 2004).

Some phytochemicals have an antioxidative action. For example, carotenoids, flavonoids and other phenolics, vitamins such as C (ascorbic acid) and E (tocopherols and tocotrienols), and some enzymes are part of the antioxidant defense system (Pénicaud, Peyron, Bohuon, Gontard, & Guillard, 2010; Yahia, 2010). Antioxidants protect living cells against the harmful effects of free radicals and other reactive oxygen species (Yahia, 2010).

Fig. 4 shows the AC measured by the FRAP (Fig. 4A) and DPPH (Fig. 4B) assays. 'Roja Pelota' and 'Camuesa' presented the highest

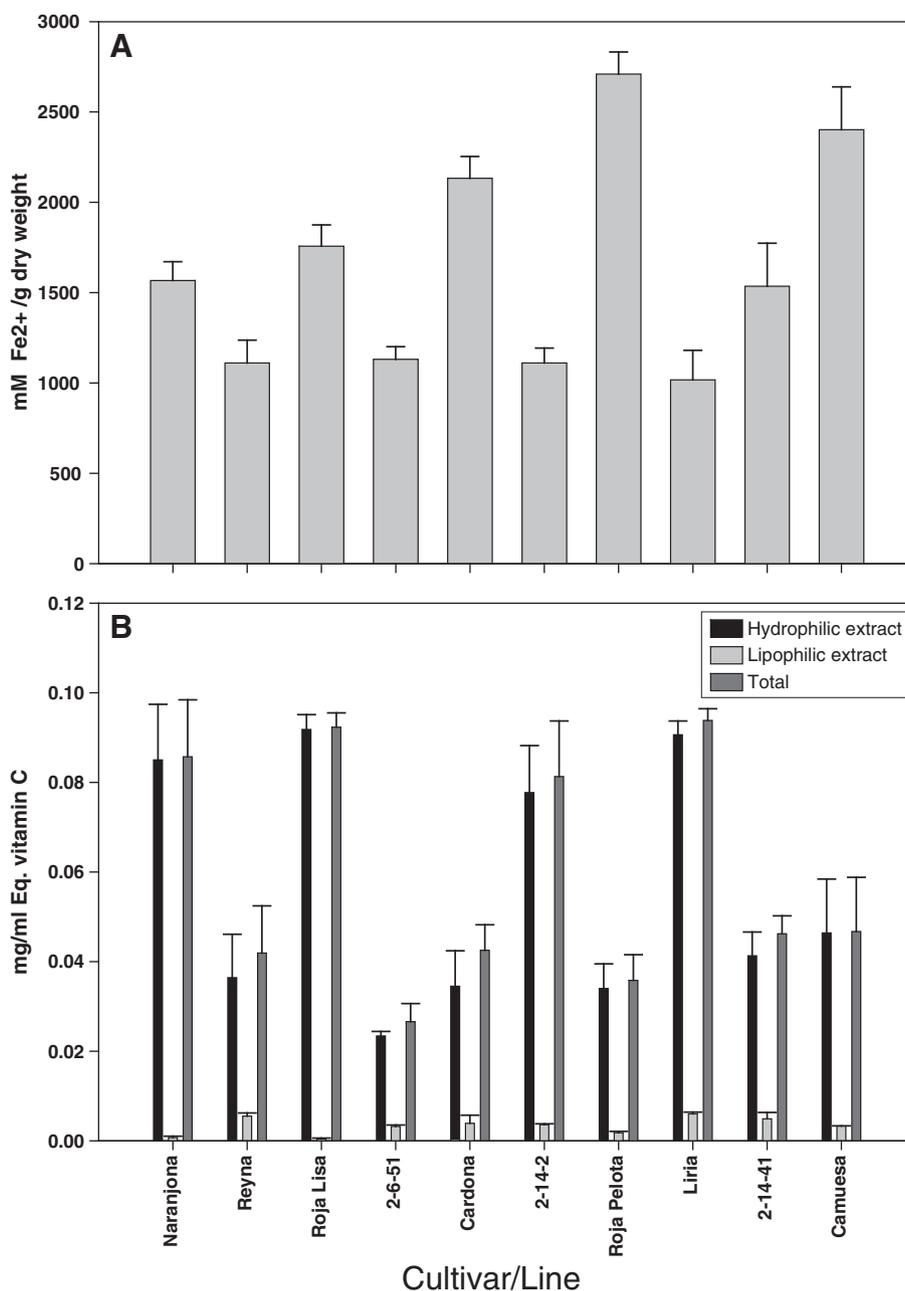


Fig. 4. Antioxidant capacity of the fruits of the cultivars/lines used in the study measured by the FRAP (A) and DPPH (B) assays. Vertical bars indicate standard errors of the means.

antioxidant capacity followed by 'Cardona'. An intermediate activity was observed in 'Naranjona', 'Roja Lisa' and '2-14-41'. The lowest AC was found in 'Reyna', '2-6-51', '2-14-2' and 'Liria'. The AC of the different cultivars/lines did not present a constant pattern with respect to the levels of the bioactive compounds contained in the different cultivars. 'Camuesa' had the most interesting pattern, presenting a higher AC related with higher levels of bioactive compounds. The highest AC was observed in the hydrophilic extracts compared with the lipophilic extracts. It appears that betalains, vitamin C and phenolic compounds contributed in higher extent to the AC than other phytochemicals such as carotenoids and tocopherols. According to Wu, Beecher, et al. (2004), Wu, Gu, et al. (2004) most of the AC associated with fruits is exerted by ascorbic acid and phenolic compounds, and only about 1% of the total AC in fruits and vegetables is due to lipophilic compounds. Similar results were obtained in the present study. The high AC observed in cactus pear fruit is comparable to that of commercial juices. Cactus pear fruit juices contained at least twice the AC of strawberry, plum, orange, grapefruit,

red and white grape, kiwifruit, apple, pear and tomato and comparable to red wine and pomegranate, Concord grape, blueberry and black cherry juices (Seeram et al., 2008).

4. Conclusions

The nutritional content and antioxidant capacity (AC) of the fruit of ten cultivars/lines with distinct pulp colors used in this study were different. 'Camuesa' had the highest betalains, total carotenoids, β -carotene, ascorbic acid, and was one of the highest total phenolic compounds, but its AC did not demonstrate outstanding differences with some other cultivars/lines that were not as rich in these compounds. 'Roja Pelota' had high AC when measured with the DPPH assay, but had low total carotenoids, β -carotene and total phenolic content. 'Reyna' had slightly low AC as measured by the FRAP assay, practically no betalains, and low vitamin C, tocopherols, β -carotene, and total phenolic content. We conclude that although different colored pulp fruit types have different

components (especially in pigment types and contents), they are all characterized by important nutritional and health components. However, some cultivars such as 'Camuesa' and 'Naranjona' can be considered as having better nutritional characteristics compared with the cultivar most commonly consumed in Mexico (Reyna), and therefore these results may hopefully help promote the consumption of other cultivars. In addition of the importance of these results to postharvest physiologists and technologists, nutritionists, marketing authorities and consumers in general, they should be of interest and help to breeders, among others.

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