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ORIGINAL ARTICLE

Physicochemical variability and nutritional and functional characteristics of xoconostles (*Opuntia* spp.) accessions from Mexico

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Abstract – Introduction. The genus *Opuntia* generally produces fruits with abundant pulp and sweet taste, but also acidic fruits known as xoconostles, which may have a high potential for use and consumption. The aim of this study was to evaluate the physicochemical, nutritional and functional characteristics of 10 xoconostle genotypes produced in Mexico. **Materials and methods.** The xoconostle genotypes were collected from Hidalgo, Zacatecas and State of Mexico in Mexico. The pH, soluble solids, and titratable acidity, as well as the proximate composition and content of total phenolic compounds, betalains and antioxidant capacity (Trolox) were determined. Results were analyzed using analysis of variance (ANOVA) procedures and the Tukey test at a significance level of 0.05. **Results and discussion.** It was observed a high variability in weight (44.5–84.3 g FW), soluble solids (4.2–6.12 °Brix), titratable acidity (0.10–0.19 g 100 g^{-1} FW), and pH (2.74–3.54) among the 10 genotypes of *Opuntia* spp. studied. The protein content varied from 0.60 to 0.87 g 100 g^{-1} FW. Xoconostle genotypes with high calcium content of 1.008 mg 100 g^{-1} FW were identified. Some xoconostle genotypes can be a good source of pigments due to their high content of betacyanins (0.76–5.06 mg 100 g^{-1} FW) and vulgaxanthins (1.83–4.76 mg 100 g^{-1} FW). The antioxidant capacity of some xoconostle genotypes was higher than that of other common fruits. **Conclusion.** The xoconostle genotypes evaluated have a potential to be exploited as a suitable source of pigments and antioxidant compounds.

Keywords: Mexico / xoconostle / *Opuntia* spp. / antioxidant activity / betacyanins / nutritional value

Résumé – Variabilité physico-chimique et caractéristiques nutritionnelles et fonctionnelles de variétés de 'xoconostle' (*Opuntia* spp.) du Mexique. Introduction. Le genre *Opuntia* produit généralement des fruits à la pulpe abondante et au goût sucré, mais aussi les fruits acides connus sous l'appellation 'xoconostle', qui ont un fort potentiel d'utilisation à des fins alimentaires ou non. Le but de cette étude était d'évaluer les caractéristiques physico-chimiques, nutritionnelles et fonctionnelles de 10 génotypes de 'xoconostle' produits au Mexique. **Matériel et méthodes.** Les variétés ont été collectées dans les états d'Hidalgo, Zacatecas et Mexico au Mexique. Le pH, les composés solubles et l'acidité titrable, ainsi que la composition globale et la teneur en composés phénoliques totaux, bétalaïnes et la capacité anti-oxydante (Trolox) ont été déterminés en poids frais (PF). Les résultats ont été analysés par analyse de variance (ANOVA) en utilisant le test de Tukey à 5% de niveau de signification. **Résultats et discussion.** Une grande variabilité de la masse (de 44,5 à 84,3 g PF), des composés solubles (4,02 à 6,12 °Brix), de l'acidité totale (de 0,10 à 0,19 g 100 g^{-1} PF), et du pH (2,74 à 3,54) a été observée parmi les 10 génotypes d'*Opuntia* spp. étudiés. La teneur en protéines a varié de 0,60 à 0,87 g 100 g^{-1} PF. Des variétés de 'xoconostle' à forte teneur en calcium de 1,008 mg 100 g^{-1} PF ont été identifiées. Certains génotypes se sont avérés être une bonne source de pigments en raison de leur teneur élevée en bétacyanines (0,76−5,06 mg 100 g^{-1} PF) et en vulgaxanthines (1,83−4,76 mg 100 g^{-1} PF). La capacité anti-oxydante

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de certains génotypes de 'xoconostle' est globalement plus élevée que celle des autres fruits communément consommés. **Conclusion.** Les variétés de 'xoconostle' évaluées ont présenté un potentiel de valorisation en tant que source appropriée de pigments et de composés antioxydants.

Mots clés : Mexique / xoconostle / *Opuntia* spp. / activité antioxidante / bétacyanines / valeur nutritionnelle

1 Introduction

Nopal or cactus pear (*Opuntia* spp.) is endemic in the Americas [1]. Most species of the genus *Opuntia* produce fruit with abundant pulp and sweet taste [2], while a minority produce acid taste fruits known as xoconostles. Both types of plants thrive under semiarid conditions in the central highlands of Mexico [3]. There are about fifteen recognized species of xoconostle, but other species producing xoconostle have been found, and they could number 20 or more, all endemic to Mexico. Xoconostle fruit consists of epicarp (skin), mesocarp (pulp) and endocarp (formed mainly by seeds) [2, 4, 5]. The mesocarp (pulp) is the edible part of the fruit and is used as a condiment in Mexican cuisine, as well as in the manufacture of sweets, jellies, jams, beverages and sauces [2, 4, 5].

The xoconostle fruit may be pale green, pink or red; it contains sugars, vitamin C, phenolic compounds, carotenoids and betacyanins [5–7], which can be used as functional ingredients in foods, providing to xoconostle their functional characteristics. Additionally, Morales *et al.* [8] reported a dietary fiber content in pulp of 30 to 34% and a high fiber content in the seeds of xoconostle 'Cuaresmeño' (*O.matudae*), which is another functional characteristic found in xoconostles. The xoconostle 'Cuaresmeño' (*O. matudae*) is the type of xoconostle most commonly marketed and consumed around the world and the one that has been more thoroughly characterized. Guzmán-Maldonado *et al.* [9] evaluated the physicochemical, nutritional and functional characteristics of xoconostle 'Cuaresmeño' fruits (*Opuntia matudae*) from central Mexico, reporting soluble phenols, ascorbic acid, betalains and carotenoids as functional constituents. Morales *et al.* [10] evaluated the nutritional and antioxidant properties of the pulp and seeds of two xoconostle cultivars (*Opuntia joconostle* F.A.C Weber ex Diguet and *Opuntia matudae* Scheinvar), both of which are widely consumed in Mexico, concluding that these fruits should be considered of great interest as sources of bioactive compounds for the addition to other food products. Moreover, in a recent study by Aguirrezabala-Cámpano *et al.* [11], the xoconostle seeds have been proposed as a potential source of trypsin inhibitors as pest control agents, demonstrating the importance of the industrial potential of xoconostle, not only in the food industry. However, there are other xoconostle genotypes that may have a high potential for use and consumption. Unfortunately, there is no information on the nutritional and functional characteristics of these materials. The main objective of this study was to evaluate the physicochemical, nutritional and functional characteristics of 10 important xoconostle genotypes produced in the states of Hidalgo, Mexico and Zacatecas, Mexico. This is the first report about the potential for exploitation and the characteristics of these xoconostle genotypes.

2 Materials and methods

2.1 Plant material

The xoconostle genotypes were collected in three states of Mexico (*table I*); four collections were made in the state of Hidalgo (altitude 2,320 m, latitude 19°53′00″ N, longitude 98°49′00″ W), whose mean minimum temperature was 6.2 °C and the mean maximum temperature was 25 °C, being the raining season from May to October [12]; six collections were made in orchards and wild areas of the municipality of Saín Alto, Zacatecas (altitude 2,193 m, latitude 23°34′46″ N, longitude 103°14′49″ W) whose mean minimum temperature is −5.45 °C and the mean maximum temperature is 38.21 °C, being the raining season from June to October [12]; and one collection was made in a commercial orchard in the state of Mexico (altitude 2,294 m, latitude 19°41′00″ N, longitude 98°54′00″ W) whose mean minimum temperature is 5.75 °C, and the mean maximum temperature is 22 °C, being the raining season from July to September [12]. The average temperature at the collection sites was between 14.5 and 16.2 °C with an average annual rainfall of between 460 and 560 mm [12].

The fruits were harvested from each one of 10 selected plants. These materials reached maturity (*i.e.*, their optimal, fully ripe stage). The maturity stage was determined by the growers of xoconostle based on the color of the fruits (*figure 1*). The fruits were refrigerated at 4 °C until use. The pericarp (skin), the mesocarp (pulp) and the endocarp (mucilage and seeds) were separated. For analysis, only the pulp (mesocarp) was used, except for the analysis of potassium, calcium, magnesium, iron and zinc, for which the epicarp and mesocarp were used.

2.2 Chemicals

2,2'-azinobis (3-ethylbenzothiazoline-6-sulphonic acid) diammonium salt (ABTS), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, citric acid, anthrone and potassium persulfate were purchased from Sigma Aldrich (Sigma Aldrich Co. Spruce Street, St Louis, MO, 63103, USA). Sodium acetate and metaphosphoric acid were purchased from Merck (Merck KGaA, 64271, Danstadt, Germany). Acetic acid, boric acid, sodium arsenate heptahydrate, sodium bicarbonate, sodium carbonate, anhydrous sodium carbonate,

Table I. General information on xoconostle accessions and data on the sites of origin.

Common name	Color	Taxonomical classification	Origin	Type
C. Zac[1]	Light green	*O. matudae* (Scheinvar)	SAZ[2]	Wild[6]
Cuerón	Light green	*O. matudae* (Scheinvar)	SAZ	Wild
Cambray	Red	*O. duranguensis* (Britton & Rose)	SAZ	Wild
Virgen	Pink	*O. duranguensis* (Britton & Rose)	SAZ	Wild
Manzano	Pink	*O. joconostle* (Weber)	NEM[3]	Cultivated[7]
Invierno	Pink	*O. tezontepecana* (Gallegos & Scheinvar)	VTH[4]	Land race[8]
Manso	Pink	*O. joconostle* (Weber)	VTH	Land race
Borrego	Pink	*O. oligacantha* (Förster)	VTH	Land race
Matizado	Red	*O. scheinveriana* (Martínez & Gallegos)	VTH	Land race
Ulapa	Red	*O. oligacantha* (Förster)	TAH[5]	Land race

[1] Cuaresmeño Zacatecano; [2] SAZ = Saín Alto, Zacatecas; [3] NEM = Nopaltepec, state of Mexico; [4] VTH = Villa de Tezontepec, Hidalgo; [5] TAH = Tezontepec de Aldama, Hidalgo; [6] Wild refers to non-domesticated species; [7] Cultivated refers to domesticated species; [8] Land race refers to semi-domesticated species.

sodium hydroxide, ammonium molybdate tetrahydrate crystal, cupric sulfate pentahydrate, potassium sulfate, anhydrous sodium sulfate and sodium tartrate potassium were purchased from JT Baker (Avator TM Performance Materials SA de CV, 55320, Xalostoc, State of Mexico, Mexico). Sulfuric acid, ethanol, Folin-Ciocalteu reagent and methanol were purchased from Meyer (Química Suater SA de CV, Pampano # 7 Col. Del Mar, Tlahuac, 13720, Mexico D.F.). Trichloroacetic acid was purchased from Macron (Avantor TM Performance Materials, Inc. 3477 Corporate Parkway, Surte 200, Center Valley, PA., 18034, USA). Zinc and phenolphthalein were purchased from HYCEL (HYCEL of Mexico SA de CV, Av. Chapultepec, 06700, Mexico D.F.).

2.3 Physicochemical properties

Total soluble solids (TSS, in °Brix) were determined from xoconostle fruit juice using a digital refractometer (PR-101, ATAGO PALETTE, Tokyo, Japan). The pH was measured with a digital pH meter (Hanna Instruments Woonsocket, RI, USA) and titratable acidity was determined by the AOAC method (942.15) based on titration of the juice with 0.1 M NaOH and pH 8.2 using phenolphthalein as indicator [13]; titratable acidity was reported in g citric acid 100 g^{-1} fresh weight (FW).

2.4 Nutritional quality

The contents of ether extract, ash, carbohydrates, and proteins were measured according to the AOAC methods 920.85, 923.03, and 959.48 respectively [13]. Potassium, calcium, magnesium, iron and zinc were determined after $HClO_4/HNO_3$ digestion [14] in an inductively coupled plasma atomic emission analyzer (GBC, 932AA Model).

2.5 Functional quality

Determination of Total Soluble Phenols (TSP). The sample (0.5 g) was extracted with 20 mL of 80% methanol in an ultrasonic bath for 20 min at 37 °C and vortexed for another 20 min. The tube was centrifuged at 4,000 *g* for 20 min and the supernatant was recovered. The extraction was repeated with 20 mL of 80% methanol. The two supernatants were combined. The residue was subsequently extracted twice with 80% methanol (20 mL each time) for 30 min at 37 °C and the supernatants were combined. Then, the residues were further extracted twice with water (50 mL each time) for 20 min at 37 °C. TSP content was estimated by the Folin-Ciocalteu method [15]. Five g of diluted sample were added to 1 mL of 1:10 diluted Folin-Ciocalteu reagent. After 8 min, 800 μL saturated sodium carbonate (75 g L^{-1}) were added. After 2 h of incubation at room temperature, the absorbance was measured at 765 nm. Gallic acid (0–500 mg L^{-1}) was used for the standard calibration curve. The results were expressed as gallic acid equivalent (GAE) g^{-1} FW sample, and calculated as mean value ± SD ($n = 3$).

2.6 Betalains

The method proposed by Nilsson [16] was used to measure betanins and vulgaxanthins. A hundred mg of freeze-dried mesocarp (edible part) were mixed with 10 mL of aqueous methanol (50%) and stirred for 60 min at room temperature. The supernatant was recovered after centrifugation at 5,000 *g*; the residue was extracted again with aqueous methanol until absence of color was obtained. All extracts were combined and the sample was spectrophotometrically measured at 476, 538 and 600 nm. Betanins and vulgaxanthins were determined using the Nilsson equations [16]:

$$\text{betanins\%} = ((a/1,129) \times DF \times 100)$$
$$\text{vulgaxanthins\%} = ((y/750) \times DF \times 100)$$

where $a = 1.095(A_{538} - A_{600})$, $y = A_{476} - (A_{538} - a) - (a/3.1)$, and DF = dilution factor. The percentages of betanins and vulgaxanthins were reported as mg 100 g^{-1}.

2.7 Antioxidant activity

The Trolox-equivalent antioxidant capacity assay (TEAC) was performed according to the method proposed by

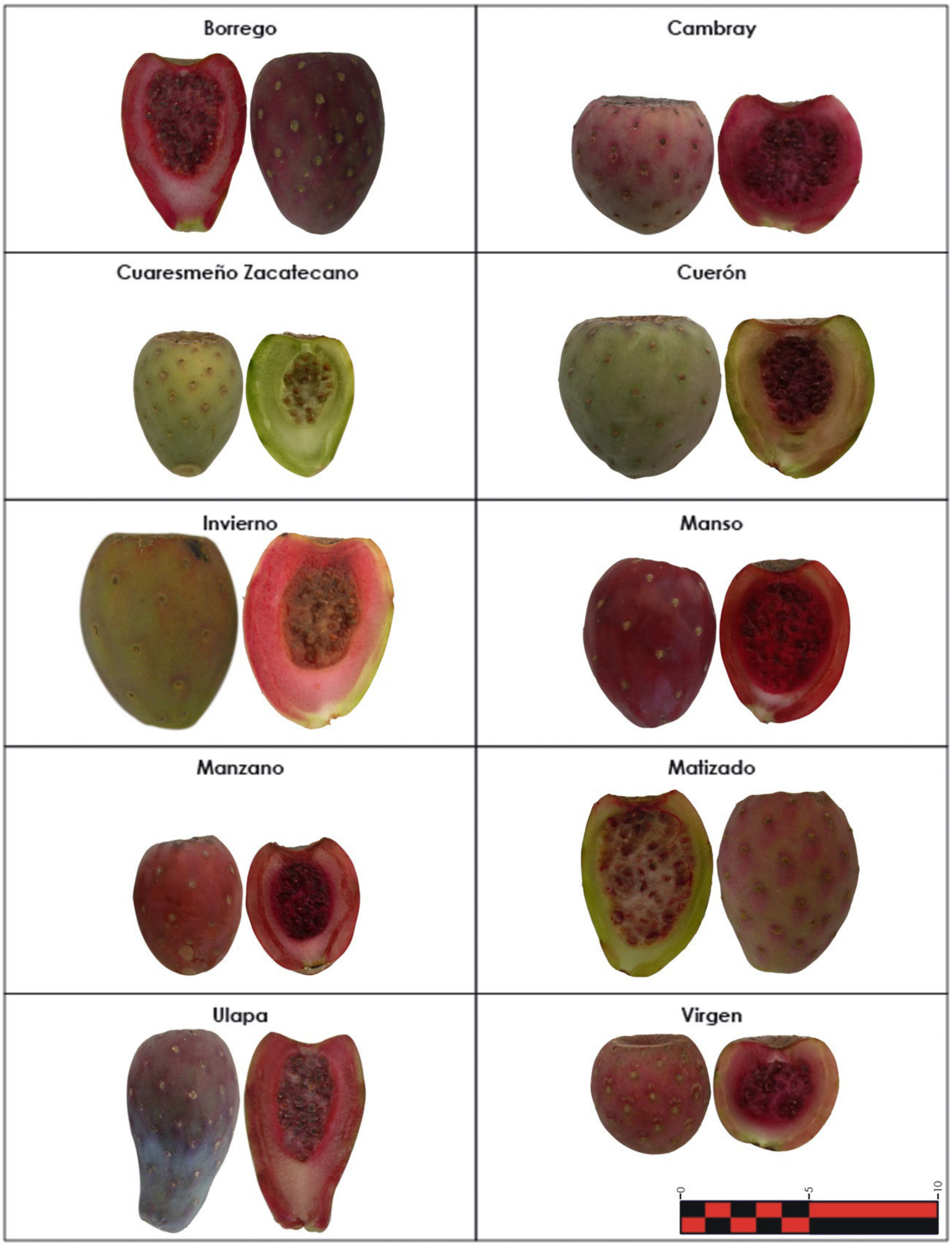

Figure 1. External and internal features of xoconostle fruit. The edible part of xoconostle is the thick mesocarp. The core full of seeds is discarded. A color figure is available at www.fruits-journal.org.

Re *et al.* [17], with the following modifications: ABTS (7mM) radical cation (ABTS-$^{+}$) solution was produced by reacting ABTS with 2.45 mM potassium persulphate and allowing the mixture to stand in the dark at room temperature for 12–24 h before use. The ABTS-$^{+}$ radical was diluted with acetate-buffer to give an absorbance of about 0.700 ± 0.002 at 754 nm. For measuring antioxidant capacity, 100 μL of extract were mixed with 3,900 μL of radical solution. Absorbance was monitored at 754 nm. The decrease in absorption at 754 nm, 120 min after addition of the sample, was used for calculating the TEAC value [17]. All the experiments were performed at least in triplicate. A calibration curve was prepared with different concentrations of Trolox diluted in ethanol, by measuring ΔA over 120 min for Trolox and the sample, absorbance values were corrected by the solvent as follows:

$$\Delta A_{\text{Trolox or sample}} = (A_{t=0\ \text{Trolox or sample}} - A_{t=120\ \text{minTrolox or sample}}) - \Delta A_{\text{solvent}}\ (0 - 120\ \text{min})$$

where A = absorbance at 754 nm. Results were expressed in terms of mmol Trolox equivalent 100 g^{-1} of fresh weight (mmol TE 100 g^{-1} FW).

Table II. Physicochemical characteristics of xoconostle accessions.

Accessions	Soluble solids (°Brix)	Titratable acidity (g citric acid 100 g^{-1} FW)	pH
Borrego	4.62 ± 0.20 cd[A]	0.16 ± 0.01 abc	3.08 ± 0.04 d
Manso	6.12 ± 0.13 a	0.10 ± 0.01 e	3.54 ± 0.05 a
Virgen	4.64 ± 0.23 cd	0.15 ± 0.02 bcd	3.10 ± 0.07 cd
Matizado	4.62 ± 0.19 cd	0.18 ± 0.01 ab	3.04 ± 0.05 d
Manzano	5.46 ± 0.15 b	0.12 ± 0.02 de	3.22 ± 0.04 b
Cambray	5.52 ± 0.19 b	0.13 ± 0.01 cde	3.30 ± 0.07 b
Cuaresmeño Zacatecano	4.28 ± 0.16 d	0.19 ± 0.01 a	2.74 ± 0.06 e
Cuerón	5.30 ± 0.10 b	0.12 ± 0.02 de	3.26 ± 0.05 b
Invierno	4.80 ± 0.27 c	0.14 ± 0.01 cde	3.12 ± 0.08 cd
Ulapa	5.36 ± 0.11 b	0.13 ± 0.01 cde	3.20 ± 0.07 bc

[A] Means in each column with different letters are statistically different (Tukey, $P \leqslant 0.05$).

2.8 Statistical Analysis

To analyze the results, a completely random experimental design was used; all data were reported as means ± SD of the 3 lots harvested at each location, each with 3 replicates ($n = 3$) taken from each lot. Statistical analyses were performed using JMP.5.0.1 software (A Business Unit of SAS, Statistics Analysis System, v. 9.0) [18]. Differences between treatment means were tested for significance using analysis of variance (ANOVA) procedures and the Tukey test at a level of significance of $P \leqslant 0.05$.

3 Results and discussion

3.1 Physicochemical characteristics

Significant differences in TSS, titratable acidity and pH in the mesocarp of the evaluated genotypes were observed (*table II*). One of the main characteristics of *O. xoconostle* is its low TSS content (4.0 to 5.9 °Brix) [9], compared with the pulp of prickly pear (*Opuntia ficus-indica*; 11.6 to 15.3 °Brix) [19]. Among the xoconostle genotypes, 'Manso' had the highest TSS content (6.12 g 100 g^{-1} FW) and xoconostle 'Cuaresmeño Zacatecano' had the lowest content (4.28 g 100 g^{-1} FW). These values were higher than those reported by Guzmán-Maldonado *et al.* [9] for xoconostle 'Cuaresmeño' from Guanajuato and Puebla (1.10 and 1.35 g 100 g^{-1} FW, respectively). Regarding the level of titratable acidity, the highest value (0.19% FW) was observed in the fruit of xoconostle 'Cuaresmeño Zacatecano', while the lowest value was observed in the fruit of xoconostle 'Manso' (0.10% FW). The values found in this work were lower than those reported by Guzmán-Maldonado *et al.* [9] for fruits of xoconostle 'Cuaresmeño' and Silos-Espino *et al.* [20] for xoconostle 'Blanco' (0.70% FW).The pH of xoconostle fruit ranged from 3.53 (xoconostle 'Manso') to 2.4 (xoconostle 'Cuaresmeño Zacatecano'), similar to that reported by Silos-Espino *et al.* [20]. Pimienta-Barrios *et al.* [21] and Contreras *et al.* [22] mentioned that the differences in the content of total soluble solids, titratable acidity and pH can be attributed to the characteristics of the different xoconostle genotypes and to the geographical conditions of the regions where the xoconostle fruit were collected. For example, the genus *Opuntia* grows under limited soil and water conditions, which could change its composition, mainly of the fruit [23]. The percentage of pulp is higher in xoconostle than in prickly pear (*Opuntia ficus-indica*), and there are differences in TSS content, which is much lower in xoconostle (about 5%), and in acidity, which is much higher. These differences entail different industrial uses for both species, being xoconostle considered as a condiment in Mexico. The transformation processes are more benign in the case of xoconostle, whose pH is less than 3.5; the low pH of xoconostle prevents the growth of harmful microorganisms, which is an advantage regarding the safety of the products [24].

3.2 Nutritional composition

The proximate composition of the pulp of the xoconostle fruit is shown in *table III*. The highest protein content (0.87 g 100 g^{-1} FW) was found in xoconostle 'Cambray', while the lowest protein content (0.308 g 100 g^{-1} FW) was found in xoconostle 'Virgen' and 'Ulapa'; these values were similar to those reported by Morales *et al.* [10] and Contreras *et al.* [22]. The relatively high protein content in the pulp of xoconostle compared to the protein content of peel and skin, suggests its potential for food use and the need to evaluate its protein quality [9]. Regarding the crude fat (lipids), values were found ranging from 0.024 g 100 g^{-1} FW (xoconostle 'Ulapa') to 0.050 g 100 g^{-1} FW (xoconostle 'Cuaresmeño Zacatecano'). For nitrogen-free extract (total carbohydrates and ash), no significant differences were found, with the values ranging from 9.10 g 100 g^{-1} FW (xoconostle 'Cambray' and 'Ulapa') to 9.40 g 100 g^{-1} FW (xoconostle 'Virgen'). El Kossori *et al.* [25] reported a protein content in tuna pulp of 5.13% DW. Other protein content values reported by Garcia-Pedraza *et al.* [4] for xoconostle cv 'Cuaresmeño' (3.4%) are twice as high as those reported by Guzmán-Maldonado *et al.* [9], (1.63% to 1.78%); these differences can be explained

Table III. Chemical composition, proteins, lipids and nitrogen free extract (total carbohydrates and ash) of xoconostle (*Opuntia* spp.) (FW: fresh weight).

Accessions	Proteins (g 100 g^{-1} FW)	Lipids (g 100 g^{-1} FW)	Total carbohydrates and ash (N-free extract) (g 100 g^{-1} FW)
Borrego	0.75 ± 0.05 ab[A]	0.049 ± 0.001 a	9.20 ± 0.10 a
Manso	0.66 ± 0.06 bc	0.046 ± 0.007 a	9.30 ± 0.10 a
Virgen	0.60 ± 0.02 c	0.048 ± 0.002 a	9.40 ± 0.17 a
Matizado	0.77 ± 0.03 ab	0.047 ± 0.004 a	9.20 ± 0.20 a
Manzano	0.73 ± 0.04 b	0.049 ± 0.003 a	9.30 ± 0.10 a
Cambray	0.87 ± 0.06 a	0.043 ± 0.002 ab	9.16 ± 0.28 a
Cuaresmeño Zacatecano	0.70 ± 0.05 bc	0.050 ± 0.001 a	9.25 ± 0.18 a
Cuerón	0.70 ± 0.02 bc	0.046 ± 0.003 a	9.30 ± 0.17 a
Invierno	0.73 ± 0.04 b	0.032 ± 0.005 bc	9.30 ± 0.10 a
Ulapa	0.60 ± 0.06 c	0.024 ± 0.002 c	9.40 ± 0.10 a

[A] Means in each column with different letters are statistically different (Tukey, $P \leqslant 0.05$).

Table IV. Mineral contents of xoconostle accessions (mean ± SD, $n = 3$).

Accessions	K (mg 100 g^{-1} FW)	Ca (mg 100 g^{-1} FW)	Mg (mg 100 g^{-1} FW)	Fe (µg 100 g^{-1})	Zn (mg 100 g^{-1} FW)
Borrego	0.271 ± 0.021 e[z]	0.861 ± 0.003 b	0.093 ± 0.003 de	0.16 ± 0.0009 c	0.006 ± 0.0006 ab
Manso	0.481 ± 0.018 b	0.161 ± 0.007 e	0.124 ± 0.005 c	0.18 ± 0.0018 c	0.007 ± 0.0002 ab
Virgen	0.367 ± 0.031 d	0.144 ± 0.013 c	0.079 ± 0.008 e	0.17 ± 0.0010 c	0.007 ± 0.0004 ab
Matizado	0.103 ± 0.0145 j	0.336 ± 0.046 c	0.106 ± 0.011 cd	0.06 ± 0.0003 d	0.001 ± 0.0001 f
Manzano	0.177 ± 0.018 g	0.116 ± 0.019 e	0.106 ± 0.011 cd	0.12 ± 0.0009 cd	0.005 ± 0.0011 d
Cambray	0.402 ± 0.040 c	0.337 ± 0.030 c	0.222 ± 0.016 b	0.30 ± 0.0016 b	0.006 ± 0.0001 bc
C. Zac.[y]	0.126 ± 0.027 i	0.143 ± 0.007 c	0.081 ± 0.003 e	0.06 ± 0.0006 d	0.003 ± 0.0001 e
Cuerón	0.640 ± 0.040 a	1.008 ± 0.005 a	0.430 ± 0.003 a	0.45 ± 0.0020 a	0.001 ± 0.0001 f
Invierno	0.142 ± 0.010 h	0.240 ± 0.019 d	0.085 ± 0.009 de	0.12 ± 0.0012 cd	0.005 ± 0.0005 cd
Ulapa	0.191 ± 0.012 f	0.368 ± 0.012 c	0.096 ± 0.003 de	0.17 ± 0.0010 c	0.008 ± 0.0001 a

[y] Cuaresmeño Zacatecano.
[z] In each column, different letters mean statistically significant difference (Tukey, $P \leqslant 0.05$).

by the different origins of xoconostle and different years of harvest [9].

3.3 Mineral Content

Table IV shows that the predominant minerals in exocarp (peel) and mesocarp (pulp) were potassium, calcium, magnesium, iron and zinc. The highest content of iron (0.002 µg 100 g^{-1} FW), potassium (0.640 mg 100 g^{-1} FW), calcium (1.008 mg 100 g^{-1} FW) and magnesium (0.430 mg 100 g^{-1} FW) was observed in xoconostle 'Cuerón', while the highest content of zinc (0.008 mg 100 g^{-1} FW) was observed in xoconostle 'Ulapa'. Xoconostles 'Manso' and 'Cuerón' showed the highest potassium content and pH value, coinciding with that reported by Sanchez *et al.* [26], who mentioned that this could be due to the presence of organic acids giving acidity to the fruit (citric, malic, ascorbic and succinic acid). The differences among the xoconostles respect to the content of K, Ca, Mg, Fe and Zn could be attributed to the genotypes and the mineral content in the soil where the xoconostles grew up.

3.4 Functional characterization

The TSP values showed that xoconostle is a good source of phenolic compounds (*table V*) compared with those of some common fruit and vegetables reported by Proteggente *et al.* [27]. The xoconostles presenting white pulp, 'Cuaresmeño Zacatecano', 'Cuerón' and 'Borrego', showed a lower value (108, 118 and 135 mg GAE 100 g^{-1} FW, respectively) of TSP and a lower concentration of betacyanins (1.70, 1.90 and 1.46 mg 100 g^{-1} FW, respectively) compared to the red xoconostles. The highest concentration of TSP was observed in xoconostle genotypes 'Matizado' (313 mg GAE 100 g^{-1} FW) and 'Ulapa' (278 mg GAE 100 g^{-1} FW). The concentration of TSP was lower than that reported by Guzmán-Maldonado *et al.* [9]. The highest content of betacyanins was found in red xoconostles 'Manso' and 'Matizado', with values of 5.06

Table V. Total phenols, betacyanins, vulgaxanthins and antioxidant activity (TEAC) in pulp of xoconostle fruit (mean ± SD, $n = 3$).

Accessions	Total phenols (mg GAE 100 g^{-1})	Betacyanins (mg 100 g^{-1})	Vulgaxanthins (mg 100 g^{-1})	Antioxidant activity (mmol TE 100 g^{-1})
Borrego	135 ± 2.0fg[z]	1.46 ± 0.51ef	3.96 ± 0.50bcd	6.99 ± 0.14def
Manso	168 ± 2.0de	5.06 ± 0.55[a]	3.43 ± 0.56cde	8.70 ± 0.43bc
Virgen	174 ± 1.0de	4.40 ± 0.53ab	3.73 ± 0.59bcde	7.52 ± 0.57de
Matizado	313 ± 1.1a	4.93 ± 0.49[a]	2.93 ± 0.50def	7.79 ± 0.24cd
Manzano	154 ± 1.0ef	4.10 ± 0.29bc	4.46 ± 0.49abc	10.26 ± 0.53a
Cambray	235 ± 1.7c	3.46 ± 0.40cd	1.83 ± 0.50f	7.39 ± 0.35ef
C. Zac.[y]	108 ± 2.0h	1.70 ± 0.37e	5.16 ± 0.64a	6.43 ± 0.32ef
Cuerón	118 ± 1.8gh	1.90 ± 0.30e	4.76 ± 0.41ab	6.10 ± 0.34f
Invierno	182 ± 2.0d	3.26 ± 0.50d	2.80 ± 0.41ef	7.43 ± 0.59de
Ulapa	278 ± 2.2b	0.76 ± 0.36f	4.50 ± 0.36abc	9.80 ± 0.22ab

[y] Cuaresmeño Zacatecano.
[z] In each column, different letters mean statistically significant difference (Tukey, $P \leqslant 0.05$).

and 4.96 mg 100 g^{-1} FW respectively, while the highest content of vulgaxanthins was found in the xoconostles 'Cuaresmeño Zacatecano' and 'Cuerón' (5.16 and 4.76 mg 100 g^{-1} FW, respectively). The highest antioxidant activity was observed in the xoconostles 'Manzano' and 'Ulapa' (10.26 and 9.80 mmol TE 100 g^{-1} FW, respectively), while the lower antioxidant activity was found in xoconostles 'Cuerón' and 'Cuaresmeño Zacatecano' (6.10 and 6.43 mmol TE 100 g^{-1} FW, respectively). These results are higher than those reported by Guzmán-Maldonado *et al.* [9], who reported a value of 2.5 mmol TE 100 g^{-1} FW for pulp of xoconostle cv 'Cuaresmeño'. The higher content of TSP in the xoconostles evaluated implies a higher antioxidant capacity. This indicates that the xoconostle genotypes studied have a higher antioxidant capacity compared to other high consumption species as the xoconostle cv 'Cuaresmeño'. The compounds and antioxidant properties shown in this work are good reasons for xoconostle fruit to be considered as a potential source of functional ingredients that can be used as an additive in other food products for the improvement of their potential to enhance health. The differences in the characteristics of total phenols, betacyanins and antioxidant activity could be due to the effect of the genotype, both of species and cultivars, as well as the growing conditions [28]. The color of the xoconostle fruit, caused by the presence of pigments (betalains), is an important parameter for its attractiveness, both for the fruits and for the products derived from them. Pimienta-Barrios *et al.* [21], mention that in healthy people, the xoconostles can help to prevent conditions of hyperglycemia and alterations in the concentration of cholesterol and triglycerides which may be related to the metabolic syndrome.

4 Conclusion

The existence of xoconostles of different colors widens the industrialization possibilities of this fruit. Due to its nutritional and functional characteristics, the pulp of xoconostle can be used as a spice in modern cuisine for making sauces, sweets and liqueurs, and can also be used for extracting betalains that can be used as natural colorants in food products and cosmetics. The compounds and antioxidant properties of the xoconostle fruit are good reasons to consider it as a source of functional ingredients. This information can be valuable to producers, breeding programs and industry.

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