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Physical-chemical quality of xoconostle fruits (*Opuntia matudae* and *O. joconostle*) in the Valle del Mezquital, Hidalgo, Mexico

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Abstract. The physical and chemical parameters of the soils are decisive in the physiological development of plants of agricultural interest. In the case of some species of Opuntia called xoconostle, the impact of the physical and chemical quality of the fruits, on the soils where they are grown, is unknown. The objective of this study was to determine the physical-chemical quality of two xoconostles fruits (*Opuntia matudae* cv. Cuaresmero and *O. joconostle* cv. Burro) cultivated and wild in the Valle del Mezquital, Hidalgo, Mexico. The physical and chemical characteristics of soils and fruits of xoconostle *O. matudae* and *O. joconostle* cultivated and wild in the state of Hidalgo, Mexico were analyzed with five repetitions. The data were treated with the JMP V8 program, expressed as mean ± standard deviation. The differences among the means of the fruits were treated with analysis of variance (ANOVA) with a significance level of P≤0.001. The differences among the means were evaluated with the Tukey test with a significance level of (P≤0.05). Among the physical and chemical properties of the soils, they presented a pale brown (10YR 6/3), with higher porosity, more acidic pH, and exchangeable ions, where wild xoconostle plants (*O. joconostle* cv. Burro) grow and develop, the fruits presented increases in the quality parameters in weight of whole fruit and pulp, longitudinal and equatorial diameter, °Brix, pH, ash, fiber, protein, K^+, Na^+, Ca^{2+} y Mg^{2+} .The xoconostle fruits of wild plants of Chapantongo *O. joconostle* showed statistically significant differences between sites and quality parameters concerning to *O. matudae* cv. Cuaresmero. Xoconostle fruits can be considered in the diet as a nutraceutical food alternative. It can also be used as a natural ingredient in food, food products, and by-products.

Keywords: *Soil quality, nutritional content, Xoconostle Burro, Xoconostle Cuaresmero.*

Introduction

The genus *Opuntia* represents a wide diversity of endemic cacti that are distributed in the semi-arid areas of Mexico (Santos-Díaz *et al.,* 2017; Kharrassi *et al*., 2016), among these plants, the xoconostle stands out, recognized for producing acidic fruits, in addition to representing a historical-cultural impact on the Mexican people since the settlement of the Mexican people, knowledge as a national symbol and food use (CONABIO, COMENTUNA and Red Nopal, 2008). Currently, there are 21 species named xoconostle which are produced in the north and center of the Mexico country (Scheinvar *et al.,* 2011). Of these species, only *O. matudae* cv. Cuaresmero and *O. joconostle* cv. Burro are cultivated and exploited commercially (Arias-Rico *et al*., 2020)

Mexico has the largest cultivated area of these species (55 254 ha) (FAO, 2017) with an approximate production of 568 000 tons (t) of which 95% is concentrated in the Estado de México with 183 000 t; they are cultivating in 176 000 ha and the rest are distributed in 3 000 ha that produces 17 000 t in the Valle del Mezquital in the state of Hidalgo, where the Cuaresmero and Burro are the representative cultivars (SIAP, 2015).

The economic importance of xoconostle fruits affects the diversity of uses as vegetables and processed foods (Dávila-Hernández *et al*., 2019; Melgar *et al*., 2017), medicinal properties (Dávila-Hernández *et al*., 2019; Cortez-García *et al*., 2015), therapeutic (Osorio-Esquivel *et al*., 2013), antioxidants (Arias-Rico *et al*., 2020) and nutritional (Castro-Muñoz *et al*., 2017). In pre-Hispanic times, part of the settlement processes of the towns were based on the supply of food and the use of natural resources of wild origin (Arias-Rico *et al*., 2020; Bravo-Hollis and Sánchez-Mejorada, 1991).

In recent years, the xoconostles were part of agriculture. However, the information on the properties of the soils for the cultivation of these cacti is limited (Scheinvar *et al*., 2011). Pimienta (1990) affirms that xoconostles develop in soils with a loamy-sandy texture, which provides support to the root system, fibrous and superficial, poor in nutrients, and with low moisture content, a situation that in the genus *Opuntia* sp. they are tolerant to water stress, a quality that allows them to survive in extreme conditions (Olivares *et al*., 2003).

Flores (1994) indicates that, in commercial plantations, the development of these plants should be in deep soils of igneous or calcareous origin, with a loam-sandy and sandy-clay texture, with good drainage and permeability. However, to date, no information that allows assessing the physical and chemical characteristics of the soils and their influence on the quality of the cultivated and wild xoconostle fruits (Gutiérrez-Rojas *et al*., 2018). To promote the sustainable production of xoconostle in soils of Valle del Mezquital, Hidalgo, Mexico, an experimental study was carried out to determine the physical-chemical quality of xoconostle fruits of *Opuntia matudae* cv. Cuaresmero and *O. joconostle* cv. Burro cultivated and wild. In this sense, it is proposed that the physical and chemical properties of the soils and fruits of wild plants differ from the soils and fruits of cultivated plants in the state of Hidalgo.

Material and Methods

This research was carried out in the Spring-Summer and Autumn-Winter 2018-2020 agricultural cycle in the Valle del Mezquital, Hidalgo, Mexico. The sampling sites were located in three xoconostle producing areas of Chapantongo between 20°17'07" N, 99° 24'46" W at 2120 m.a.s.l.; Huichapan between 20°22'24" N, 99°38'56" W at 2108 m.a.s.l. and Tula de Allende between 20°03'23" N, 99°20'31" W at 2020 m.a.s.l. The region is dominated by a temperate sub-humid climate with rains in summer, with an average annual rainfall of 550 mm and an average temperature of 18 °C (INEGI, 2016). The climate, based on Köppen (1936), modified by García (2004), is BS1 kw" (w) (e) temperate subhumid with rains in summer and Cw2 temperate-cold in winter. The dominant soil groups are Phaeozem (63.2%), Vertisol (20.0%), Leptosol (12.0%), Planosol (3.0%) and Rendzina (1.8%) (INEGI, 2009, INAFED, 2010, INEGI, 2017).

The study sites were labeled Site 1Ch-C Chapantongo where *O. matudae* cv. Cuaresmero, Site 2Ch-S Chapantongo and Site 3TA-S Tula de Allende with production of wild plants of *O. joconostle* cv. burro and Site 4Hu-C Huichapan with a culture of *O. joconostle* cv. Burro.

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Based on a 1:50 000 spatial georeferencing map in the four study sites, the xoconostle production areas were delimited. The history of the sampling sites with wild xoconostle corresponded to grazing soils and the soils with cultivated xoconostle plants showed tillage activity, and incorporation of organic material, without a fertilization program with a commercial activity of four years.

Soil sampling

Based on the distribution of the xoconostle plants, five quadrants of 25 m^2 were drawn, they were georeferenced with Garmin Etrex 20X® GPS. The soil sample was taken in the center of the 0-20 cm deep quadrant (20 samples composed of the four sites) were placed in sterile polyethylene bags at 4 °C to be transported to the soil analysis laboratory.

Analysis of soils

The physical-chemical characteristics of the soils were made based on the Guide for the Evaluation of Soil Quality and Health (USDA, 1999) and the techniques described in the Official Mexican Standards (NOM-004-SEMARNAT-2002 and NOM-021-RECNAT-2000), the analyzes of the soil samples were made with five repetitions. The samples were dried at room temperature and sieved with a 2 mm diameter mesh. The physical characteristics that were determined in the soil were the color, texture, bulk density (Bd), and real density (Dr). The chemical characteristics were based on the determination of the Cation Exchange Capacity (CEC), electrical conductivity (EC) with a Hanna® conductivity meter in a soil: water mixture in a 1: 2.5 proportion, pH with a Conductronic pH 120® potentiometer at a proportion 1: 2 H_2O, organic matter (OM) based on Walkley-Black (1947). The exchangeable Ca^{2+} and Mg^{2+} were titrated with 1N EDTA, Na^+, and K^+ with a Corning 400® photoflamometer.

Fruit sampling

In each cultivar, five points were considered and in each one, a 25 m^2 quadrant was drawn, per site ten fruiting plants were selected and from each plant, five pink fruits were cut as an indicator of physiological maturity, per site the sample was constituted out of 250 fruits, the samples were labeled and stored in sterile poly-paper bags at 4 °C until their analysis in the laboratory.

Physical and chemical characterization of the fruits

Based on the Graphic Manual Varietal Description of Nopal Tunero and Xoconostle (*Opuntia* spp.) (Gallegos-Vázquez *et al*., 2005) and the NMX-FF-030-SCFI-2006, by the fruit Longitudinal (LD) and equatorial (ED) diameter with Vernier Mitutoyo Absolute Digimatic Caliper® (Mitutoyo America Corporation, 2017), whole fruit weight (PFC) and mesocarp-pulp (PP) with Citizen® analytical balance. The nutritional content of the pulp was determined based on the Proximal Chemical Analysis (AQP) of the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC, 1990). The humidity was based on the evaporation of water at 65 °C for 24 h in a Riossa® oven; the samples were pulverized in an IKA® mill and preserved in sterile plastic bags. The ashes were obtained from calcining pulverized pulp at 550 °C in Felisa® muffle. The ether extract was determined with petroleum ether with a Labconco® fat extractor, the crude protein was digested and distilled in a Microkjeldahl Foss® and the crude fiber was determined with the acid-alkaline digestion by Weende in a Labconco fiber extractor®. The sugar content expressed in Brix degrees was determined with a HANNA Instruments® refractometer and the pH with a Conductronic pH 120® potentiometer. Interchangeable Ca^{2+}, Mg^{2+}, Na^+, and K^+ were quantified with a Corning 400® photoflamometer. The analyzes of the xoconostle fruits were carried out with five repetitions.

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Statistical analysis

The data were treated with the JMP V8 program (Journal of Mathematical Physics) and were expressed as the mean ± standard deviation. The differences between the means of the fruits were made with an analysis of variance (ANOVA) and a significance level of P≤0.001. The differences between the means were evaluated with the Tukey test at the significance level of P≤0.05.

Results and discussion

Physical and chemical properties of soils

In the plots where the xoconostles were cultivated, the soil of Site 1Ch-C of Chapantongo presented gray color (10YR 5/1) and Huichapan 4Hu-C yellowish brown (10YR 5/4). Unlike the sites where xoconostles grow in the wild, 2Ch-S pale brown (10YR 6/3) and 3TA-S grayish brown (10YR 5/2). The brown colors that these soils presented are because the parent material is made up of volcanic ash, which can be compacted and/or cemented as a result of its exposure to the formation processes of the soils (Besoain *et al*., 2000; Alvarado *et al*., 2014). The gray and yellowish-brown soils, with cultivated xoconostle plants, differ from the pale brown soils where the wild xoconostles were found, possibly because the contribution of organic materials from the plants is not removed from the surface and these are integrated into greater quantity into the soils (Porta *et al*., 2003). This agrees with the pale brown soils of 2Ch-S where wild plants grow and develop with fruits that presented better quality parameters in longitudinal and equatorial diameter, pulp weight, and complete fruit, in addition, to less acidic fruits (Figures 1 and 2). The bulk density was higher in soils where cultivated xoconostle plants develop, unlike where wild plants of this cactus grow (Table 1). Probably attributable to the fact that in the latter there is a greater contribution of organic residues to the soil; while in cultivated plants, it is less, which is subject to pruning and the removal of plant remains.

Table 1. Physical properties of soils with *O. joconostle* cv, Burro and *O. matudae* cv. Cuaresmero cultivated and wild from Valle del Mezquital, Hidalgo, Mexico.

Area	Place	Density (g cm^{-3})		Porosity	Partícles of soil (%)			T	Colour
		Apparent	Real	(%)	sands	silts	clays		
Xoconostles cultivated									
1	Chapantongo	1.04 ± 0.03^{a}	2.19 ± 0.02^{c}	52.81 ± 0.96^{c}	53.64 ± 4.85^{d}	20.72 ± 1.60^{b}	25.64 ± 7.16^{c}	Cra	10YR 5/1 Gray
4	Huichapan	1.06 ± 0.01^{a}	2.37 ± 0.01^{a}	55.31 ± 0.44^{b}	54.36 ± 4.92^{c}	19.64 ± 1.52^{c}	26.00 ± 7.26^{b}	Cra	10YR 5/4 yellowish brown
Xoconostles wild									
2	Chapantongo	0.95 ± 0.02^{b}	2.29 ± 0.01^{b}	58.51 ± 0.59^{a}	55.64 ± 5.03^{b}	18.00 ± 1.39^{d}	26.36 ± 7.36^{a}	Cra	10YR 6/3 Pale brown
3	Tula de Allende	0.91 ± 0.02^{b}	2.10 ± 0.03^{d}	56.67 ± 0.46^{ab}	65.64 ± 5.94^{a}	22.00 ± 1.70^{a}	12.36 ± 3.45^{d}	Ca	10YR 5/2 gray brown

T: Texture: **Cra** = Loamy-clay-sandy; **Ca** = sandy loam
Different literals between rows indicate statistically significant differences (Tukey P≤0.05). Data were expressed as the mean ± standard deviation

The real density presented different values between sites, due to the content of mineralogical elements such as clays, quartz, and feldspars that are common constituents of volcanic ash and that are similar to those obtained by Vela and Flores (2004). Density did not express significant changes in fruit quality parameters of cultivated and wild xoconostle plants. Soils with a higher porosity percentage were observed where wild plants bear fruit, which produces fruits of better weight and size (Figure 1). Although the dominant texture was loam-clay-sandy, soils with wild xoconostles are less subject to trampling by tillage practices; they also present spatial distribution among plants that, in a cultivated plot, favor the circulation of water and gases.

Soils with wild plants from Site 2Ch-S presented statistically significant differences in pH (5.20) compared to 1Ch-C, 3TA-S, and 4Hu-C. According to USDA (1999), NOM-004-SEMARNAT-2002 and NOM-021-RECNAT-2000, the CIC observed in the four sites where xoconostle plants develop is classified as low (Table 2), when comparing Results with Acevedo-Sandoval *et al*. (2010) the $cmol_c\ kg^{-1}$ of the CIC of the studied soils can be considered as average. However, the CIC of the 3TA-S presented 72% above the 2Ch-S. However, by site, no changes were observed in the quality parameters of xoconostle fruits. Exchangeable ions showed statistically significant differences between sites. However, the presence of Na^+ in Site 1Ch-C was higher in soils and xoconostle fruits in the other sites (Table 3). Furthermore, the concentration of ions present in fruits of wild and cultivated plants differs in the four study sites.

Table 2. Chemical properties of soils with *O. joconostle* cv. Burro and *O. matudae* cv. Cuaresmero cultivated and wild from Valle del Mezquital, Hidalgo, Mexico.

Area	placer	pH	MO* (%)	C (%)	C:N	CIC ($cmol_c\ kg^{-1}$)
Xoconostles cultivated						
1	Chapantongo	6.16 ± 0.25^a	7.85 ± 3.54^c	6.00 ± 0.01^a	11.67 ± 0.05^a	6.60 ± 0.62^b
4	Huichapan	6.03 ± 0.17^a	10.32 ± 0.04^a	5.99 ± 0.02^a	11.59 ± 0.02^a	7.92 ± 0.81^b
Xoconostles wild						
2	Chapantongo	5.20 ± 0.10^b	9.54 ± 0.13^b	5.54 ± 0.07^b	11.57 ± 0.03^a	5.28 ± 1.24^b
3	Tula de Allende	6.69 ± 0.12^a	9.28 ± 0.25^b	5.38 ± 0.14^b	11.64 ± 0.09^a	18.92 ± 1.87^a

* **MO**: Organic matter.
Different literals between rows indicate statistically significant differences (Tukey P≤0.05). Data were expressed as the mean ± standard deviation.

Table 3. Exchangeable ions of soils with *O. joconostle* cv. Burro and *O. matudae* cv. Cuaresmero cultivated and wild from Valle del Mezquital, Hidalgo, Mexico.

Area	Place	Exchangeable ions (meq $100g^{-1}$)			
		Ca^{2+}	Mg^{2+}	Na^+	K^+
Xoconostles cultivated					
1	Chapantongo	1.16 ± 0.01^a	2.72 ± 0.01^{ab}	5.13 ± 0.02^a	1.51 ± 0.02^a
4	Huichapan	0.45 ± 0.01^c	3.01 ± 0.04^a	0.38 ± 0.01^c	0.72 ± 0.01^c
Xoconostles wild					
2	Chapantongo	0.69 ± 0.01^b	2.01 ± 0.03^b	0.44 ± 0.01^c	1.22 ± 0.03^b
3	Tula de Allende	0.21 ±0.02^d	2.72 ± 0.02^{ab}	1.90 ± 0.12^b	1.26 ± 0.04^b

Different literals between rows indicate statistically significant differences (Tukey P≤0.05). Data were expressed as the mean ± standard deviation.

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Physical characterization of the fruits

The fruits of *O. joconostle* cv. Burro and *O. matudae* cv. Cuaresmero presented significant differences (P≤0.05) between sites in the quality parameters of fruit as a Longitudinal (LD) and equatorial (ED) diameter, whole fruit weight (PFC), mesocarp-pulp (PP), and total sugars (Figures 1 and 2). The LD of the wild fruits of this research surpassed the fruits of wild xoconostle *O. matudae* from the state of Zacatecas (55.7 mm) (Gallegos *et al*., 2014), also the fruits of wild *O. joconostle* from the state of Hidalgo (44.50 mm) (Pinedo-Espinoza *et al*., 2014). The DE of the fruits in the four sites was lower than the parameters reported by Pinedo-Espinoza *et al*. (2014) (77.80 mm). The DE of the fruits of wild xoconostle *O. matudae* with 46.79 mm (Gallegos *et al*., 2014) is within the average (48.23 mm) of the four wild and cultivated study sites of Chapantongo, Huichapan, and Tula de Allende, Hidalgo. The PFC of the fruits of wild plants [95.87 (2Ch-S) and 61.48 g (3TA-S)] and cultivated [(59.67 (1Ch-C) and 68.48 g (4Hu-C)] of the study sites differ from the weight of fruits of *O. joconostle* cv Burro de Hidalgo with fertilization management (100.4 g) (Zavaleta *et al*., 2001). The same authors mention that xoconostle fruits with organic fertilization are larger, a difference from the unfertilized fruits.

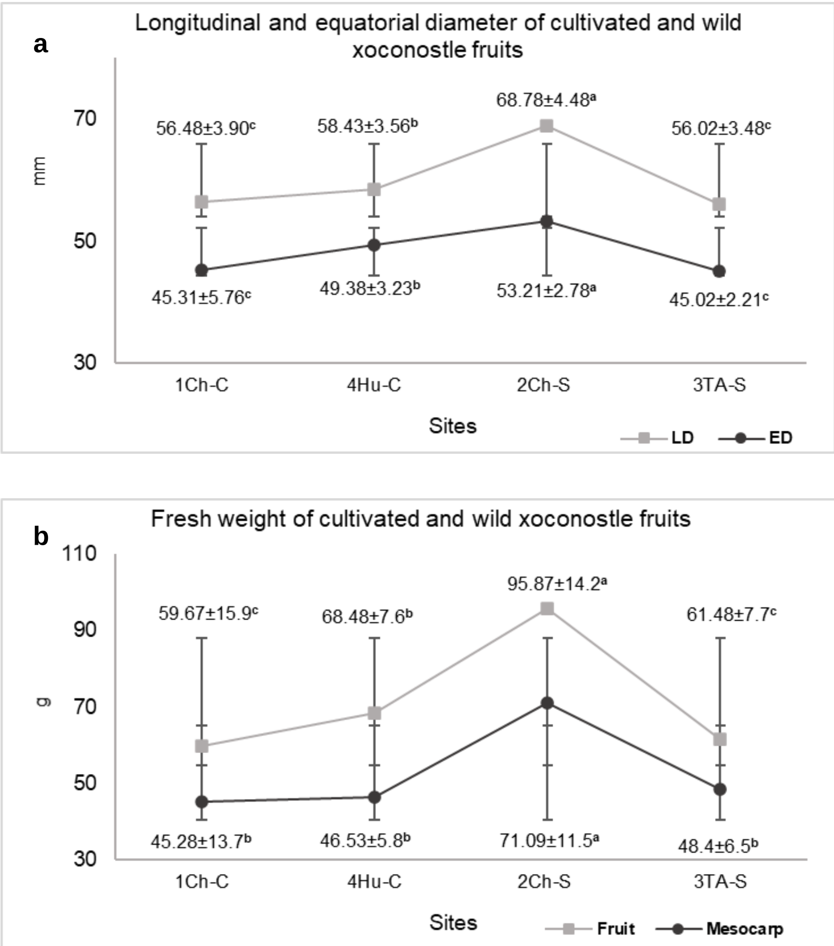

Figure. 1. Morphometric characteristics of xoconostle fruits cultivated and wild of *O. joconostle* cv. Burro and *O. matudae* cv. Cuaresmero from Valle del Mezquital, Hidalgo, Mexico. **a)** Longitudinal and equatorial diameter y **b)** Fresh weight of Fruit and Mesocarp. **LD:** Longitudinal diameter; **ED:** Longitudinal equatorial. Sitios: 1Ch-C: Chapantongo-Cultivated, 4Hu-C: Huichapan-cultivated, 2Ch-S: Chapantongo-wild and 3TA-S: Tula de Allende-wild. Different literals between lines indicate statistically significant differences (P≤0.05). Data were expressed as the mean ± standard deviation.

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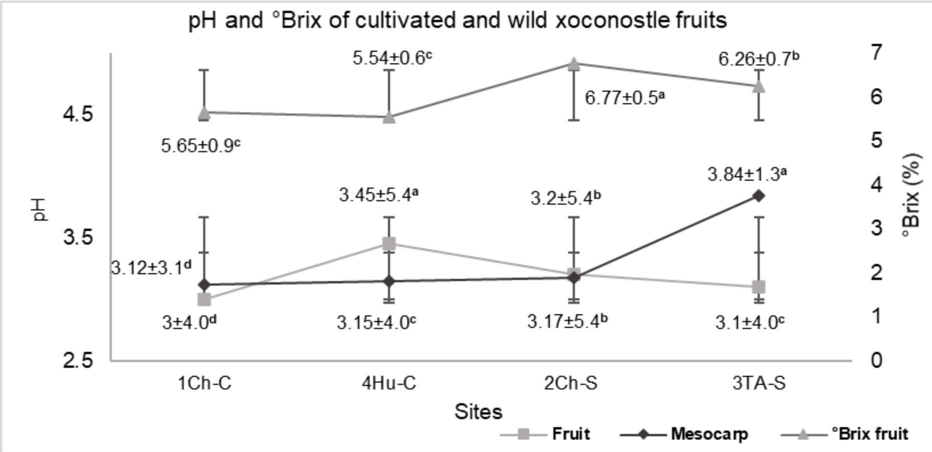

Figure. 2. pH y °Brix of xoconostle fruits cultivated and wild of *O. joconostle* cv. Burro and *O. matudae* cv. Cuaresmero from Valle del Mezquital, Hidalgo, Mexico. Sitios: 1Ch-C: Chapantongo-Cultivated, 4Hu-C: Huichapan-cultivated, 2Ch-S: Chapantongo-wild and 3TA-S: Tula de Allende-wild. Different literals between lines indicate statistically significant differences (P≤0.05). Data were expressed as the mean ± standard deviation.

The PP of the fruits of wild plants presented a higher weight with respect to the fruits of cultivated plants, Site 2Ch-S showed significant differences (P≤0.0001). The differences in the parameter of PP in the wild fruits de Chapantongo outperformed the wild fruits of *O. matudae* (54.1 g) (Gallegos *et al*., 2014). In short, Site 2Ch-S of Chapantongo with wild xoconostle showed significant differences (P≤0.0001) between sites and between parameters quality of xoconostle fruits (DL, DE, PFC, and PP) the differences may be because the xoconostle plants were scattered and there was no nutrient competition between them, unlike Site 3TA-S where the plants were found in conjunction with other species.

Chemical characterization of the fruit

The total sugar content observed in the xoconostle production sites (Figure 2) was similar to that reported by Gallegos *et al*. (2014), who reported 6.3% of total sugars in wild fruits *O. matudae*. Monroy-Gutiérrez *et al*. (2017) showed lower percentages (4.92%) in fruits of *O. matudae* cv. Cuaresmeño Blanco in Zacatecas, Mexico. Zavaleta *et al*. (2001) mention that the concentration of °Brix in xoconostle fruits tends to increase when the cactus is treated as a crop and the application of agronomic practices carried out from transplantation to harvest. The pH values in whole fruits and pulp of cultivated and wild xoconostles showed statistically significant differences between sites. The differences were marked by the lowest pH value (3.06) of 1Ch-C, the results agree with that reported by Gallegos et al. (2014) in wild fruits of O. matudae (3.10). In this sense, Gutierrez-Rojas et al., 2018 indicate that the concentration of sugars and acidity in the pulp of the fruits can be used to make sauces, jams, vinegars, liqueurs and spicy dehydrated fruit.

The percentages in the AQP of xoconostle fruit pulp showed statistically significant differences (P≤0.05) between sites (Table 4). The protein and ethereal extract values of the xoconostle fruits between sites were lower, in contrast to the percentages of moisture, ash and crude fiber. The percentages of moisture in the pulp of 1Ch-C, 2Ch-S and 4Hu-C were above 93%, these percentages agree with those reported by Morales *et al*. (2012), in cultivated fruits of *O. joconostle* cv. Cuaresmero (93.24%) and *O. matudae* Scheinvar cv. Rosa (94.11%), Hidalgo state. The water content in the pulp of the fruits influences the production and quality of vinegar, liqueurs and jams

(Gutiérrez-Rojas *et al*., 2018). The percentage of protein in the pulp of the fruits of Site 2Ch-S was similar to the percentage found in the pulp of *O. joconostle* fruits (0.66%) (Morales *et al*. 2012). However, in the fruits grown from Site 1Ch-C (2.75%) it was similar to that reported by Guzmán-Maldonado *et al*. (2010) in pulp of *O. matudae* cv. Cuaresmero of Guanajuato (2.75%), Estado de México (2.38%) and Puebla (2.47%). That is, the percentage of protein observed in the pulp of xoconostle fruits is not a food with high nutritional content, but it does present higher protein content than sweet prickly pear (1%) (Sumaya-Martínez *et al*., 2010).

The ethereal extract present in the wild fruits in Chapantongo (1.31%) and Tula de Allende (1.89%) and cultivated fruits in Huichapan (1.12%) and Chapantongo (2.06%) were higher than the values reported by Morales *et al*. (2012) in fruits of *O. joconostle* (0.03%) and *O. matudae* (0.04%). Based on the fat content, these fruits can be an alternative food supplement. The fiber content of the pulp in the four study sites is above 8% and exceeds the percentage of fruits of *O. matudae* (1.74%) and *O. joconostle* (2.71%) (Morales *et al*., 2012). The same authors mention that the fruit ripening stages of *O. matudae* cv. Cuaresmero are affected by the quality of fiber present in the fruit. According to Gutiérrez-Rojas *et al*. (2018), Castro-Muñoz *et al*. (2017) and Álvarez and Peña (2009), the percentage of total fiber present in xoconostle fruits can be used as a nutritional supplement and prevent chronic diseases. The percentage of ash showed significant differences in the pulp of Site 4Hu-C (14.32%) with respect to the percentages of 1Ch-C (13.29%), 2Ch-S (13.02%) and 3TA-S (10.24%), same that agree with the determinations by Guzmán-Maldonado *et al*. (2010), in fruit pulp of *O. matudae* cv. Cuaresmero of Guanajuato, Puebla and Estado de México (13.57%, 13.70% and 14.04%, respectively).

Table 4. Proximal Chemical Analysis of pulp of xoconostle fruits cultivated and wild of *O. joconostle* cv. Burro and *O. matudae* cv. Cuaresmero from Valle del Mezquital, Hidalgo, Mexico.

Determination	Xoconostles cultivated		Xoconostles wild	
(%)	1 Chapantongo	4 Huichapan	2 Chapantongo	3 Tula de Allende
Humidity[2]	94.21 ± 0.48[b]	93.36 ± 1.10[b]	95.13 ± 0.58[a]	75.11 ± 0.63[c]
Dry matter[2]	5.79 ± 0.48[b]	6.64 ± 1.10[b]	4.87 ± 0.58[c]	24.89 ± 0.63[a]
Organic matter[1]	86.71 ± 0.98[b]	85.68 ± 0.55[b]	86.98 ± 0.41[b]	89.76 ± 0.52[a]
Protein[1]	2.75 ± 1.11[b]	2.20 ± 0.07[c]	0.69 ± 0.34[d]	4.00 ± 0.12[a]
Ethereal extract[1]	2.06 ± 0.22[a]	1.12 ± 0.06[a]	1.31 ± 0.34[a]	1.89 ± 0.21[a]
Ashes[1]	13.29 ± 0.98[b]	14.32 ± 0.54[a]	13.02 ± 0.41[b]	10.24 ± 0.52[c]
Fiber[1]	11.10 ± 1.32[a]	10.24 ± 0.51[ab]	8.14 ± 0.58[b]	8.00 ± 0.43[b]
N	0.44 ± 0.02[b]	0.37 ± 0.04[c]	0.11 ± 0.05[d]	0.62 ± 0.03[a]
ELN[1]	70.77 ± 1.63 [c]	72.14 ± 0.63 [b]	76.82 ± 0.77 [a]	76.02 ± 0.83[a]

[1]Dry Base; [2]Base Wet; ELN: Nitrogen Free Extract. Different literals between columns indicate statistically significant differences (Tukey P≤0.05). Data were expressed as the mean ± standard deviation.

The content of mineral elements in the fruits of xoconostles makes this sour tuna maintain special nutritional characteristics. In this study, the nutritional content of xoconostle fruits from cultivated and wild plants showed statistically significant differences between sites. Also, xoconostle fruits from wild and cultivated plants showed statistically significant differences in ion content between sites. Between sites, K^+ marked the difference with respect to Na^+, Ca^{2+} and Mg^{2+} ($P \leq 0.0001$) (Table 5). The average $cmol_c$ Kg^{-1} of Na^+ (6.33), Ca^{2+} (5.6) and Mg^{2+} (6.20 1) detected in the pulp of xoconostle fruits from the four sites differ from the result of other investigations carried out in xoconostle fruits, in the case Na^+ was higher than the concentrations observed in fruits of *O.*

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heliabravoana, *O. joconostle* and *O. ficus-indica* in Hidalgo with 4.70, 3.31 and 3.63 mg kg^{-1}, respectively (Prieto-García *et al*., 2016; Prieto-García *et al*., 2006). Ca^{2+} was also found above the values observed by Guzmán-Maldonado *et al*. (2010) in fruit pulp of *O. matudae* in Guanajuato, Puebla and Estado de México (1 410, 1 890 and 1 960 mg / 100 respectively). Consuming Hidalgo xoconostle fruits with Ca^{2+} levels can strengthen bones, regulate heart rate, lower cholesterol levels, and lower blood pressure. Also, Mg^{2+} showed values with peaks above those reported by Prieto-García *et al*. (2016) with 259.5, 2990.8 and 1431.2 mg kg^{-1} in fruits of *O. heliabravoana*, *O. joconostle* and *O. ficus-indica* in Hidalgo, respectively. This mineral element is an indicator that the xoconostle fruit can be considered food with antioxidant properties (Mendoza-Mendoza *et al*., 2020). According to Prieto-García *et al*. (2016), the K^+ present in the pulp of wild fruits of Tula de Allende (10.95 $cmol_c$ Kg^{-1}) differs from the content reported in the fruits of *O. heliabravoana*, *O. joconostle* and *O. ficus-indica* (223.2, 178.6 and 239.7 mg kg^{-1}, respectively). The K^+ present in xoconostle fruits can be an alternative to prevent cardiovascular problems (Morales *et al*., 2015). According to Monroy-Gutiérrez (2017), the quality parameters related to the mineral elements presented by the xoconostle fruits from the state of Hidalgo can be considered a potential supplement of usable ingredients and used in other food products.

Table 5. Exchangeable ions in mesocarp of xoconostle fruits cultivated and wild of *O. joconostle* cv. Burro and *O. matudae* cv. Cuaresmero from Valle del Mezquital, Hidalgo, Mexico.

Area	Place	Exchangeable ions ($cmol_c$ kg^{-1})			
		Ca^{2+}	Mg^{2+}	Na^+	K^+
		Pulp			
Xoconostles cultivated					
1	Chapantongo	4.74 ± 0.01^d	6.53 ± 0.02^b	6.78 ± 0.25^a	10.21 ± 0.10^b
4	Huichapan	5.82 ± 0.21^b	5.11 ± 0.19^d	6.57 ± 0.20^b	7.48 ± 0.05^d
Xoconostles wild					
2	Chapantongo	6.68 ± 0.22^a	6.14 ± 0.15^c	6.15± 0.15^c	8.97 ± 0.06^c
3	Tula de Allende	5.17 ± 0.03^c	7.03 ± 0.05^a	5.84 ± 0.09^d	10.95 ± 0.14^a

Different literals between rows indicate statistically significant differences (Tukey $P \leq 0.05$). Data were expressed as the mean ± standard deviation.

Conclusion

The soils of Chapantongo, Hidalgo with physical and chemical properties classified as pale brown (10YR 6/3), higher porosity, more acidic pH and exchangeable ions, where wild xoconostle plants (*O. joconostle* cv. Burro) grow and develop; the fruits showed increases in the quality parameters in weight of whole fruit and pulp, longitudinal and equatorial diameter, °Brix, pH, ash, fiber, protein, K^+, Na^+, Ca^{2+}, and Mg^{2+}.

The physical and chemical characteristics of the Chapantongo, Tula de Allende and Huichapan soils can influence the quality of the fruits of xoconostle *O. matudae* cv. Cuaresmero and *O. joconostle* cv. Burro wild and cultivated in Hidalgo, Mexico.

Xoconostle fruits can be considered in the diet as a nutraceutical food alternative, in addition to being used as a natural ingredient in food products and by-products.

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