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Influence of different semiarid zones of Hidalgo in wild xoconostle prickly pear morphometry

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Abstract. The transcendence of wild xoconostle prickly pear species -wild or cultivated in semi arid zones- dates to its Mexican origin, historical, gastronomic, cultural and medicinal customs and potentially a product of interest for rural areas due to its demand in regional and international markets. A few studies have been carried out on climate influence and arid conditions on fruit quality and no regulations exist, which allows more competitive advantages in the market. The objective of this study was to know the impact of different characteristics of arid zones, specially on morphometric differentiation in wild xoconostle prickly pear species. The study was performed in three cardinal points, Northeastern, Southern and Western of Mezquital Valley, Hidalgo, Mexico. A total of 1,000 fruits were collected, 25 and 10 per location with four replications. The morphometric variables evaluated were fruit shape and weight, equatorial and longitudinal diameter, shell thickness, areole density, developed seed number, fruit surface color uniformity, juiciness and pulp color. Three main xoconostle variants were found geographically and identified according to the region. In the northeast, *Opuntia matudae* (cv. Blanco) predominates in spherical prickly pear shape; in the West, a greater *O. matudae* (cv. Cuaresmeño) abundance is observed with predominant characteristics from elongated to ovoid shapes; in the South, more predominant *O. joconostle* (burrona type) is observed with a typical elliptical fruit shape. The morphometric characteristics in fruit showed significant differences among sites ($P \leq 0.01$); *O. joconostle* had higher values in quantitative variables, unlike *O. matudae* Blanco and Cuaresmeño. The semi-arid zone impact in Valle del Mezquital have influenced the morphometric characterization of wild xoconostle prickly pear species.

Keywords: *nutraceutical, crude fiber, calcium; characterization.*

Introduction

Mexico is known worldwide for its great cactus diversity practically throughout the national territory with a more widespread distribution towards the northwestern national territory, particularly in the Northern (Chihuahua, Durango, Coahuila) and Western (Sonora, Baja California and Baja California Sur), where arid conditions are typical of Chihuahua and Sonora deserts (CONABIO, 2009; SEMARNAT, 2016). The genus *Opuntia* is the most representative cacti, possibly the most recognized icon of national identity and considered one of the most important forest resources because it is closely linked to culture and culinary traditions of the region (Tenorio-Escandón *et al*., 2022; Venado-Campos *et al*., 2017). Thus, some species or morphometric variants are highly valued as ornamentals, especially those species considered exotic that have a high demand in the local informal market (Tel-Zur, 2013; Novoa *et al*., 2017; Senanayaka *et al*., 2024).

On the other hand, cacti are crucial for maintaining aridity indices at a sustainable degree and where the most notable influence is ecological balance avoiding soil degradation and positively impacting around 43.5 million hectares (Shackleton *et al*., 2017; Stavi, 2022; Rodríguez-González *et al*., 2024). In addition, cacti are some of the most diversified wild and/or cultivable resources with a diversity of uses, from industrial, pharmaceutical and cosmetic (Prisa, 2022), flavoring preparation, and as a bioactive compound source (Melgar *et al*., 2017; Monroy-Gutiérrez *et al*., 2017; Arias-Rico *et al*., 2020). Also, is used in regional food preparation (Dávila-Hernández *et al*., 2019), as source of xanthine-type pigments (Hernández-Fuentes *et al*., 2015), antioxidants and organic acids (López-Martínez *et al*., 2015; Garcia-Saavedra *et al*., 2019) and highly valued traditional medicine (Cortez-García *et al*., 2015; Melgar *et al*., 2017). In this context, xoconostle is an important forest resource that may become a new paradigm in food and industry with an excellent projection in local and international markets (Corrales-Garcia *et al*., 2007; Álvarez-Castro *et al*., 2014; Mazri, 2021; Monteiro *et al*., 2023; Coquiero *et al*., 2024).

The xoconostles (nochtli = tuna, xoco/sour) or acid prickly pear have very particular characteristics because it is considered an endemic plant of Mexico and constitutes one of the phytogenetic resources with a great distribution worldwide (Montiel *et al*., 2012; Gallegos-Vázquez *et al*., 2011; Santos-Díaz *et al*., 2017; Valadez-Moctezuma *et al*., 2018). In Mexico, approximately 80 cactus species have been described, which is one of the main assemblages of native desert plants (Hernández and Gomez-Hinostrosa, 2005). According to SIAP (2020), the production of xoconostle and sweet prickly pear in Mexico was more than 427,000 tons in 2020, that is, an increase of 0.7% compared to the previous year (SADER, 2021). The main countries to which cactus products are exported is estimated around 17,000 tons, whose main exporters are the United States of America (USA) and Canada followed by Germany, Japan, the United Kingdom, the United Arab Emirates (UAE) and China (Díaz-Sánchez *et al*., 2024). In Mexico, the local market is important, and *Opuntia* diversification is broad, although its distribution, use and diversification are greater in the Central region of Mexico. The states of Guerrero, Puebla, Oaxaca, Veracruz, Querétaro, Hidalgo, Morelos, Tlaxcala and the State of Mexico are the ones that have registered an increase in the most cultivated area and the per capita consumption in these States is highest (Scheinvar *et al*., 2011; Paiva *et al*., 2016).

Mexico is the center of origin of numerous Opuntia species, where a great diversity of species and varieties can be found. However, the greatest diversity is found in the semi-arid Altiplano of Mexico where the Central States of Mexico converge (Hidalgo, Estado de México, Guerrero, Puebla and Oaxaca) (Garcia-Saavedra *et al*., 2019). The most predominant species with positive commercial expectations are *Opuntia matudae* Scheinvar, *O. lasiacantha* Forster and *Opuntia joconostle* F.C.A. Weber ex Diguet. Although xoconostle is present throughout Mexico, its geographic distribution, abundance and use remain limited by multiple factors, mainly climatic and edaphic elements

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(Gutiérrez-Rojas *et al*., 2022). Moreover, the interactions between factors that limit the geographical distribution are complex and multivariate; however, the understanding of the correlation between these factors should necessarily be understood by region. For example, studies carried out using MaxEnt modeling with four species of cactus in the Chihuahua Desert indicated that the highest correlation between distribution was with rain and temperature, rather than with soil conditions (Cortes *et al*., 2014). The optimal soil for the development of xoconostle plants is soils of igneous or calcareous origin, with low moisture content, pH of 6.5 to 9.5, sandy loam or sandy-clay texture, with good drainage and permeability (Pimienta, 1990; Flores and Olvera, 1994). Nevertheless, Scheinvar and Sule (2010) found that the distribution is highly correlated with soil structure and texture, relief, and botanical diversity (of cacti and other species). For example, texture, minerals and organic matter can influence and promote asexual reproduction due to the regrowth of axillary buds and the diversification of other xerophytic plants can influence dispersion due to seed mobilization by migratory birds (Bregman, 1988; Huynh, 2023).

On the other hand, the climatic and soil conditions can be a limiting factor in recollecting or producing xoconostle fruit, whose demand for fresh fruit has increased in Mexican territory and with an excellent projection for export, mainly to the USA, Canada and eventually, to some European and Asian countries (SIAP, 2015). Particularly, regional markets appreciate some characteristics, such as fruit acidity typical of the varieties *O. matudae* (c.v. Blanco, Rosa) and *O. joconostle* (Gutiérrez-Rojas *et al*., 2022). However, external markets demand a higher percentage of industrialized products or fresh prickly pears with quality conditions considering shape, homogeneous coloration, size (≥ 5cm), good fleshiness with a lower number of seeds, thinner shell (DOF, 2006). However, despite the demand for these morphometric characteristics, no specific records have been found in national or international official standards that establish quality parameters to promote their trade, whether for consumption (local or export), gourmet food, metabolite market or industrial use.

In this context, the factors that influence the quality of the xoconostle fruits should be understood, particularly those related to climate and soil. In other words, monitoring should be standardized by region, sampling and collection techniques, and thus be able to make a more appropriate interpretation of the data and how the environment influences quality of the fruit. Therefore, the objective of this study was to know the impact of different characteristics of arid zones, especially on morphometric differentiation in wild xoconostle prickly pear species.

Material and Methods

Study site

The study area was Mezquital Valley (20° 27′ 10″ N and 99° 14′ 57″ W) in the state of Hidalgo, Mexico, where the valley conditions have been historically associated with wild xoconostle abundance and diversity. The valley borders are the north with Sierra of Juárez, the south with El Mexe mountain, the east with Sierra of Actopan and the west with Sierra of Xinthé. The environmental conditions of the region are typical of arid zones, some regions with ecological niches with lower temperatures typical of a sub-humid climate with the presence of atypical frosts and irregular rainfall. The Valley has seasonal cultivation areas, with preference for sandy soils for planting beans and maize. Occasionally, caliche (limestone) and saline soils have been found and to a lesser extent, other types of soils as rendzina, planosol, leptosol, vertisol and phaeozem (INAFED, 2010; INEGI, 2017). The soil profile is superficial and thin, no more than 30 cm, where flora diversity is forests of stone pine, yucca, mesquite,

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chaparral, agave and cactus (INEGI, 2016). According to this classification, the criterion was taken to divide the study area by the cardinal points; south, west and northeast.

Recognition of xoconostle around the selected areas

These native species proliferate naturally in the semi-arid zones of lake origin in the region of Mezquital Valley, Hidalgo. The xoconostle fruits were collected at the point of maturity of wild Opuntia; then, the selected fruits were classified into three main categories depending on visual appearance, based on the color, shape and size of the fruit. The differentiation of the fruit was assigned according to the literature and popular knowledge as white xoconostle, ash prickly pear (tuna ceniza/ash) and xoconostle "tuna de burro" (donkey prickly pear). The selected species are plants in production that are eventually collected due to the demand in local, national and international markets. The selected species were productive plants that had eventually been collected in previous harvest years. The sample and collection were performed according to the methodology of Scheinvar and Gallegos (2011).

Collection of biological material

The sampling was carried out during 2020, 2021 and 2022. The harvesting was performed at the point of maturity (six months, pink coloration) in three cardinal points of Mezquital Valley. The selection was made randomly using the quadrant method (15 ×15 m) (Gutiérrez-Rojas *et al*., 2022). Four replications of 10 fruits per replication were carried out in 25 locations with 1,000 experimental units in 27 municipalities of the northeast, including Nicolás Flores, Ixmiquilpan, Cardonal, Progreso de Obregón, Santiago de Anaya, San Salvador, Actopan, Francisco I. Madero, Ajacuba, San Agustín Tlaxiaca, and El Arenal. The western region included the municipalities of Tecozautla, Huichapan, Nopala of Villagrán, Tasquillo, Alfajayucan, Chapantongo, Tepetitlán, and Chilcuautla. The southern region included the municipalities of Tula of Allende, Tepejí del Río of Ocampo, Tezontepec of Aldama, Mixquiahuala of Juárez, Tlahuelipan, Tlaxcoapan, Tetepango, Atotonilco of Tula, and Atitalaquia. The surveys and samplings were carried out from April to November with 65% of the collection in the months of July and September and were performed mainly in grazing areas, edges, hills, agricultural and backyard areas. The geographic coordinates were taken with GPS Garmin Etrex 20X® (USA). The fruits were collected from the upper stratum according to the cardinal points considering color homogeneity and uniformity in size (Martínez-Soto *et al*., 2012). The samples were labeled and stored at 4 ºC until the analysis in the laboratory.

Morphometric variables

The samples were analyzed according to the graphic manual varietal description of nopal tunero and xoconostle (Gallegos-Vázquez *et al*., 2005) and to the morphometric and physicochemical characteristics (Núñez-Gastélum, 2018; Gutiérrez-Rojas *et al*., 2022). The morphometric characterization of the fruits was evaluated according to Kharrassi *et al*. (2016), taking account the equatorial diameter (ED), longitudinal diameter (LD) and fruit shell thickness (FST). The visual inspections were carried out to determine areole density (AD), number of seeds per fruit (NS), fruit weight (FW) and fruit shape (FS), color uniformity of pulp and juiciness (Kharrassi *et al*., 2016). The measurements of ED, LD and FST were made using a vernier (Mitutoyo Absolute Digimatic Caliper®, Mitutoyo Corporation, Japan) and a vernier (Mitutoyo® America Corporation). The fruit weight was determined using an analytical balance (Citizen®, Bombay, India. Citizen Scale India Pvt. Ltd.).

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Statistical analysis

The data were analyzed using the Journal of Mathematical Physics statistical package (JMP V8 program). The results were expressed as the mean ± standard deviation. The normal distribution of the study variables was determined with Shapiro-Wilk test (Flores and Flores, 2021).

Results and discussion

The shape, color and juice of xoconostle in the edaphoclimatic conditions of the Mezquital Valley, Hidalgo, Mexico

The shape, color and juiciness indices showed differences between cardinal points where edaphic and climatic factors influence fruit quality in terms of palatability and the market expectations. The juiciness indices were found more marked in the northeastern region, mainly in the towns of Ixmiquilpan, Actopan, Ajacuba, and Tlaxiaca. In the western region high indices were also found and mostly in the municipalities of Tecozautla, Huichapan, Nopala de Villagrán, Tasquillo and Tepetitlán. The yellow-fleshed xoconostle was found more distributed in the southern region in the municipalities of Tula of Allende, Tezontepec of Aldama, Mixquiahuala of Juárez, Tlaxcoapan, Tetepango, Atotonilco of Tula and Atitalaquia (Table 1).

Table 1. The shape, color and juiciness of the pulp of xoconostle fruit from Mezquital Valley, Hidalgo, Mexico.

Cardinal points	Coloration[1]			Juiciness		Fruit shape		
	Y	P	G	High	Medium	Ovoid	Elliptical	Circular
	%			%		%		
Northeastern	8	2	40	50	0	0	0	92
Western	12	0	38	44	6	98	0	0
Southern	34	1	15	0	50	0	94	0

[1] Estimation valued on visual scales, depending on coloration, where Y = yellowish, P = pinkish and G = greenish.

The soil of Mezquital Valley corresponds to that reported in the arid regions of Hidalgo, where the edaphic conditions are typical of those that prevail in the central plateau scrubland ecoregions. The edaphic characteristics prevalent in the study areas are neutral pH, slightly alkaline and with high percentages of cation exchange capacity, such as permeable soils that favor fruit harvesting and semi-domestication for good production with minimal management and maintenance pruning (Pérez-García *et al*., 2012).

The geographic conditions found in the study areas are valleys and plains with defined hills and small mountainous areas, together with altitude (1800 to 2400 M.A.S.L.) and average temperatures of 16 °C with predominantly dry climate type BS1kw (w) (i') with an average annual rainfall of 800 mm corresponding to that reported by INEGI (2021). The characteristics are important factors that favor dispersion or adaptation of other varieties with good production rates (Ruiz-Juarez *et al*., 2023).

On the other hand, high fruit proliferation has been reported with igneous or calcareous soils like those of the region, where natural depressions and the likelihood of the valley origin with sandy-clay textures and good drainage and permeability can favor natural proliferation of fruit in wild plants (Scheinvar *et al*., 2009).

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Botanical typification and abundance of xoconostle

The Mezquital Valley ecosystem, xoconostles showed different morphometric characteristics corresponding to the three prevalent species in the region, *Opuntia matudae* Scheinvar*, O. matudae* and *O. joconostle* Weber, which were the most common varieties, white xoconostle (*O. matudae* cv Blanco), ash xoconostle (*O. matudae* cv cuaresmeño) and xoconostle burro (*O. joconostle*). The figure 1 shows the differences of xoconostle variants in the region, where white xoconostle have a well-defined characteristic from 1.5 to 2 m in height, round dull green cladodes, flowers white/pinkish and globose whitish fruits, while the variant Cuaresmeño appears with shrubbier and shorter appearance (1-1.5 m) with a more ash coloration (bluish-green cladodes). Likewise, the color of the spines (whiter) and more purple areoles was more evident.

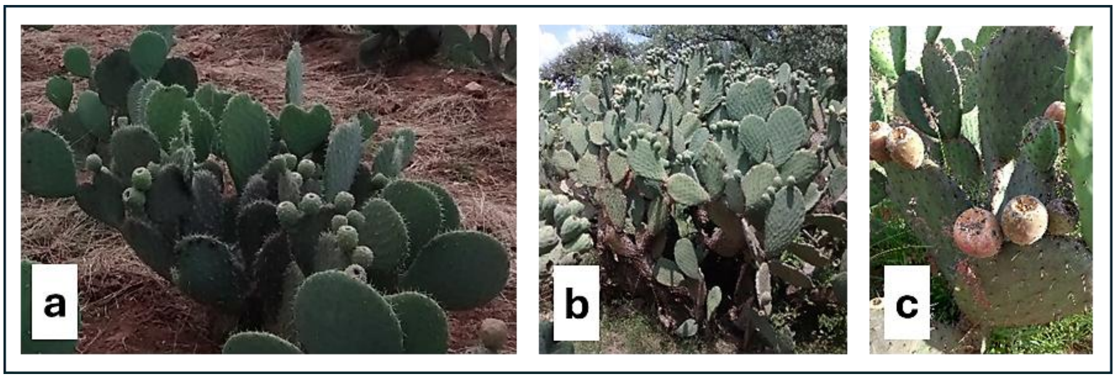

Figure 1. Xoconostle variants in different arid zones of Mezquital Valley, Hidalgo, Mexico showing differences in size, color and shape. (**a**) *Opuntia matudae* cv Cuaresmeño; (**b**) *O*. *matudae* cv Blanco and (**c**) *O. joconostle*. The disposition of the prickly pears and bushier appearance in *O. matudae* are observed.

A high fruit proliferation has been reported with igneous or calcareous soils like those of the region, where natural depressions and the likelihood of the valley origin with sandy-clay textures and good drainage and permeability can favor natural proliferation of fruit in wild plants (Srivastava *et al*., 2021). In general, a differentiation in the morphometric characteristics of the xoconostles was found in the present study because of the climate and soil type in each of the regions. Additionally, a differentiation of the same conditions was found in fruit quality in terms of pulp diameter and fruit size, besides the differences recorded for each species in the regions (Ruiz-Juarez *et al*., 2023).

Conversely, the environment in these regions proliferates the *Asparagaceae* family with a greater dispersion of the *Agavoideae* subfamilies, which include agaves (*Agave salmiana*), yuccas (*Yucca queretaroensis* Piña) and cacti of the genus *Pachicereus.* The most predominant cacti in Mezquital Valley are the genus *Opunti*a sp., which have adapted to the harsh changes in the environment, soil, and water which make up an important part of the region's forest resources, besides being part of the rural landscape and predominate in all the localities in study (Medellin-Leal and Gomez-Gonzalez, 1979; Magallán-Hernández *et al*., 2014; Villaseñor *et al*., 2022).

Moreover, a differentiation of reliefs in the studied regions was observed with a higher percentage (67%) of soil conformation in hills, banks and plains, same conditions that favor mass production for self-consumption and most of it for the local market (SCFI, 2006). The results in the present study coincide with those reported for these regions, recording that the areas of the greatest production are

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designed for national and international trade, where these products were observed to be particularly highly valued in the national market (Scheinvar *et al*., 2009; SIAP, 2018). In addition, it is important to mention that due to the diversity and wide distribution, numerous common and colloquial names for the species are known, whose local names depend on the region where the most common references are nopal, cacomistle, trimpanilla, tuna blanca, xoconoxtli, joconostle chambray, xoconostle burro, chihuanosta (CONABIO, 2020).

The variants of xoconostles are widely dispersed; they were found delimited by conditions such as surface soil, presence of hills and environmental conditions corresponding its geographical distribution through the transverse neo volcanic belt, which includes several States in the center of Mexico where Hidalgo is located (Figure 2).

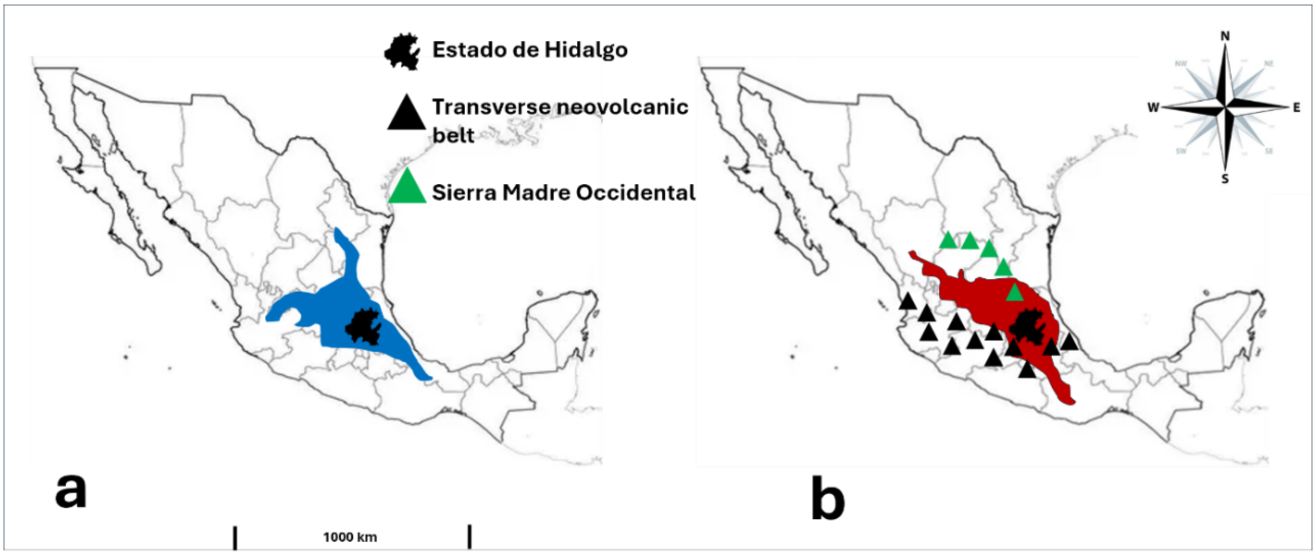

Figure 2. The geographic distribution of predominant species of prickly pear cacti (*Opuntia* spp.) in the Mezquital Valley, Hidalgo, Mexico. The distribution of *Opuntia joconostle* is seen in blue (a) and *Opuntia matudae* is represented in red (b). The triangles represent the distribution of both species across the transverse neo volcanic belt and part of the Sierra Madre Occidental, which covers several States of the central plateau of Mexico.

The results in the present study coincide with that reported in the region, studying that Opuntia distribution and diversification is delimited by geographical, edaphic and climatic factors, where the average size of the adult plants was from 2 to 2.5 m, with the presence of 20 cm, stalks, yellow flowers and eventually mature xoconostles (Scheinvar and Gallegos, 2011).

Morphometric xoconostle variables

Significant differences were observed in the morphometric values of the xoconostles in all cardinal points. The highest values of equatorial (ED) and longitudinal (LD) diameter and fruit shell thickness (FST) were found in *O. joconostle* (LD = 60 mm, ED = 50 mm, EC = 70 mm) while cv. Blanco showed the lowest values (DC = 25 mm) in FST in shell thickness (Figures 3 & 4).

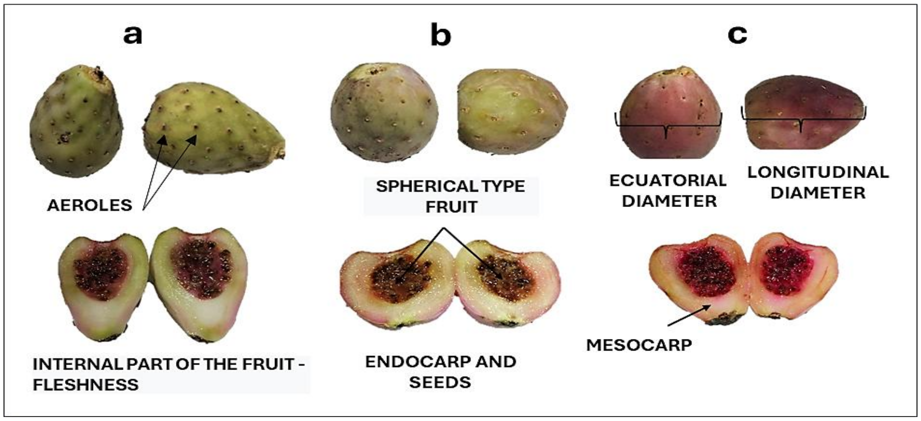

Figure 3. The morphometric characteristics in xoconostle fruit in Mezquital Valley, Hidalgo, México. (a) *Opuntia matudae* cv. Cuaresmeño has an elongated shape with a greater number of areoles; (b) *O. matudae* cv. Blanco tends to have more spherical shape and less roughness; (c) *O. joconostle* is observed more elliptical and with a greater coloration, tending to purple in its maturation and more reddish endocarp.

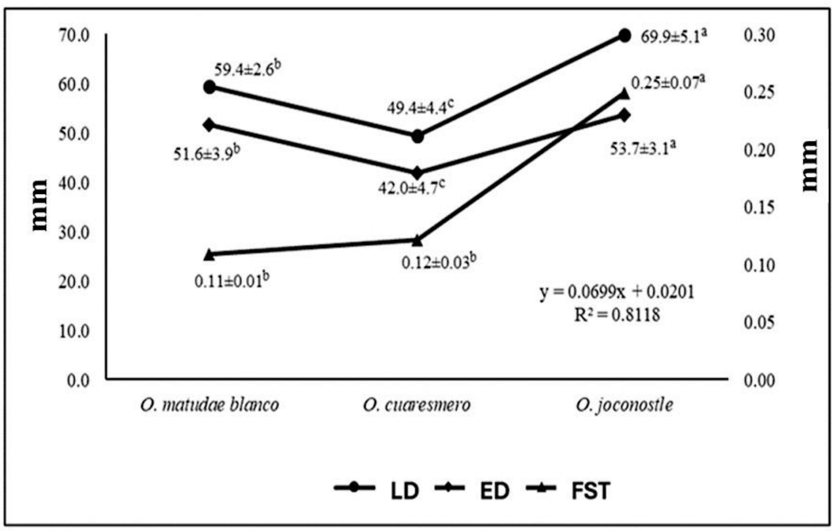

Figure 4. The morphometric variables comparison in xoconostle fruit *Opuntia matudae* cv Cuaresmeño, *O. matudae* cv Blanco and *O. joconostle* burro in Mezquital Valley, Hidalgo, México. A larger size is observed in *O. joconostle*, expressed in longitudinal (LD) and equatorial (ED) diameter.

The flowers were bright yellow with red spots, which changed to pink and red over time, while the fruits were purplish green with pink pulp and ellipsoid to pyriform in shape. According to Scheinvar *et al*. (2009) and the tradition of the locals, this variant is also known as xoconostle cenizo (ash prickly pear). *Opuntia joconostle* (Fig. 1c) is a shrubby plant that reaches up to 2.5 m in height; its branching is compact and leafy, an erect and cylindrical trunk is 20 cm wide and grayish in color, very similar to the common prickly pear but with a sour flavor. This species (*O. joconostle*) is the most used xoconostle by residents, while *O. matudae* cv Blanco are little marketed. Despite its smaller size (52-60 mm), the white xoconostle could have some advantage in the market compared to the other variants, due to lower thickness (±0.1cm) of its shell (Gutiérrez-Rojas *et al*., 2022). The wild fruits (cv. Blanco) have been reported up to 77.8 mm in diameter in the region (Pinedo *et al*., 2014a). Gallegos-Vázquez *et al.*

(2014b) found the maximum value in the same species of 55.7 mm in DL in Zacatecas. This point can be very important, because the differences between longitudinal and equatorial diameter may imply some advantages in the market, where consumers may prefer colorful, large (≥5 cm), smooth and rounded fruits.

In addition to genetic characteristics, morphometric differences of cladodes, flowers and xoconostle fruit can be influenced by external factors, such as soil texture and structure, relief, soil quality (organic matter and minerals) (Luna-Valadez *et al*., 2016). For example, in brown-gray sandy loam soils with little organic matter (≤ 2%) and acidic pH 5-6.7, fruit weight may range from 60 g in wild plants to 94.3 g in cultivated plants (Gutiérrez-Rojas *et al*., 2018; Gutiérrez-Rojas *et al*., 2022). The climate and soil conditions have been documented to have a positive effect on metabolite production and substances used in industry, such as antioxidants, tinctures, perfumery essences, antimicrobial compounds, giving it an important advantage in the market (Agostini-Costa, 2022). In Mexico, the pulp and peel are the most used structures in food transformation such as jelly, jams, sweet or salty pickled fruits, fresh water, sauce, wines, marmalade, vinegar and medications used in alternative medicine (Guzmán-Maldonado *et al*., 2010).

The morphometric variables studied here confirm that fruit shape quality indices, equatorial diameter, longitudinal diameter, shell thickness, weight, developed seed number, fruit surface color uniformity, juiciness and xoconostle pulp color are important attributes required by the local, regional and international market for xoconostle fruit mobilization. These distinctive fruit characteristics of Mezquital Valley, Hidalgo are preferred in comparison to wild fruits from other States of Mexico, such as the Mexico State, Puebla, Querétaro, San Luis Potosí and Zacatecas. *Opuntia joconostle* fruit showed higher values in size although with a thicker shell – a characteristic that could imply a certain disadvantage in preference of local and national markets. Nevertheless, it could also mean a longer shelf life and greater ease in export (Figure 5).

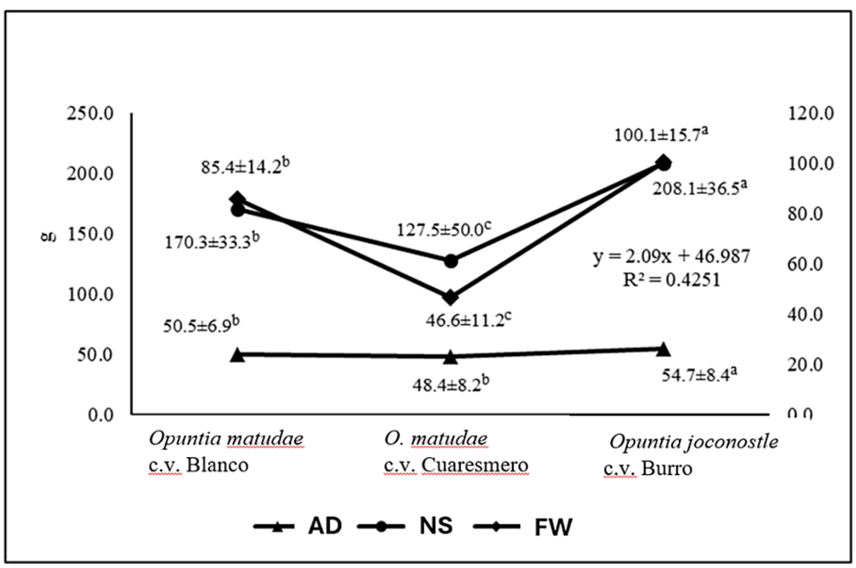

Figure 5. The morphometric variables in xoconostle fruit in Mezquital Valley, Hidalgo, Mexico. A lower number of seeds (NS) is observed in *Opuntia matudae* cv. Cuaresmeño, a characteristic that makes it desirable in the local market. The highest fruit weight (FW) was observed in *O. jonostle* burro. No differences were observed in areole density (AD).

This is the first study with morphometric data recorded to establish the relationship between the influence of external factors specific to the region and xoconostle quality standards. The geographic distribution and morphometric characteristics of *O. matudae* (c.v. Blanco and Cuaresmeño) and *O. joconostle* correspond to those previously recorded in regions surrounding Mezquital Valley, Hidalgo (Scheinvar *et al.,* 2009; Espinoza *et al,* 2013; Gallegos-Vazquez *et al.,* 2014a; Martínez-Gonzalez *et al.,* 2015; Gutiérrez-Rojas *et al.,* 2022).

Conclusions

Three main xoconostle variants were found geographically and identified according to the region. In the northeast, *Opuntia matudae* (cv. Blanco) predominates in spherical prickly pear shape. In the western, a greater *O. matudae* (cv. Cuaresmeño) abundance is observed with predominant characteristics from elongated to ovoid shapes. In the south, the more predominant *O. joconostle* (burro type) is observed with a typical elliptical fruit shape. *Opuntia joconostle* had higher values in quantitative variables, unlike of *O. matudae* Blanco and Cuaresmeño. The xoconostles are one of the most important genetic resources in the country with deep cultural and nutritional roots and great potential that it could have in the industry. This situation implies knowledge, validation and evaluation of morphometry and knowing how climatic and edaphic factors influence wild or cultivated production in Mezquital Valley to explore the agronomic potential of this important natural resource and improve living conditions of marginalized communities of Mexico and other arid areas of the world.

ETHICS STATEMENT

Not applicable

CONSENT FOR PUBLICATION

The author warrants that their contribution is original and has not been published before.

COMPETING INTEREST

The authors declare that they have no competing interests

AVAILABILITY OF SUPPORTING DATA

Not applicable

AUTHOR CONTRIBUTION

Conceptualization, D.R-J. Methodology, D.R-J., M.G-R. Validation, J.O-G. Formal analysis, RP.E-O. Research, WG.C-C. Resources, RJ.H-P. Visualization, D.R-J. Literature review, M.G-R. Supervision, D.R-J. Review of the final version and approval of the manuscript before sending it, D.R-J., M.G-R., J.O-G., RP.E-O., WG.C-C., RJ.H-P.

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