REVISTA BIO CIENCIAS
http://revistabiociencias.uan.edu.mx
https://doi.org/10.15741/revbio.12.e1793
ISSN 2007-3380

Artículo original / Original article

Morphological characterization of fig trees collected in the Region Lagunera

Caracterización morfológica de higueras colectadas en la Región Lagunera

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Please cite this article as/Como citar este artículo: Urrieta Velázquez J. A., Macías Rodríguez H., Andrade Hoyos P. (2025). Morphological characterization of fig trees collected in the Region Lagunera. *Revista Bio Ciencias*, 12, e1793. https://doi.org/10.15741/revbio.12.e1793

Article Info/Información del artículo
Received/Recibido: October 14th 2024.
Accepted/Aceptado: May 21th 2025.
Available on line/Publicado: June 19th 2025.

ABSTRACT

One of the strategies to address climate change is the use of adapted genotypes, such as local fig germplasm, which exhibits morphological and physiological traits that reduce water consumption and enhance adaptation to hot and arid climates, additionally, it possesses nutraceutical properties desirable for the international market. Hence, this study aimed to characterize fig tree collections at the morphological level and assess certain biophysical indicators of their adaptation to the regional climate. In the initial nursery phase, cuttings were collected from fig trees aged 25-40 years in the Lagunera Region. After 90 days in the nursery, foliar characterization was conducted by separating qualitative and quantitative leaf variables, which were analyzed through clustering and ANOVA, respectively. This analysis revealed three distinct groups in both qualitative and quantitative traits, highlighting significant biodiversity in morphological characteristics. Notably, the properties of latex, stomata, and trichomes stood out as key environmental protection mechanisms. Based on this analysis, it was determined that fig trees in the Lagunera Region exhibit biodiversity and long-term adaptation, possessing morphological biological mechanisms that enable them to tolerate the region's hot and arid climate.

KEY WORDS: *Ficus carica*, germplasm, morphology.

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ISSN 2007-3380

R E S U M E N

Una de las vías para enfrentar el cambio climático es el uso de genotipos adaptados como el germoplasma local de higuera, el cual posee características morfológicas y fisiológicas que le permiten reducir su consumo de agua y adaptarse a climas cálidos y áridos, además tiene propiedades nutracéuticas deseables para el mercado internacional. Así, el objetivo de esta investigación fue caracterizar colectas de higuera a nivel morfológico y medir algunos indicadores biofísicos de su adaptación al clima regional. En una primera fase de vivero, se colectaron varetas en la Región Lagunera de higueras de 25-40 años de crecimiento. Después de 90 días en vivero, se hizo la caracterizaron a nivel foliar separando variables cualitativas y cuantitativas de la hoja, las cuales fueron analizadas mediante agrupamiento y anova respectivamente. Con ello pudieron observarse tres grupos tanto en caracteres cualitativos como en los cuantitativos, habiendo una biodiversidad importante en las características morfológicas, resaltando las propiedades del látex, estomas y tricomas como mecanismos de protección al ambiente. Con base en éste análisis fue posible determinar que existe biodiversidad de higueras en la Región Lagunera con varios años de adaptación, las cuales poseen mecanismos biológicos a nivel morfológico que les permiten tolerar el clima local cálido y árido.

P A L A B R A S C L A V E : *Ficus carica*, germoplasma, morfología.

Introduction

The fig tree is one of the oldest cultivated fruit species in the world, and since ancient times, various civilizations have leveraged the nutraceutical properties of its fruits (Çalişkan & Polat, 2011). In recent years, the quantification and study of these properties have increased its demand (Mawa *et al*., 2013; Zhang *et al*., 2018). Native to the Middle East, the fig tree was introduced to Mexico in 1683 by Franciscan missionaries. It is particularly attractive for regions with limited water availability, as its water requirements are lower compared to those of other fruit trees (Muñoz *et al*., 2017). This characteristic makes it a valuable option for addressing climate change as a long-term strategy, as well as for the sustainable production of food to meet the short-term demand for this fruit in export markets (Pacheco & Arenas, 2017). In 2023, Mexico harvested over 12,000 tons of this highly valued fruit, with the state of Morelos leading production due to its warm and favorable climate, followed by Baja California Sur, Veracruz, Sonora, and Puebla (SIAP-SADER, 2025). The fig tree's low water demand is attributed to its leaf morphology, stomatal biology, and physiological traits, which regulate transpiration and photosynthesis (Males & Griffiths, 2017; Liu *et al*., 2019). Studies have reported that it possesses sunken stomata with a frequency of 68.90 ±

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6.24 stomata·mm^2 and a length of 33.35 ± 2.84 μm (Klimko & Truchan, 2006), which are protected by large trichomes and a thick cuticle (Sosnovsky, 2015). Additionally, its leaf parenchyma cells contain amorphous calcium carbonate (cystoliths) and calcium oxalate deposits, which serve as a source of carbon and nutrients while also providing protection against radiation (Pierantoni *et al*., 2018). Given these adaptations, it is essential to document and characterize local fig germplasm suited to such conditions. In Mexico, research efforts have been made to improve fig production, focusing on topics such as genetic material characterization (García-Ruíz *et al*., 2013), fertilization strategies (Garza-Alonso *et al*., 2019; Márquez *et al*., 2019; Mendoza-Castillo *et al*., 2019), and protected systems for intensive production (Mendoza-Castillo *et al*., 2017). However, there is still a need to enhance the production chain for this species, as various fig-producing regions across the country have unique environmental conditions and specific requirements that must be addressed. One such example is northern Mexico, characterized by low precipitation levels (CONAGUA, 2018), particularly in the Lagunera Region, where high temperatures are recorded in spring and summer, with a monthly average of 28.8 °C and peak temperatures reaching up to 44 °C (Servicio Meteorológico Nacional, 2022). These climatic conditions, along with the region's solar radiation, favor fig cultivation. However, low winter temperatures pose a challenge, as freezing conditions can threaten production. In light of these factors, this study aimed to characterize fig tree collections from the Lagunera Region and assess key biophysical indicators of their adaptation.

Material and Methods

In the initial experimental phase, germplasm was collected from the municipalities of Rodeo and Gómez Palacio in Durango, as well as Parras in Coahuila. Cuttings measuring 30 cm in length (with 6-8 internodes) and a mid-section diameter of 1.0-1.5 cm were selected from backyard fig trees (mother trees) at the locations listed in Table 1. Vegetative material from the commercial variety Black Mission was obtained from a commercial orchard in the municipality of Rodeo, Durango. At the time of collection, all cuttings were transported and stored at room temperature in plastic bags until transplantation. Additionally, the skin color of the fruits from the mother fig trees was recorded.

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Table 1. Fig trees collected in the Laguna Region.

Local name	Code	Place	Age (years)	Coordinates	Altitude masl*
Higo Negro grande de Parras	HNGP	Parras, Coahuila	45	25° 26' 44" N 102° 11' 02" W	1530
Higo Blanco Grande de Parras	HBGP	Parras, Coahuila	45	25° 26' 44" N 102° 11' 02" W	1530
Rodeo Higo Negro	RHN	Ejido amoles, Rodeo, Durango	48	25° 07' 54" N 104° 26' 46" W	1320
Casa Acuña Parras	CAP	Parras, Coahuila	47	25° 26' 44" N 102° 11' 02" W	1530
Higo Negro Gómez	HNG	Ejido 5 de mayo, Gómez Palacio	40	25° 34' 45" N 103° 28' 17" W	1129
Higo Pasa Parras	HPP	Parras, Coahuila	43	25° 26' 44" N 102° 11' 02" W	1530
Monigal de Parras	MP	Parras, Coahuila	46	25° 26' 44" N 102° 11' 02" W	1530
Black Mission	BM	Ejido Amoles, Rodeo, Durango	30	25° 07' 54" LN 104° 26' 46" LW	1320

*meters above sea level.
Source: Own elaboration based on field data.

The cuttings were planted in transparent bags (20 × 40 × 10 cm) filled with a substrate mixture of sand and perlite (80:20, v:v) under protected conditions (chapel-type greenhouse with lateral ventilation) in March 2020. Both the cuttings and the substrate were disinfected with food-grade hydrogen peroxide (59 %), applying 3 mL·L^{-1} by immersion and 1 mL·L^{-1} as a drench. A randomized complete block experimental design with three replications was used, with the Black Mission (BM) variety serving as the control. Once rooting began, a rooting stimulant (1 g·L^{-1} of Raizal 400®)was applied, followed by weekly applications of a complex fertilizer (12-43-12) with micronutrients (1 g·L^{-1}).

Three months after transplantation, variables related to gas exchange were measured, including latex density, protein content, amino acids, and carbohydrates in latex, as well as stomatal frequency, length, and width. Latex density (weight/volume) was determined by collecting a known volume aliquot from the axil and petiole of a recently matured leaf using a micropipette (20-100 μL) and weighing it on an analytical balance (resolution 0.0001 g). At this same stage, stress-related compounds were quantified: protein content (Bradford method), amino acids (Ninhydrin assay), and sugars (Anthrone method), following the methodology described by Nigam (2007). Stomatal frequency, length, and width were determined by making leaf impressions with cyanoacrylate glue (Kola Loka® dropper) on both the adaxial and abaxial surfaces of the central lobe's midsection. A small drop of glue was applied, then pressed with a glass slide to create a thin film (approximately

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90 seconds for the adaxial surface and 120 seconds for the abaxial surface). The impressions were observed under a 10X microscope (Zeiss Scope.A1), and images were captured using a digital microscope camera (Velab® VE-MC3, 3.2 µm X 3.2 µm) with a known scale of 500 µm. The images were analyzed using UTHSCSA ImageTool 3.0 for Windows XP (Wilcox *et al*., 2002) to measure stomatal length along the polar axis and width along the equatorial axis. Stomatal frequency was determined by averaging counts from eight images, considering two fields of known area as determined by the software.

Additionally, leaf length and width, petiole length, and plant vigor expressed as dry matter weight of roots, stems, and leaves, were quantified. Leaf length was measured along the main vein from the base to the apex, while width was measured at the midpoint. Dry matter content was determined by separately drying each organ to a constant weight at 75 °C, with total dry matter calculated as the sum of all components. Leaf characterization and fruit color (from mother plants) were assessed based on fig descriptors (IPGRI & CIHEAM, 2003) as qualitative variables.

In the second phase of the experiment, crop temperature was measured using a portable infrared thermometer (Fluke 62 Mini, 630–670 nm, Class II) on the edges of recently matured leaves exposed to solar radiation. Simultaneously, air temperature and relative humidity were recorded using a thermo-hygrometer (TER-150, -50-90 °C, 10-99 % RH), while radiation was measured with a lux meter (Steren HER-410, scale X1, X10, X100), expressed in $\mu mol \cdot m^{-2} \cdot s^{-1}$ using the X100 scale and multiplying by 0.185, following the methodology of Niechayev *et al*. (2019). Additionally, different trichome types were observed on the adaxial and abaxial surfaces of selected samples and classified according to the descriptions by Ogunkule & Oladele (2008) for fig trees.

Qualitative variable analysis was performed using cluster analysis with Ward's method, while quantitative variables were analyzed using Euclidean distances with R software version 4.1.0 (The R foundation for Statistical Computing Platform, 2021). The analysis was conducted using the ggplot (DendroCL) package and the library(factoextra) and library(dendextend) functions. Furthermore, variance analysis (ANOVA) and mean grouping tests were conducted for latex density, stomatal length, stomatal width, and stomatal density using SAS/STAT V9.3 for Windows (SAS Institute Inc., 2002–2010).

Results and Discussion

The leaf characteristics observed in the collected samples, according to fig descriptors, showed differences in the number and shape of lobes, leaf color, and petiole color (Table 2). Regarding the fruit, the skin color recorded at the time of collection was also a distinguishing variable. The analysis of these qualitative variables revealed significant biological diversity among the samples from the Región Lagunera, indicating a clear differentiation between collections from the Parras region, which formed two distinct groups: MP, HPP, and HNGP, characterized by having 3-5 lobes, a cordate leaf base, and spatulate lobes. HBGP, which had the highest number of lobes (7), a calcarate leaf base, and linear lobes. An exception was CAP, which clustered with samples

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from Rodeo (RHN), Gómez Palacio (HNG), and Black Mission, forming a third group (Figure 1a), distinguished by having 5 lyrate lobes and a calcarate leaf base. Leaf morphology (number of lobes, lobe shape, and leaf base shape), along with size, are species-specific traits that have developed since the fig's origin and have been maintained in the warm, arid climate of the Región Lagunera. Therefore, these materials hold agronomic potential for propagation, diversification, and conservation of the crop in the region, as these traits have developed over years of adaptation, similar to observations in other parts of the world (Podgornik et al., 2010;Almajali *et al*., 2012; Baziar *et al*., 2018; El Oualkadi & Hajjaj, 2019; Podgornik *et al*., 2010).

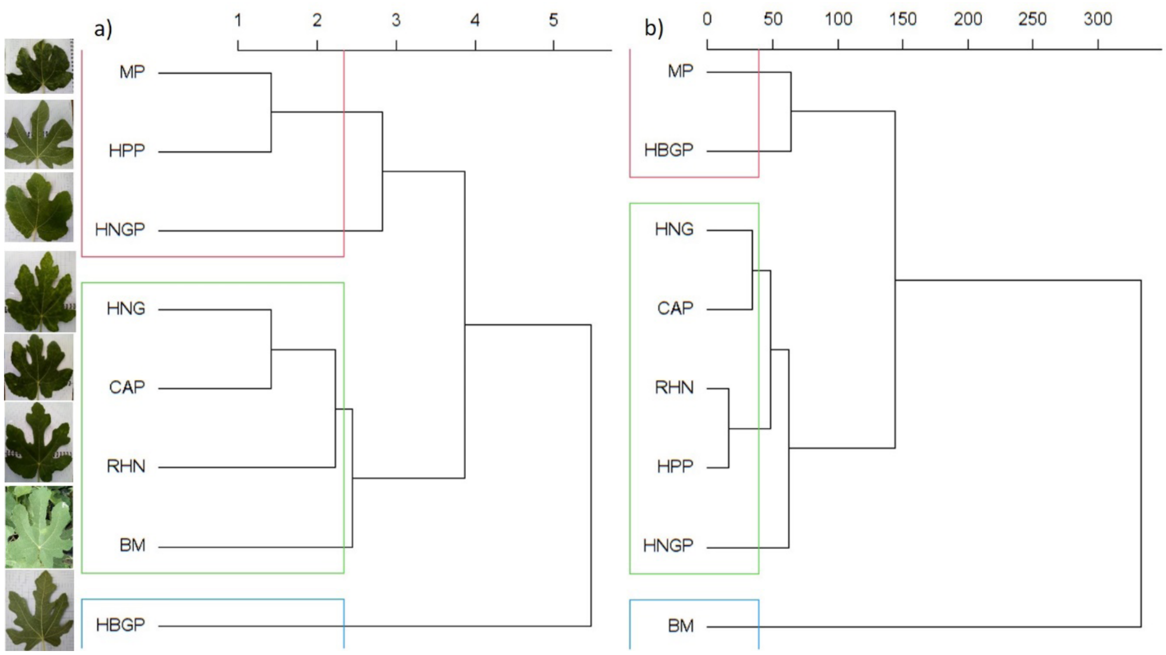

Figure 1. Grouping of qualitative (a) and quantitative (b) morphological characters of fig collections in the Laguna Region. (MP: monigal de Parras; HPP: higo pasa Parras; HNGP: higo negro grande de Parras; HNG: higo negro Gómez; CAP: casa Acuña Parras; RHN: Rodeo higo Negro; BM: black mission; HBGP: higo blanco grande de Parras).

Source: Own elaboration based on field data.

Table 2. Qualitative morphological characteristics of fig trees collected in the Laguna Region.

Code	Qualitative variables							
	NL*	TH**	PH†	LO‡	LBS‖	LC††	PC‡‡	FSCⁱ
MP[1]	5	Medium	Average	Spatulate	Cordate	Green	Light green	Purple
HBGP[2]	7	Small	Bad	Linear	Calcarate	Dark green	Light green	Light green
HNG[3]	5	Medium	Average	Lyre-shaped	Calcarate	Green	Light brown	Black
RHN[4]	5	Large	Average	Linear	Calcarate	Dark green	Light brown	Black
HNGP[5]	3	Small	Good	Linear	Calcarate	Dark green	Light green	Purple
CAP[6]	5	Medium	Bad	Lyre-shaped	Calcarate	Green	Light brown	Black
HPP[7]	5	Medium	Good	Spatulate	Cordate	Green	Light green	Black
BM[8]	5	Large	Average	Lyre-shaped	Calcarate	Green	Light green	Black

[1]: Monigal de Parras; [2]: Higo Blanco Grande de Parras; [3]: Higo Negro Gómez; [4]: Rodeo Higo Negro; [5]: Higo Negro Grande de Parras; [6]: Casa Acuña Parras; [7]: Higo Pasa Parras; [8]: Black Mission; *: Number of lobes; **: Leaf size; †: Plant health; ‡: Lobe outline; ‖: Leaf base shape; ††: Leaf color; ‡‡: Petiole color; ⁱ: Fruit skin color.
Source: Own elaboration based on field data.

In the analysis of quantitative morphological traits (Table 3), the collected samples also formed three distinct groups, with those from Parras separating into two subgroups: 1) MP and HBGP, 2) CAP, HPP, HNGP, RHN, and HNG, 3) BM, which was isolated into a third group, as shown in Figure 1b. Part of this diversity in quantitative traits among the samples from Gómez Palacio and Rodeo may be attributed to environmental differences influencing their adaptation. According to historical records of annual precipitation and average monthly temperature (SMN-CONAGUA, 2020), Gómez Palacio has a drier climate (194 mm of annual precipitation) and higher temperatures (Figure 3b) compared to Rodeo (417.3 mm) and Parras (356.3 mm). Additionally, the Región Lagunera exhibits interannual and multiannual fluctuations, with alternating warm periods (Villanueva *et al*., 2010). Moreover, Inzunza-López *et al*. (2011) reported an increase in both maximum and minimum temperatures in the Región Lagunera of 1.46°C and 1.47°C, respectively, over 30 years leading up to the 2000s.

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Tabla 3. Quantitative morphological characteristics and growth of fig trees collected in the Laguna Region.

Code	Quantitative variables										
	LD*	**LL****	**LW*****	**PL†**	**SL††**	**SW‡**	**SD‡‡**	**TDMⁱ**	**LDMⁱⁱ**	**SDMǁ**	**RDMᶦ**
MP[1]	1.29	19.00	16.50	3.00	23.22	14.74	516.63	74.79	23.94	20.27	30.57
HBGP[2]	1.28	17.00	14.50	2.00	24.36	17.39	578.63	62.09	16.65	16.67	28.77
HNG[3]	1.23	19.00	17.00	3.00	26.03	16.48	389.25	74.11	22.88	19.66	31.57
RHN[4]	1.29	24.00	21.00	3.00	25.52	17.92	413.50	94.05	28.87	26.95	38.23
HNGP[5]	1.26	10.00	9.50	2.00	22.79	19.73	442.75	59.55	16.18	16.65	26.72
CAP[6]	1.42	16.00	16.00	3.00	31.80	18.57	363.13	91.81	23.34	25.86	42.61
HPP[7]	1.17	16.00	17.00	3.00	24.10	15.24	421.50	98.41	35.80	30.41	32.20
BM[8]	1.14	15.40	15.60	3.00	14.47	9.78	118.00	21.52	5.080	5.76	10.68

[1]: Monigal de Parras; [2]: Higo Blanco Grande de Parras; [3]: Higo Negro Gómez; [4]: Rodeo Higo Negro; [5]: Higo Negro Grande de Parras; [6]: Casa Acuña Parras; [7]: Higo Pasa Parras; [8]: Black Mission; *: Latex density; **: Leaf length; ***: Leaf width; †: Petiole length; ††: Stomatal length; ‡: Stomatal width; ‡‡: Stomatal density; ⁱ: Total dry matter; ⁱⁱ: Leaf dry matter; ǁ; Stem dry matter; ᶦ: Root dry matter.

Source: Own elaboration based on field data.

Some of the quantitative traits determined (Table 3) contribute to morphological adaptations for water deficit tolerance, as indicated by Ammar *et al*. (2020). The fig tree is reported as a fruit crop with low water requirements compared to other fruit species (Muñoz *et al*., 2017). This is partly because it lacks stomata on the upper leaf surface, as observed in the analyzed fig samples (Figure 2b), a trait previously reported for the species (Mamoucha *et al*., 2015). This adaptation reduces water loss through transpiration; however, it is not sufficient to cool these organs, as leaves exposed to solar radiation follow a temperature pattern similar to that of the surrounding air (Figure 3a). A more detailed study of the cuticle is recommended to better understand this phenomenon.

In addition to their position, the stomata on the underside of the leaf are sunken between prominent veins (Figure 3d), increasing resistance to water loss through transpiration, similar to desert species (Males & Griffiths, 2017). Another mechanism for reducing water loss is the size of trichomes on the abaxial surface, as they cover the stomata, forming another physical barrier to transpiration (Figure 2a). These structures primarily protect against biotic and abiotic stressors, and various types exist in *Ficus* species (Ogunkunle & Oladele, 2008). In this study, glandular trichomes were identified only on the adaxial surface of two collections (HNG and RHN), while the HNGP collection exhibited glandular trichomes on both surfaces (Figure 2c and 2d). Some researchers (Giordano *et al*., 2019) suggest that glandular trichomes generally secrete flavonoids, terpenes, and hydroxycinnamates to protect fig trees from pathogens and herbivory.

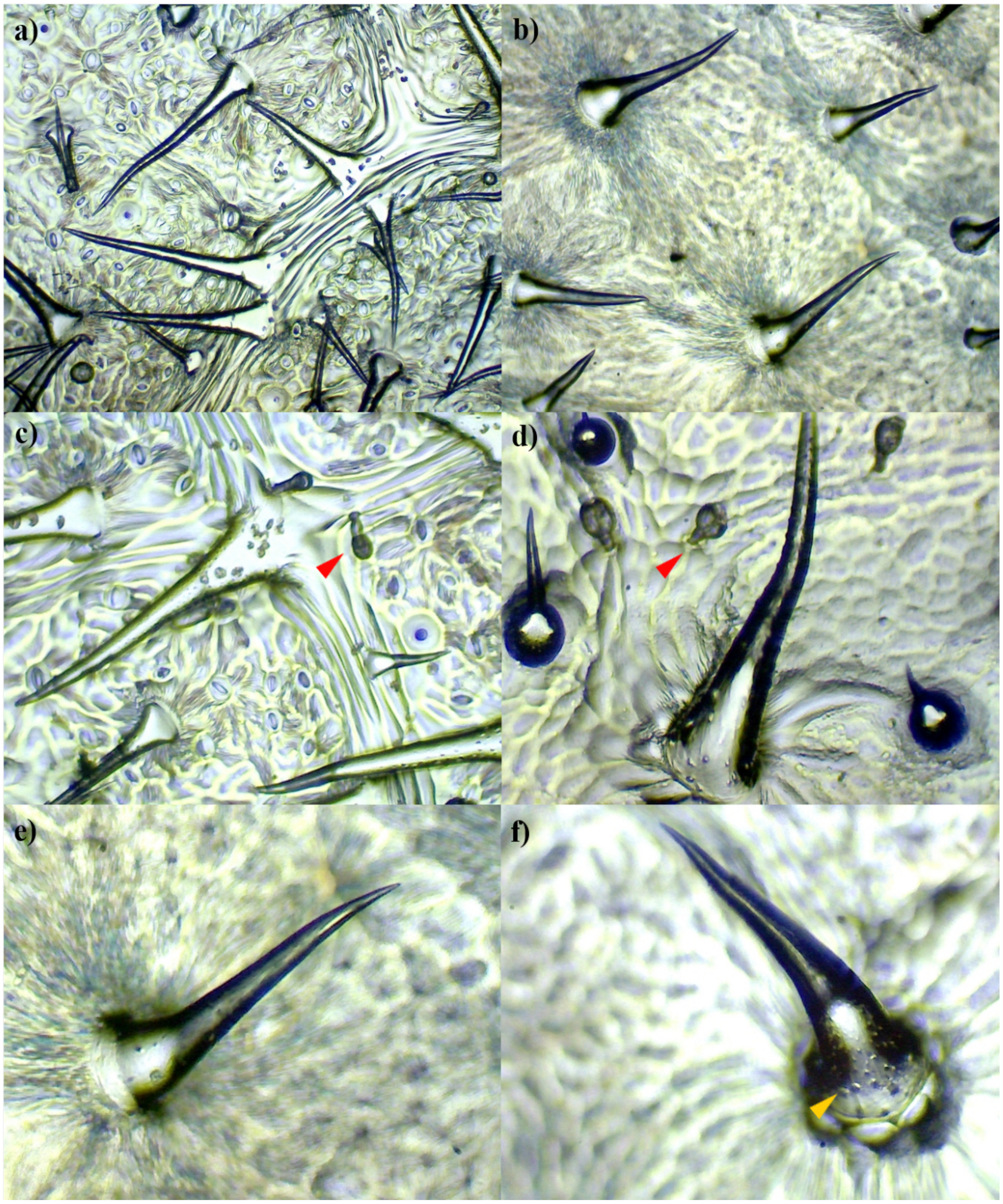

Figure 2. Leaf morphology of fig collections from the Laguna Region: a) underside with trichomes, b) upper side without trichomes, c) glandular trichomes on the underside, d) granular trichomes on the upper side, e) filamentous trichome and f) papillae and accompanying apidermal cells at the base of the filamentous trichomes.

Source: Own elaboration based on field data.

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In filamentous (non-glandular) trichomes, papillae were observed at their base, along with accompanying epidermal cells (Figure 2f, yellow arrow), as reported in other studies on *Ficus carica* L. (Mamoucha *et al*., 2015). These traits are important taxonomically as they illustrate the biological diversity of the analyzed materials, and agronomically, as they serve as indicators of water-use efficiency.

Stomatal frequency, as well as polar and equatorial diameters, vary in fig trees as an adaptation to environmental conditions. High stomatal frequency has been reported in open-field conditions (363 stomata·mm^2) with a larger polar diameter (27.5 µm) than longitudinal diameter (18.2 µm) in the variety 'Roxo de Valinhos' (Fráguas *et al*., 2012). However, in the collections from the Región Lagunera, stomatal frequency was lower, ranging from 58.25 to 121.50 stomata·mm^2 (Table 4). This frequency may decrease further during the adaptation process from nursery to field conditions and could serve as a classification parameter for water-use efficiency in fig collections.

Stomatal length showed highly significant statistical differences (α≤0.0001) among the evaluated collections. The commercial variety BM had the shortest stomata, followed by HBGP, HNGP, HPP, MP, and RHN, which exhibited similar means (Table 4). The HNG collection had the second longest stomata, while CAP had the longest. Stomatal width also showed significant statistical differences (α≤0.0001), with HNGP having the greatest width. Next, CAP, HBGP, HNG, and RHN had similar widths, whereas HPP and MP also shared comparable values. Finally, Black Mission (BM) had the narrowest stomata, approximately 50% smaller than the widest stomata recorded. An inverse relationship was observed between stomatal frequency and size (length and width), as they exhibited a negative correlation (α≤0.0001 and α≤0.0117). This indicates that stomatal frequency decreases as stomatal size increases, as seen in the commercial variety Black Mission (Table 4).

Table 4. Stomatal and latex characterization in fig trees collected in the Laguna Region.

Code	Length	Width	Frequency	LD‡
	µm		Stomata·mm^2	g·mL^{-1}
MP[1]	23.22 [bz]	14.74 [b]	516.50 [ab]	1.42 [a]
HBGP[2]	24.36 [b]	17.39 [ab]	578.71 [a]	1.28 [a]
HNG[3]	26.03 [ab]	16.48 [ab]	389.19 [c]	1.22 [a]
RHN[4]	25.52 [b]	17.93 [ab]	413.51 [bc]	1.25 [a]
HNGP[5]	22.79 [b]	19.73 [a]	442.66 [bc]	1.17 [a]
CAP[6]	31.80 [a]	18.57 [ab]	363.09 [c]	1.29 [a]
HPP[7]	24.10 [b]	15.24 [b]	421.52 [bc]	1.28 [a]
BM[8]	14.47 [c]	9.78 [c]	118.00 [d]	1.14 [a]

†: Latex density. [z]Values in the same column followed by the same letter are statistically equal (α=0.05). [1]: Monigal de Parras; [2]: Higo Blanco Grande de Parras; [3]: Higo Negro Gómez; [4]: Rodeo Higo Negro; [5]: Higo Negro Grande de Parras; [6]: Casa Acuña Parras; [7]: Higo Pasa Parras; [8]: Black Mission.

Source: Own elaboration based on field data.

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Transpiration is the loss of water in the form of vapor through the stomata, helping to maintain stable crop temperatures, reaching a maximum relative to air temperature according to thermometry studies (Ammar *et al*., 2020). This same effect was observed in leaves exposed to solar radiation in the Black Mission variety. However, unlike other species, its leaf temperature follows a pattern similar to that of the air, regardless of solar radiation behavior, as shown in Figures 3a and 3b. The leaf temperature reached 30.68 °C, which was 2-3 °C lower than the ambient temperature (33.3 °C), indicating its low cooling capacity and heat tolerance, pending a more detailed study of its gas exchange. Despite the lack of statistically significant differences in latex density (Table 4), this substance may contribute to heat tolerance in fig trees. As shown in Figure 4c, latex contains protective compounds such as carbohydrates, proteins, and amino acids. Specialized proteins called ficins have been identified in fig trees, with phytoprotective functions (Upadhyay, 2013; Magaña-Álvarez *et al*., 2016) and industrial applications, all reported as thermoprotective (Chaves-Barrantes & Gutiérrez-Soto, 2017a; Martínez-Bastidas *et al*., 2017; Hu *et al*., 2020).

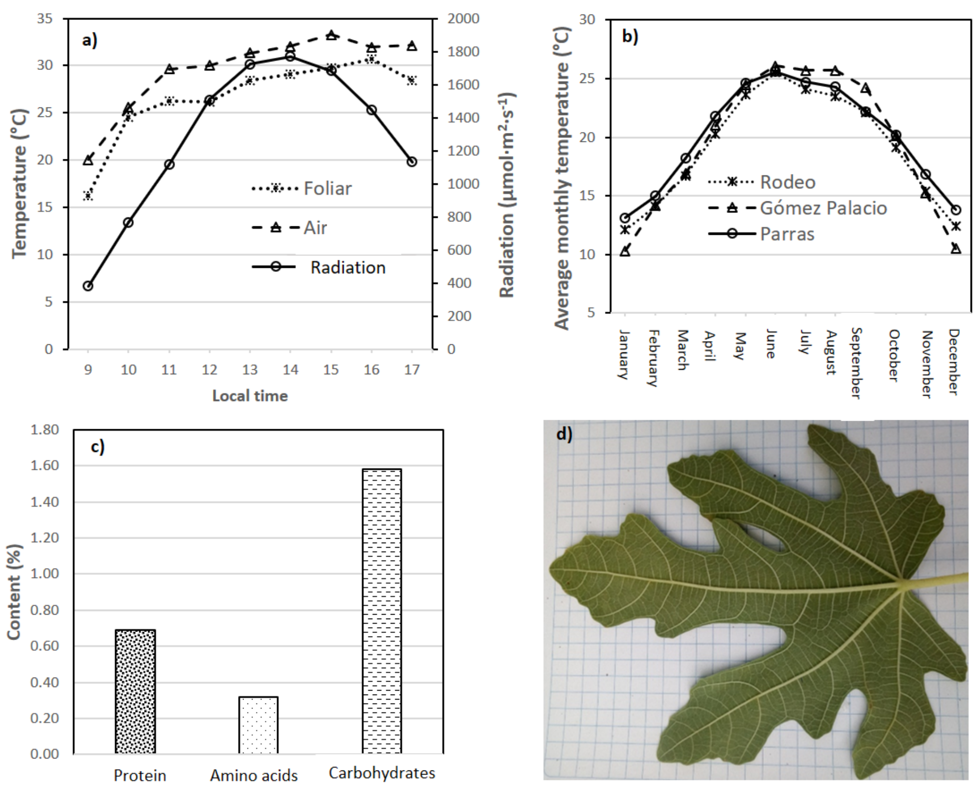

Figure 3. Leaf temperature of the "Black Mission" fig tree (a), average monthly temperature in the Laguna Region (b), latex composition (c), and its veins (d).

Source: Own elaboration based on field data.

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ISSN 2007-3380

Latex contains carbohydrates, proteins, amino acids, and other substances, causing its density to vary (Konno, 2011). However, in this characterization, no statistically significant differences were detected, as indicated in Table 4 (α =0.05). This may be since sampling was conducted on nursery plants under protected conditions. Figure 4c shows that fig tree latex primarily contains carbohydrates, which are rapidly assimilated substances that help meet energy demands in tissues under heat stress (Chaves-Barrantes & Gutiérrez-Soto, 2017b).

Proteins were the second most abundant substance found in fig tree latex. These molecules can specialize in protecting plants from high temperatures, such as heat shock proteins, which stabilize cell membranes (Urano & Jones, 2014). It has been observed that ficins (fig-specific proteins) in latex have thermal stability between 40 and 70 °C, which partially explains their ability to tolerate high temperatures (Gagaoua *et al*., 2014). Finally, amino acids were found in smaller amounts, some of which are produced in response to specific stressors and act as osmolytes or play a role in protein synthesis to tolerate water and heat stress (Mardinata *et al*., 2021).

The Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO, 2025), through its climate change and biodiversity explorer, projects increases in maximum temperature for the periods 2015-2039, 2045-2069, and 2075-2099, with values approaching 40 °C for the Región Lagunera. Considering additional variables such as precipitation and soil characteristics, Martínez-Macías et al. (2022) predict a scenario ranging from unfavorable to moderately favorable for fig cultivation in northern Mexico. Nevertheless, it is crucial to consider the biological characteristics of this species, which allow it to tolerate some of the climatic conditions projected for the coming years. Significant morphological variations in stomatal size, frequency, position, and trichome presence are specific traits developed by each collection within their respective microclimates. These traits could be harnessed for the sustainable production of figs in certain regions of northern Mexico, where water resources are limited and temperatures are rising. In conjunction with the properties of their latex, these figs may be capable of withstanding the climatic conditions projected for the years ahead.

Conclusions

The morphological analysis of the fig trees collected from the Region Lagunera showed significant differences in both qualitative and quantitative traits, highlighting the biological diversity at the local level. The fig trees were grouped into three categories based on their qualitative traits such as lobe shape, number of lobes, leaf base shape, petiole color, and leaf size: 1) MP, HPP, and HNGP, 2) CAP, RHN, and HNG, similar to the “Black Mission” variety (BM, control), and 3) HBGP. In terms of quantitative traits such as stomatal size, stomatal frequency, petiole length, biomass, and leaf length and width, three groups were also observed: 1) HBGP and MP, 2) CAP, HPP, HNGP, RHN, and HNG, and 3) BM.

The qualitative and quantitative characteristics analyzed in the fig trees, such as latex content, trichomes, stomatal size, frequency, and position, are related to tolerance to the regional warm climate and also serve as barriers to prevent water loss through transpiration. It was recorded that the crop is capable of tolerating temperatures above 30 °C in the leaf tissue, making these characteristics of the local fig trees a germplasm with agronomic potential for northern Mexico.

Author contributions

Work conceptualization, UVJA.1, RMH.2.; development of the methodology, UVJA.1, RMH. 2.; experimental validation, UVJA.1, RMH.2.; analysis of results, UVJA.1, RMH.2., AHP.3.; data management, UVJA.1.; writing and preparation of the manuscript, UVJA.1, AHP.3.; writing, reviewing, and editing, UVJA.1.; acquisition of funding, RMH.2.

All authors of this manuscript have read and agreed to the published version.

Funding

This research was funded by the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), project number 14164035164.

Ethics declarations

The project was reviewed by the CENIDA-RASPA and INIFAP collegiate group prior to its competition for fiscal resources from the same Institute. The project was finally executed, and the field log is available.

Acknowledgments

To the Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias support of the project, and to researchers Dr. Julián Cerano Paredes, Dr. Juan Estrada Ávalos, and Ms.C Vicenta Constante García for providing equipment for this research in the laboratory and field.

Conflict of interest

The authors declare no conflict of interest.

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