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Edaphological and Morphometric Analysis of wild populations of common bean (*Phaseolus vulgaris* L.) in Durango, México

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Abstract

Knowledge of wild populations of common bean (*Phaseolus vulgari*s L.) and their relationship with soil quality is essential for biodiversity conservation and crop improvement. The identification of soils with high contents of nutrients such as calcium, magnesium, potassium and other trace elements can be key to the development of bean varieties more resistant to adverse conditions. In this sense, the objective was to establish the integrated diagnosis of nutrients in soils where some wild forms of common bean grow in the State of Durango and correlate it with the morphometric characteristics of pods and seeds. Soil samples were collected in five municipalities of the State of Durango (El Mezquital, Súchil, Nombre de Dios, Canatlán and Nuevo Ideal), a sample was taken from a depth of 20 cm, evaluating the amounts of organic matter, Ca, Mg, K, P, S, Zn, Cu, Fe, Mn. There is great variability in the soil samples where wild forms of common bean grow, with the municipality of Canatlán having the highest content of beneficial elements for plants. In terms of the morphometric analysis of pods and seeds, those from Nombre de Dios and El Mezquital were the longest, widest and thickest. Variations in morphological characteristics in relation to soil quality could allow strategies for the recovery and improvement of genetic resources in a context of climate change and food security.

Keywords: Soil nutrients, Morphometric variability, X-ray fluorescence, wild *Phaseolus* species.

Introduction

Wild species represent a genetic resource that can be used as a source of variability to improve the quality of current cultivars. Their adaptive characteristics, such as resistance to adverse conditions like extreme temperatures, droughts, and insect attacks, are crucial for plant development and the quality of harvested seed (Anđelković *et al.*, 2020; Arroyo-Peña *et al.*, 2015); In addition, its potential to improve the nutritional quality of domesticated variants has been recognized. (Salgotra *et al.*, 2021). This potential benefit justifies the need for detailed studies to support the use of wild beans and their vast genetic diversity, thereby allowing for the definition and evaluation of the stability of their phenological, morphological, physiological, biochemical, and biophysical characteristics in relation to agronomic, culinary, and nutritional quality. (Tomlekova, 2012).

In the area of soil analysis, near-infrared spectroscopy (NIRS) has proven highly effective in simultaneously analyzing various physical, chemical, and biological properties of soil. This method is utilized in the wavelength range of 400 to 2500 nm (600–4000 cm^{-1}) and allows for the estimation of properties such as total carbon, nitrogen, cation exchange capacity (CEC), as well as the presence of calcium,

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magnesium, and other elements that are fundamental to understanding soil health and productivity (Shin *et al.*, 2025; Mukherjee & Laskar, 2019; Nocita et al., 2015).

On the other hand, X-ray fluorescence (XRF) is an analytical technique for determining the elemental composition of various materials, including soils (Jenkins *et al.*, 2024). In recent years, the XRF has many pedological, environmental and agronomic applications, mainly after the appearance of portable equipment (pXRF) (Jenkins *et al.*, 2024). This technique has been recently adopted and used successfully for the characterization of soils throughout the world, especially in soils of developing countries. The characterization of the soil includes the complete determination of the elemental composition (nutrients, trace elements and rare earths) and allows estimation of some physical and chemical properties of the soil (Hart & Siebecker, 2024). The objective of this study was to analyze the morphological variations of the pods and seeds of wild forms of common bean in relation to soil quality.

Materials and methods

Study area, soil samples and processing

The soils where the wild common bean grows, as well as pods, were collected in six locations, these localities are representative of the southern, central and northern areas of the state in Durango, Mexico, from september to november of 2020, during the rainy season (June-august) months in which the species flourishes. Around one kilogram of soil and between 50-100 pods were collected in each location. Table 1 shows the geographic data of the collection sites. Seeds for each wild form were deposited in the CIIDIR herbarium, which were taxonomically identified.

The soils in Durango, Mexico, exhibit diverse characteristics influenced by various environmental factors and land use practices (Table 2). The predominant soil type in Durango, Mexico, specifically in the characterized watershed, is regosol. This soil type is associated with the dry scrubland land use in the area, which features average slopes of 7.8 %. (Hurtado *et al.*, 2013)

Soil analysis

Samples of 1000 g of soil were collected from each location at a depth of 20 cm. For the analysis, two samples from the same site were grouped together. The samples from each site were combined and stored in plastic bags until analysis. The soil parameters analyzed were: silica (Si), aluminum (Al), iron (Fe), potassium (K), calcium (Ca), strontium (Sr), magnesium (Mg), titanium (Ti), manganese (Mn), zinc (Zn), sodium (Na), phosphorus (P), sulfur (S), rubidium (Rb), barium (Ba), zirconium (Zr), arsenic (As), molybdenum (Mo), copper (Cu), and chlorine (Cl), as well as chromium (Cr).

Collected soils were air-dried, homogenized, and sieved for standard lab analysis (Figure 1). The size distribution of the soil particles will be reduced, with the pipette method (Remillard, 2022). The samples were prepared for the method, Identity test of the main bands. The analysis of the samples was obtained, according to the parameters indicated: Sample: solid, Gas used: He, Analysis time: 7 min, Type of analysis: complete analysis.

Morphometric data *in situ*

Data collection in situ was conducted on seven plants per population, recording three trifoliates per plant, resulting in a total of 21 trifoliates per population. Regarding reproductive structures (pods and seeds), a total of 100 pods and 100 seeds were recorded per population. The dimensions of the leaves, pods, and seeds were measured using a digital caliper (Surtek, 0-150 mm; model 122200). The weight of the seeds was determined using an analytical balance (Velab, model Ve204, with a maximum capacity of 220 g and a minimum of 0.1 g, with a precision of 0.0001 g).

Fourier Transform Spectroscopy

The samples were analyzed by Fourier transform infrared spectroscopy with attenuated total reflection (FTIR-ATR), using an FTIR spectrometer (Vertex 70, Bruker) in the Attenuated Total Reflectance (ATR) mode to obtain information on functional groups and chemical structures

Table 1. Origin and geographic coordinates of the sites of origin of the bean populations used in the soil analysis.

Municipality	Latitude N*	Longitude O*	Altitude (m)	Temperature Max/Min °C**	Precipitation (mm)**
El Mezquital	23° 26´ 48.1´´	104° 21´ 49.5´´	1400	42.1/-0.2	391.8
Súchil 1	23° 39´ 24.7´´	104° 02´ 20.9´´	1963	35.7/-6.4	511.0
Súchil 2	23° 39´ 02.4´´	104° 02´ 26.7´´	1964	35.7/-6.4	511.0
Nombre de Dios	24° 04´ 71´´	104° 14´ 23´´	1877	36.7/-3.5	446.6
Canatlán	24° 51´ 03.4´´	104° 51´ 44.8´´	2039	35.1/-7.3	525.6
Nuevo Ideal	24° 45´ 11.9´´	105° 00´ 05.6´´	2037	36.2/-5.0	692.5

* The data were taken with coordinates WGS84

** Data obtained from CONAGUA, average for the year 2018.

Table 2. Soil type according to the book Vegetation and Ecoregions of Durango (Elizondo *et al.*, 2007).

Municipality	Soil type	Characteristics	Region	References
El Mezquital	Leptosol	The soil has low content of organic matter and nutrients, which can be influenced by local factors such as parent material and vegetation.	Dry or tempered climates	Warren, 2022; Kimeklis et al., 2021
Canatlán				
Súchil 1	Regosol	They have a low organic matter and nutrient content, making them less suitable for agriculture without improvements.	Hillslopes and regions with volcanic activity	Pedron et al., 2024
Súchil 2				
Nombre de Dios	Kastañozem	These soils show a high mobility of chemical elements (CHEs) such as Ca, Mn and K, which are weakly bound by acid-soluble compounds.	Semiarid	Kimeklis et al., 2021
Nuevo Ideal	Pheoezem	These soils usually have a favorable texture that supports agricultural productivity, making them suitable for various crops.	Tempered	Hu et al., 2021

Edaphological information taken from INEGI 2020.

Figure 1. Soil types where wild common bean populations grow (*Phaseolus vulgaris*).

present in the samples. Signal processing, peak fitting, surface fitting, statistics and signal processing were analyzed using Origin software. The spectra were recorded between 4,000 and 600 cm^{-1}, the instrument has a spectral resolution of 4 cm^{-1}. The samples were stored in paper bags and transported to the laboratory for further analysis. Table 1 shows the geographic information of the localities to which the wild common bean samples belong. The samples did not require any preparation procedure for analysis in the infrared spectrum, they were only ground in a mortar and placed on the surface of the ATR glass.

Spectral treatment

Once the FTIR spectra (raw spectra) were obtained, a standardized normal random variable (SNV) normalization was applied using the Unscrambler X version program 10.3 (CAMO Software AS). Subsequently, the calculation of the second derivative of each spectrum was performed using the algorithm Savitzky-Golay, which applies a successive fit of adjacent subsets of data points with a low polynomial degree by least squares to the linear approximation.

Data analysis

Morphometric data were subjected to analysis of variance ($P \leq 0.05$) and the means were compared with Fisher's test, using XLSTAT 2021.2.1 (Addinsoft, 2025). To evaluate the contribution of each attribute (in each type of data) to the differentiation between wild common bean populations, matrices were constructed and subjected to principal component analysis (PCA) using Past 3.0, while to establish the similarity between the wild common, the same matrices were analyzed, they were submitted to the clustering analysis, using Past 3.0 (Hammer *et al.*, 2001)

Results and discussion

Physicochemical properties of the soil.

The results of the physicochemical analysis of the soil of each collection site are shown in Table 3. Significant variations were found between populations. The soils had low concentrations of P and Na, but high in K, Si and Al. Regarding to Mg, the soil belonging to the municipality of Canatlán had a higher relevant level than the rest of the evaluated soils.

The analyzes show that the soil where the wild form of Canatlán grows is the one with the most beneficial elements (Si, Al, Ca, Mg, K, P, S, Zn, Cu, Fe, Mn) for optimal plant growth. and the one with the fewest elements is the soil of the municipality of El Mezquital (Table 3).

The soils of Durango exhibit significant variability in organic matter content and nutrient levels, influenced by local factors such as vegetation and parental material. Research indicates that different soil types, including leptosols, luvisols, and vertisols, show distinct characteristics in organic carbon storage and nutrient availability (Kimeklis *et al.*, 2021; Kalinichenko *et al.*, 2019).

The soils with the highest amount of organic matter were those of Súchil (Regosol) and Nombre de Dios (Kastañozem), and those with less organic matter El Mezquital and Canatlán (Leptosols). Arsenic (As) was found in the evaluated soil of Nuevo Ideal, although in somewhat high concentrations (0.0162%) and low in the evaluated soil of Súchil (0.0136%). Generally, the soils where the wild forms of common bean grow tend to be of low fertility (Beaver *et al.*, 2021; Romanyà & Casals, 2020).

According to Yang *et al.* (2024) guide for germplasm regeneration, the content of exchangeable bases (Ca, Mg and K) largely defines the degree of the soil fertility. Fertility soils are distinguished by their high Ca and Mg content. Of the soils evaluated, Súchil had the highest percentage of Ca (6.58%), while the highest Mg content was found in Canatlán (1.59%). Very acidic soils generally have low Ca and Mg content, as was found in the soils evaluated: Nuevo Ideal had the lowest Ca content (1.92%), while El Mezquital had the lowest Mg content (0.359%).

In our results the soil evaluated in Nombre de Dios, presents the highest percentage in P (0.388%), compared to the rest of the soils evaluated. Phosphate is an element of great importance in plant nutrition and frequently presents limitations in soil fertility (Kaur *et al.*, 2017). Very acid soils such as red Acrisols, and soils of volcanic origin such as Andosols, have a high P fixation capacity that further decreases its availability for plants (Alakeh *et al.*, 2022).

Morphometry of reproductive structures

The comparison between the morphometric attributes of the pods in situ among the five wild common beans ana-

Table 3. Elements found in the soil expressed as a percentage (%)

Parameter	El Mezquital	Súchil 1	Súchil 2	Nombre de Dios	Canatlán	Nuevo Ideal
Si	54.00 ± 1.55 b	59.50 ± 0.56 a	62.5 ± 2.89 a	44 ± 0.21 c	62.00 ± 0.21 a	52.00 ± 0.77 b
Al	15.00 ± 1.27 b	12.05 ± 0.49 c	10.6 ± 0.63 c	17.95 ± 0.91 a	11.95 ± 0.92 c	16.45 ± 0.63 ab
Fe	13.80 ± 0.98 b	7.75 ± 0.74 c	7.63 ± 0.65 c	24.78 ± 0.55 a	8.50 ± 0.56 c	13.20 ± 0.14 b
K	8.63 ± 0.79 c	9.86 ± 0.61 b	10.72 ± 0.11 a	2.38 ± 0.41 d	9.57 ± 0.41 b	6.44 ± 0.29 c
Ca	3.17 ± 1.06 c	6.38 ± 0.28 a	4.32 ± 0.21 bc	5.81 ± 0.01 ab	3.65 ± 0.01 c	7.62 ± 0.41 a
Sr	0.05 ± 0.043 bc	0.04 ± 0.005 b	0.004 ± 0.004 c	0.05 ± 0.01 bc	0.07 ± 0.01 b	0.27 ± 0.03 a
Mg	1.26 ± 0.13 b	0.57 ± 0.09 cd	0.45 ± 0.03 d	0.85 ± 0.14 c	1.69 ± 0.14 a	1.62 ± 0.23 a
Ti	0.84 ± 0.14 c	0.75 ± 0.01 c	0.643 ± 0.15 a	2.18 ± 0.06 a	0.89 ± 0.06 c	1.74 ± 0.32 b
Mn	0.25 ± 0.02 a	0.25 ± 0.01 a	0.25 ± 0.11 a	0.28 ± 0.06 a	0.23 ± 0.06 a	0.23 ± 0.007 a
Zn	0.08 ± 0.003 a	0.05 ± 0.007 b	0.05 ± 0.005 b	0.07 ± 0.004 a	0.05 ± 0.004 b	0.05 ± 0.01 b
Na	1.42 ± 0.21 a	1.29 ± 0.05 ab	1.45 ± 0.13 a	0.41 ± 0.18 d	0.64 ± 0.18 cd	0.97 ± 0.14 bc
P	0.148 ± 0.03 cd	0.26 ± 0.01 a	0.002 ± 0.03 e	0.12 ± 0.01 d	0.19 ± 0.01 bc	0.20 ± 0.006 bc
S	0.15 ± 0.005 bc	0.15 ± 0.03 abc	0.13 ± 0.01 c	0.23 ± 0.06 ab	0.23 ± 0.06 a	0.11 ± 0.02 c
Rb	0.07 ± 0.00 a	0.07 ± 0.002 a	0.08 ± 0.007 a	0.03 ± 0.00 c	0.07 ± 0.00 a	0.05 ± 0.006 c
Ba	0.47 ± 0.05 c	0.32 ± 0.005 cd	0.54 ± 0.02 a	0.14 ± 0.05 b	0.25 ± 0.05 cd	1.11E-16 ± 0.00 c
Zr	0.55 ± 0.03 a	0.16 ± 0.004 b	0.16 ± 0.005 b	0.09 ± 0.006 c	0.13 ± 0.006 b	0.2 ± 0.006 b

*Units in percentages (%). Physicochemical parameters: silicon (Si), aluminum (Al), Iron (Fe), Potassium (K), Calcium (Ca), Strontium (Sr), Magnesium (Mg), Titanium (Ti), Manganese (Mn), Zinc (Zn), Sodium (Na), Phosphorus (P), Sulfur (S), Rubidium (Rb), Barium (Ba), Zirconium (Zr), Arsenic (As), Molybdenum (Mo), Copper (Cu), Chlorine (Cl), Chromium (Cr). Tukey's analysis of means ($P \leq 0.05$), Only in Mn it was not significant with a $P = 0.776$, for the other parameters the difference was significant.

lyzed revealed significant differences in the pod (length, width and thickness) and seed (length, width and thickness) characteristics (Figure 2).

The differences in the types of soil of the places of origin of the wild forms of common bean can be seen in Table 1. In the municipality of Nombre de Dios, the type of soil is Kastañozem (chestnut earth), alkaline soil found in semiarid areas, while the one in the municipality of Canatlán is Leptosol, a very stony soil with a depth of less than 10 cm, which depends sufficient water. The soil of Canatlán has high concentrations of beneficial elements for plants, resulting in seeds with exceptional characteristics.

Different characteristics were observed in the wild forms analyzed. The size of the leaflets coincides with what was reported by Meza-Vázquez *et al.* (2015), Wallander et al., (2022), Morales-Santos et al., (2017) the length ranges from 3.1 cm to 8.5 cm, and the width from 0.5 cm to 6 cm.

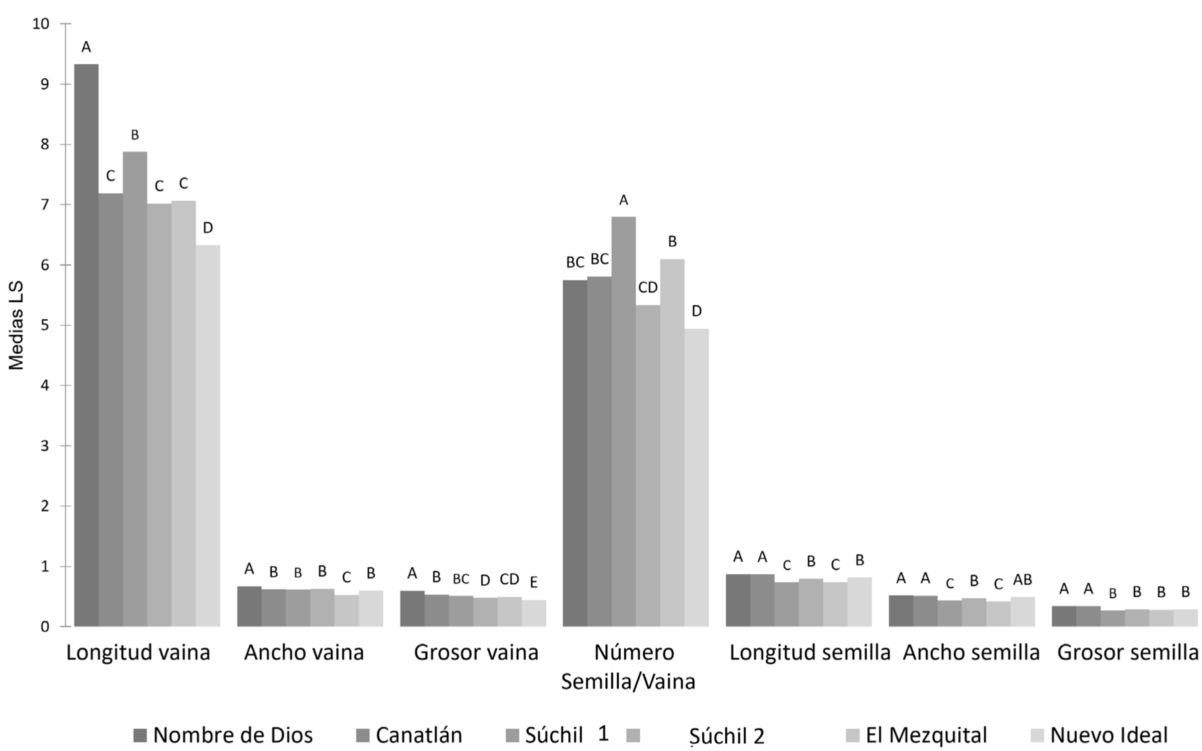
The length of the pods, presented wide variation (Figure 2) which was larger than what was Lépiz & Ramírez (2010) reported, ranging from 1.2 cm to 6.3 cm. There were also differences in the length, width, and thickness of the seeds, which agrees with the results obtained by Freytag & Debouck (2002) and Lépiz *et al.*, (2010). They defined that the morphometry of wild common bean forms is small, ranging from 0.30 to 0.79 cm in length, ranging from 0.30 to 0.54 cm in width.

The morphometry of the trefoils is shown in Figure 3. Previous studies have shown that the central leaflet is larger than the left and right leaflets, which is consistent with our results. The El Mezquital and Súchil populations had the largest clovers, and the Canatlán population, had the smallest clovers. This information is useful, since beans are generally used as livestock fodder.

Analysis of principal components and grouping.

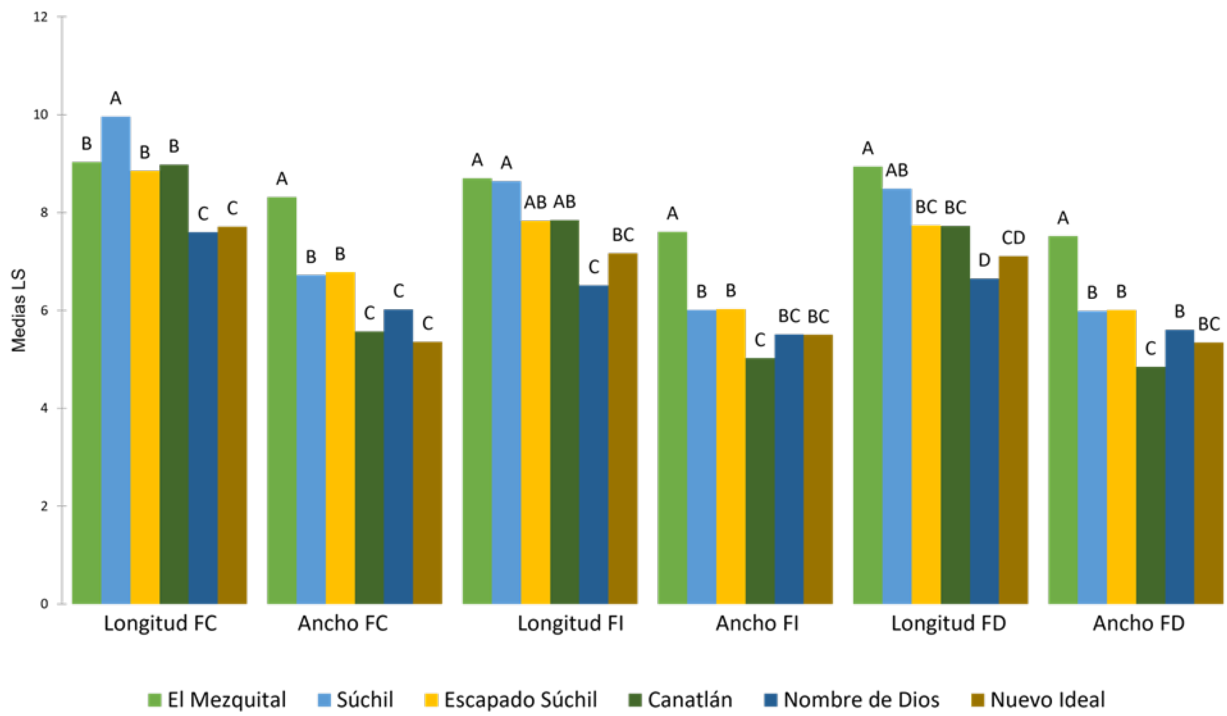
Global chemical variation among the analyzed populations was evaluated using a PCA (Figure 4A). The PCA was then plotted in two dimensions, based on the morphometric characteristics of the pod and seed. The principal components PC1 and PC2 explained 86.80 % of the total variance in the data, (61.32% and 25.48%, respectively).

PC1 grouped the wild forms into two subgroups and PC2 into another group with two subgroups. It can be observed that, within the group, PC1 clearly separated Súchil 1, and Súchil 2 and El Mezquital, in group 2 from PC2 Nombre de Dios, Canatlán and Nuevo Ideal. PC1 was correlated with the morphometric characteristics of the trefoils and the number of seeds, and had a higher discriminative power (4.82). PC2 was correlated with the morphometric characteristics of the pod (length, width and thickness) and seed (length, width and thickness), and had a lower discriminatory power (3.43), while the results of a clustering analysis, based on the same data are shown



Different letters indicate significant differences between populations, Tukey's analysis of means ($P \leq 0.05$).

Figure 2. Morphometric data of pods and seeds of six wild forms of common bean growing *in situ* in Durango.



Different letters indicate significant differences between populations, Tukey's analysis of means ($P \leq 0.05$).

Figure 3. Morphometric data of trefoils, Central Leaf (FC), Left Leaf (FI) and Right Leaf (FD) of six wild forms of common bean growing *in situ* from Durango.

in Figure 4B. These results confirmed the discrimination between the populations of wild forms, showing at the same time a greater similarity between the populations of Súchil 1 and Súchil 2, and Canatlán and Nuevo Ideal, different from the wild forms of El Mezquital and Nombre de Dios.

Correlation between physicochemical and environmental variables.

A Multiple Correspondence Analysis (MCA) test was performed to determine the relationship among these variables.

The CCA showed that the CCA1 and CCA2 axes explained 94.70% of the total variance (Figure 5). CCA1 axis was mainly associated with soil physicochemical parameters. The significantly correlated variables were ($P \leq 0.05$) were Mn ($r = 0.73$), Al ($r = 0.96$), Si ($r = 0.44$) and Fe ($r = 0.11$).

In the grouping analysis, three main groups were observed, according to the correlation of the morphometric variables, separating from the rest of the populations that of Nombre de Dios, having very variable values in the elements found in the soil, high in Si (63.2 %), K (11.7%) Na (1.27%), and low in Al (12.1%), Fe (7.11), Sr (0.0256%), Mg (0.359%), and Mn (0.172%), among others, the related morphometric variables are larger seeds and pods, compared to the rest of the wild forms analyzed. The subgroups formed group those from the same locality, Súchil 1 and 2.

Fourier Transform Spectroscopy

The FTIR spectra for the evaluated soil showed different peaks. Peaks were found in all analyzed soils at 1004 cm^{-1}, 785 cm^{-1}, 694 cm^{-1}, 521 cm^{-1}, 459 cm^{-1}, and 426 cm^{-1} (Figure 6). In the Nombre de Dios and Nuevo Ideal populations, nine peaks were identified, one more than in the rest of the analyzed soils. The spectra were grouped into three categories based on the number and distribution of peaks: Group 1, consisting of Súchil 1, Súchil 2, and Canatlán; Group 2, include Nombre de Dios and Nuevo Ideal; and Group 3, is represented by El Mezquital, whose spectrum exhibits distinct peaks.

Functional groups, found in the samples after extraction are shown in Table 4. The different peaks observed in the soil samples correspond to different molecular vibrations, each of which is characteristic of specific bonds in the molecule. The results indicated that many functional groups were associated.

The band observed at 1632–1621 cm^{-1} can serve as an indicator of water-resistant soil, which relates directly to its wettability (Margenot et al., 2017). The aromatic

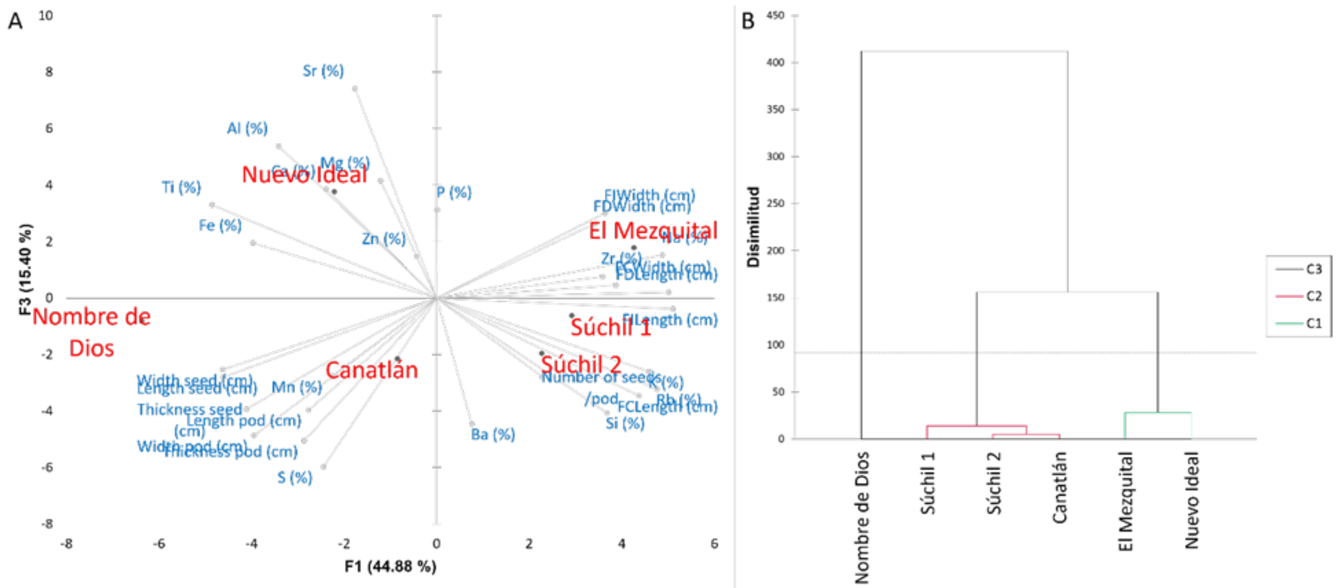


Figure 4. A) Results of a principal component analysis and B) Dendrogram resulting from the cluster analysis of soil data, as well as trefoils, pod and seed morphometry, for six wild populations of common bean (*Phaseolus vulgaris*) from Durango, Mexico.

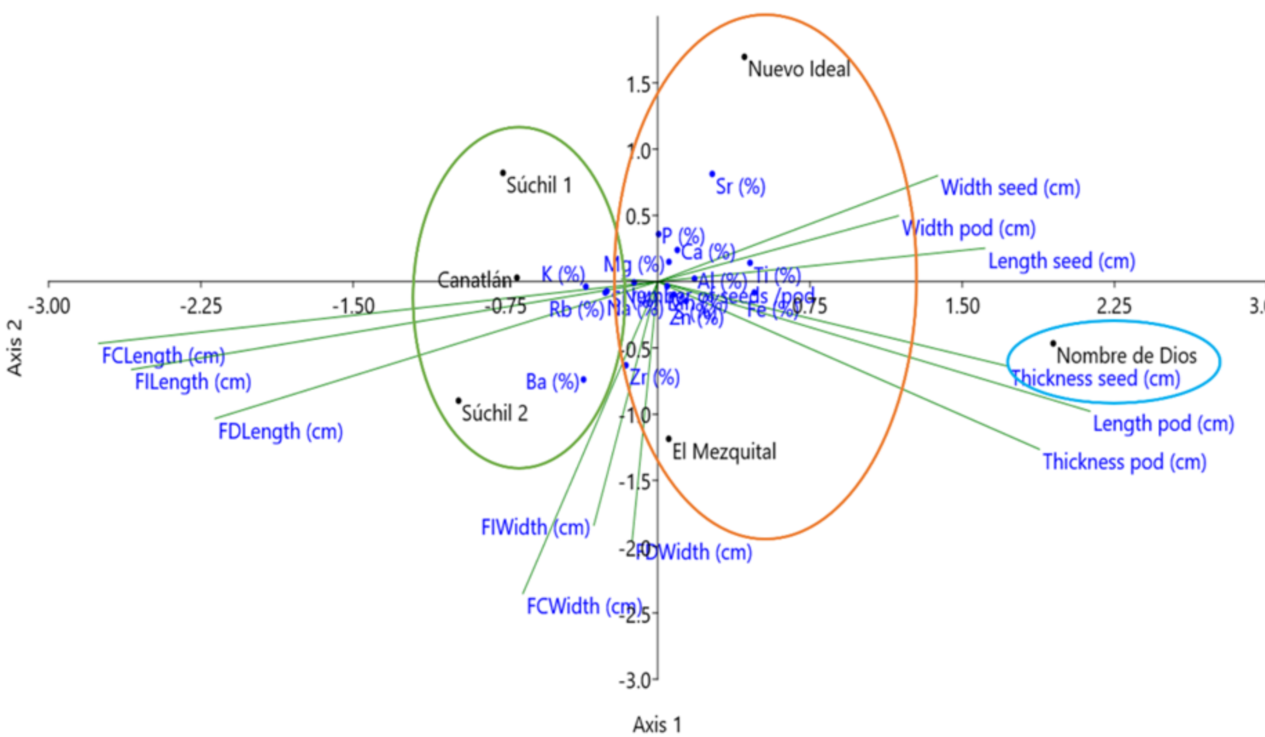


Figure 5. Results of a Canonical Correspondence Analysis (CCA) of morphometric data and soil physicochemical from six wild populations of common bean (*Phaseolus vulgaris*) from Durango, Mexico.

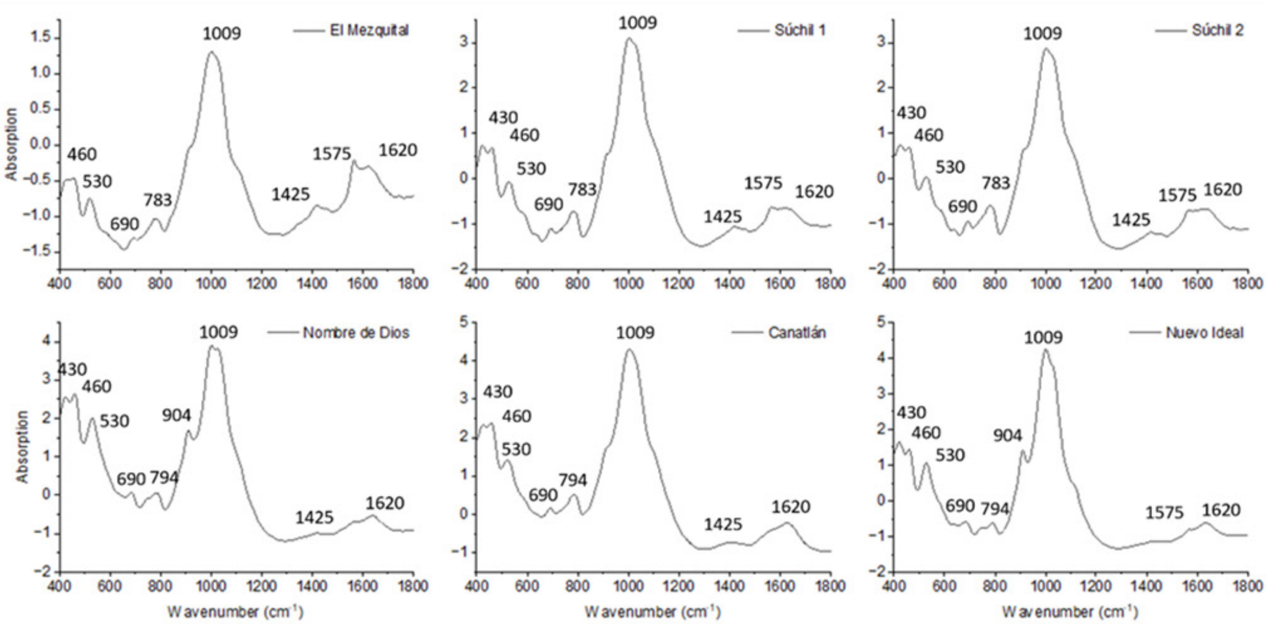


Figure 6. FTIR spectra of wild bean seeds represented in the biological fingerprint region (1800-400 cm^{-1}), from different locations in Durango.

Table 4. Vibrational bands corresponding to the analysis of the wavelength from 1800 to 400 in analyzed soil.

	Wavenumber (cm^{-1})	Vibration band	Molecule	Vibration mode	Reference
1	1620	(C=C)	Amide I (Protein)	stretching	Kumari & Ramakrishnan, 2023; Dovbeshko *et al.*, 2023
2	1575	N-H	Amida II (Proteína) Protein amide II 3 absorption- predominatelyb-sheet of amide II	stretching	Chatterley *et al.*, 2022
3	1425	C-H (–CH_3)	aliphatic compounds, particularly in methyl	bending vibrations	Bakshi *et al.*, 2014
4	1029	indicative of C-O and C-OH	carboxylic acids	stretching	Duan *et al.*, 2024
5	1009	C-OH	bonds in oligosaccharides such as mannose & galactose	stretching	Schindler *et al.*, 2017
6	904	C-H d (monosustituído)	Alqueno	bending	Dovbeshko *et al.*, 2023
7	794	C-H d (meta)	Aromatic C-H out-of-plane bend;increasing wavenumber with increasingdegree of substitution	bending	Sharma & Kumar, 2023
8	690	Vs Fe-O	Fe-O-(H)	bending	Margenot *et al.*, 2017
9	530	C=C, C-Br t	Torsion and ring torsion of phenyl (1), Haluros de alquilo	strech	Siddique, 2024
10	460	BrCN	It primarily focuses on the rovibrational analysis of BrCN isotopomers and their spectral data	strech	Siddique, 2024; Fayt *et al.*, 2002
11	430	C-OH_3δs (O-P-O)	Tosion methoxy group, PO4 3– in phospates	bending	Siddique, 2024

C=C stretching ratio at 1632–1621 cm^{-1} has been used as an index of humification (Serafimova & Dedelyanova, 2023). Phyllosilicates are the most abundant class of soil minerals. They consist of aluminum coordinated with hydroxyl-bound oxygen, coupled with silicon films in tetrahedral coordination with oxygen. (Margenot *et al.*, 2017). This is because 2:1-layer silicates exhibit a single broad absorption peak at 1029–1009 cm^{-1}.

Conclusion

The population that exhibited the largest trifoliate leaves, seeds, and pods was El Mezquital, whereas the population with smaller pods and seeds corresponded to Nuevo Ideal. In the latter site, soil analysis revealed one of the highest deficiencies in essential nutrients for plant growth.

The morphometric characteristics of pods and seeds of wild *Phaseolus vulgaris* were compared in relation to the type of soil in which they develop. Populations collected from soils with higher nutrient content produced larger pods and seeds, in contrast to those from soils with greater deficiencies in beneficial elements, which showed lower morphometric values.

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