

Location and tissue effect on physicochemical, mineral and amino acid profile of *Moringa oleifera*

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ABSTRACT

Introduction: *Moringa oleifera* is a medicinal plant with multiple biological uses, whose tissues have not been studied individually. The objective of this work was to evaluate the location effect on physicochemical, techno-functional, mineral and amino acid profile of two *Moringa* tissues (leaflets and petioles).

Methods: Two *Moringa* tissues grown in three different locations were characterized physicochemically (fat, fiber, moisture, protein, carbohydrates), techno-functionally (water-holding capacity, swelling capacity, oil-holding capacity and organic molecule absorption capacity), mineral (by fluorescence x-rays) and amino acid (by HPLC). **Results:** Results indicated that leaflets showed higher dry matter content ($89.40 \pm 0.86\%$), ash ($11.66 \pm 0.59\%$), protein ($34.61 \pm 3.75\%$), fat ($15.01 \pm 1.51\%$), water-holding capacity (5.03 mL/g), and swelling capacity ($7.28\text{ cm}^3/\text{g}$) compared to petioles which presented higher fiber content ($36.21 \pm 3.75\%$), oil-holding capacity (2.67 g oil/g), and organic molecule absorption capacity (2.91 mL oil/g). In addition, leaflets showed a higher mineral content in comparison to petioles, in both tissues, the major elements were Ca, K, Mg and S. On the other hand, leaflets showed a higher content and diversity of essential and nonessential amino acids.

Conclusion: In conclusion, quality and physicochemical, techno-functional, elemental and amino-acid profile are affected by tissue and location.

Introduction

Currently, importance of ingredients and functional foods has been of great relevance, because they have ability to meet basic nutritional requirements and have a positive effect on the consumer's health [39]. One of this type of food has been multiple plant species, among which *Moringa* (*Moringa oleifera*) has been one of the most outstanding, since it has been documented that it has a high percentage of proteins, micro-nutrients and bioactive compounds of interest for the consumer's metabolism [11,18,25]. It has been documented this type of crops in which a high nutritional value has been recorded, with a good amount of vitamins, chemical elements and quality proteins, the latter due to the amino acid profile in which the presence of essential and non-essential

amino acids stands out [18,29], including histidine and arginine, generally present in animal proteins [27] and sulfur amino acids such as methionine and cystine present mainly in legumes [37], important for the growth and development of organisms. Therefore, *M. oleifera* could be considered as an important ingredient for the formulation of multiple dietary supplements [8,11,25], mainly in developing countries due to marginal areas the access to animal proteins is limited, besides representing a more sustainable option comparable to animal proteins or products [10]. In addition, within the general composition of the leaves of this crop, the presence of phytochemical compounds with diverse bioactive properties have been described, presenting antioxidant, anti-inflammatory and chemo-preventive potential [15]. Likewise, its mineral conformation has been described in which the content of Ca, K,

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Fe, Cu and Se [18,40] considered as trace elements, which can contribute positively to structural and coagulation functions, enzyme formation, development, salt and fluid balance, improvement of general health, and avoidance of certain pathological conditions such as diabetes, anemia, circadian gene expression and sleep stages [19,20,40].

The selection of *Moringa oleifera* as the object of this study is based on its high agri-food relevance, particularly in the context of food security in semi-arid regions. This plant has been widely recognized for (i) its high content of protein, essential amino acids, trace minerals, and bioactive compounds, as documented in several international studies [1, 25]; (ii) its potential as a functional ingredient, dietary supplement, and plant-based alternative to animal proteins [10]; and (iii) its notable adaptability to extreme climatic conditions, such as drought or nutrient-poor soils, making it a viable nutritional alternative for vulnerable areas like northeastern Mexico.

Although previous studies on *Moringa* in Mexico exist [11,42], to date there has been no systematic differentiation between tissues (leaflets and petioles) nor a multivariate comparative analysis of their nutritional composition in relation to local edaphic conditions. Therefore, this study offers a novel approach from a physicochemical, functional, and nutraceutical perspective.

It should be noted that most works focus on the general study of the leaf, which is made up of small leaflets (up to seven leaflets) and petioles [36]. Which could present a different composition among themselves, since this composition is provided or affected depending on the type of tissue, as well as the environmental, geographical and soil conditions where it is produced ([15]; Gontes [16]). Considering the importance of understanding how anatomical and environmental factors influence the nutritional and functional composition of *Moringa oleifera*, and based on the hypothesis that this composition—physicochemical, functional, elemental, and amino acid—varies significantly between tissues (leaflets and petioles) and is modulated by local edaphic and environmental conditions, this study aimed to evaluate the effect of geographical location on these profiles. This approach seeks to distinguish the quality and characteristics of each tissue, reinforcing the application of *Moringa* as a functional and sustainable ingredient, especially in agro-environmentally constrained regions. To support the study's aim, four analytical axes were selected: physicochemical traits to assess basic nutritional composition; technofunctional properties to evaluate potential use in food processing; elemental analysis to explore macro- and trace elements; and amino acid profiling to determine protein quality. The inclusion of 43 elements serves an exploratory purpose, allowing detection of location- and tissue-specific accumulation patterns.

Materials and methods

Vegetal material

Leaves and petioles were obtained from *M. oleifera* cropped in three different locations in the State of Coahuila, Mexico: the UAAAN Experimental Station of Zaragoza (28° 33' N, -100° 5' W, 350 m.a.s.l.) (location 1), Las Norias town, Ramos Arizpe (25° 24' N, -100° 45' W, 1100 m.a.s.l.) (location 2) and Saltillo town (25° 22' N, -101° 22' W, 1743 m.a.s.l.) (location 3). Vegetal material was transported in brown paper bags and left to dry in the shade at room temperature for five days. Leaflets and petioles were manually separated and dehydrated at 60 °C for 6 h, to remove traces of moisture. Finally, samples were ground and sieved to obtain a particle size of 500 and 1000 μm , respectively, and stored at room temperature.

Physicochemical analysis

For physicochemical characterization, the bromatological analyses were performed using two types of moringa tissue. Analyses were performed using the proposed AOAC techniques, total dry matter, moisture [3], ash [5], protein [4], fat [6], crude fiber [7] and carbohydrate were

determined. Analyses were performed in triplicate using standard methods.

Techno-functional properties

Water-holding capacity (WHC). This parameter was determined according to the method reported by Laguna et al. [21], briefly, 1 g of each *Moringa* sample was placed in a 15 mL Falcon tube, with distilled water (1:10, w/v), and mixed with a vortex for 1 min, and finally, samples were left to rest for 24 h at room temperature. Then, samples were centrifuged at 1000 rcf for 30 min using an equipment (Eppendorf, 5415D, German), and supernatant volume was immediately measured. Results were expressed as mL of water retained per g of sample.

Swelling capacity (SC). This property was determined by the method used by [34]. Briefly, 0.2 g of each moringa sample were weighed into 15 mL Falcon tubes, measuring sample volume, which was mixed with 5 mL of water, allowing it to stand for 24 h at room temperature. The final volume of the sample was measured, and results were expressed in cm^3 of water per g of sample.

Oil-holding capacity (OHC). This assay was performed according to Garcia-Ortiz et al. [13], 1 g of moringa sample was placed in a 15 mL Falcon tube with 10 mL of commercial vegetable oil (density = 0.89 g/mL) in a proportion of 1:5. The sample was mixed with a vortex 2×3 Velp Scientifica for 1 min, centrifuged at 2200 rcf for 30 min, the supernatant was removed and the sample was weighed. Results were expressed in g of oil/g of sample.

Organic molecule absorption capacity (OMAC). This property was determined according to Garcia-Ortiz et al. [13] with certain modifications. Briefly, 0.5 g of moringa sample were weighed and 10 mL of commercial oil were added, sample was mixed with a vortex for 1 min and left to rest for 24 h at room temperature. Then, samples were centrifuged 2200 rcf for 10 min, to finally measure the supernatant. Results were expressed in mL of oil/g of sample.

Soil analysis

Preliminary tests were carried out to evaluate the soil quality of each of the locations, for which soil samples were taken at a depth of 30 cm. The organic matter content was analyzed by gravimetric analysis after an incineration process [5], nitrogen percentage by total nitrogen analysis (N%) using the Kjeldahl method [4], pH and electrical conductivity (EC) using a potentiometer (Conductronic, PH140, Mexico) and finally texture by direct observation.

Determination of mineral content

For this purpose, an X-ray fluorescence equipment (XRF, Epsilon 1, United Kingdom), was used, following the methodology described by Gontes Perez et al., [16]. For this test, both tissues (LM and PM) as well as a soil sample from each of the regions obtained at a depth of 30 cm were used. Briefly, 3 g of each sample were weighed and placed in a plastic sample holder, covered with a polyurethane membrane. Subsequently, the sample was loaded. Then, sample was loaded into the fluorescence spectrometer so that the X-rays, irradiated at a current of 1.5 mA using a 15 W high stability lamp at a maximum voltage of 50 kV, fell on the surface of the sample. The signals were processed using the Panalitic-Omnian program and expressed in percentage and ppm.

Profile of free amino acids

Determination of free amino acids was performed by HPLC. *Moringa* leaves were washed and dried at room temperature for five days, leaflets were separated from petioles and dehydrated separately at a temperature of 60°C for 6 h using a Memmert® brand oven. Samples from leaflets and petioles were milled and sieved to a particle size of 500 and 1000 μm , respectively, and stored in previously labeled glass jars, which

were covered with aluminum paper and left at room temperature.

Acid hydrolysis. In glass bottles with a capacity of 10 mL and with a silicone rubber-lined screw cap, 10 mg of each moringa sample was weighed, 3 mL of 6 M HCl was added to each of the six bottles with slight stirring and removal of the air with nitrogen. Later, for their hydrolysis, flasks with samples were placed in a Memmert 854 Schwabach (Germany) oven at a temperature of 100°C for 22 h and allowed to cool to room temperature. Briefly, 4 mL of borate stopper were added, and the pH was adjusted with 5 M NaOH. The liquid content of the samples was placed separately in a 50 mL test tube and was completed with a 10 mL borate stopper and then passed through a filter of nylon membrane (0.22 µm). In this case, 200 µL of each filtered sample were placed in glass vials for HPLC, and brought to the HPLC [30]. Each sample lasted approximately two hours to read. The experiment was realized by duplicate.

Determination of free amino acids by High Performance Liquid Chromatography (HPLC). To determine the free amino acids content in moringa, the internal standard method (homoserine and norvaline) was carried out. The specifications for determination of amino acids determination by HPLC were as follows: A high-resolution liquid chromatography with a fluorescence detector and “autosampler” was used, Merck Chromolith® Performance RP18 column (4.6 × 100 mm) and employing as eluents A (Na₂HPO₄ × 2H₂O, propionic acid, dimethylsulfoxide, acetonitrile, and ultra-pure water) and eluent B (methanol, acetonitrile dimethylsulfoxide, and ultra-pure water). The average flow was kept at 0.8 mL/min. Detection was carried out using a fluorimetric detector (Jasco-821 FP) λ_{ext.} 356 nm and λ_{emis.} 445 nm [30].

Statistical analysis

Experiments were established under a randomized complete block design with three repetitions, the proximal analysis data and functional properties were analyzed by means of an analysis of variance, and when it was needed, the comparison of means was performed using the Tukey multiple range test. (α=0.05) with the statistical program SAS (9.0 v). For chemical elements, a principal component analysis was performed using OriginPro (version 2021).

Results and discussion

Proximal analysis

The analysis of variance (annexes) detected significant differences in most of the response variables for the sources of variation: locations, plant tissue and the interaction between location and tissue (except for the carbohydrate and fat variables, where no significant differences were detected in the type of tissue and for the interaction between tissue and location). Table 1 shows the physicochemical analysis according to tissue type and location. In general, the data showed a significant difference according to tissue type, with higher values for leaflets (LM) in dry matter content (89.40 ± 0.86 %), ash (11.66 ± 0.59 %), protein (34.61 ± 3.75 %), fat (15.01 ± 1.51 %), likewise, petioles showed a higher fiber content (36.21 ± 3.75 %), finally, the carbohydrate content did not show significant differences (with values between 33.18 ± 4.35 and 33.73 ± 1.61 %), which indicates that in both parts of the plant a similar number of this type of compounds could be found in the form of sugars.

Leaflets from location 1 (Zaragoza) showed higher moisture (11.75 ± 0.07 %), ash (12.37 ± 0.33 %), fiber (5.61 ± 0.09 %) and carbohydrate (38.75 ± 0.39 %) contents and lower protein (29.79 ± 0.22 %) and fat (13.49 ± 0.24 %) contents. Likewise, petioles from location 1 (Zaragoza) presented higher contents of moisture (12.24 ± 0.09 %), ash (11.17 ± 0.09 %) and carbohydrates (34.89 ± 0.55 %).

The highest protein content found in this study (showed in leaflets from location 3 (Saltillo)) resulted in an average of 38.14 ± 0.15 %, which was higher than values reported in other studies in Mexico [11,

Table 1

Contents of the proximal analysis of two types of *Moringa oleifera* tissue from three localities.

Variable (%)	Moringa leaflets			Moringa petioles		
	Loc 1	Loc 2	Loc 3	Loc 1	Loc 2	Loc 3
Dry material	88.31 ± 0.07 _e	89.74 ± 0.27 _c	90.17 ± 0.17 _a	87.76 ± 0.09 ^f	90.02 ± 0.27 _b	89.64 ± 0.16 _d
Moisture	11.75 ± 0.07 _b	10.26 ± 0.27 _d	9.83 ± 0.17 ^f	12.24 ± 0.09 _a	9.98 ± 0.27 ^e	10.36 ± 0.16 _c
Ash	12.37 ± 0.33 _a	11.16 ± 0.21 _d	11.45 ± 0.18 _b	11.17 ± 0.09 _c	9.06 ± 0.18 ^e	8.97 ± 0.06 ^f
Protein	29.79 ± 0.22 _c	35.91 ± 0.21 _b	38.14 ± 0.15 _a	9.29 ± 0.05 ^f	10.95 ± 0.28 _e	12.52 ± 0.40 _d
Fat	13.49 ± 0.24 _c	16.21 ± 0.13 _a	15.34 ± 1.79 _b	9.15 ± 1.01 ^e	10.30 ± 1.25 _d	8.78 ± 0.62 ^f
Fiber	5.61 ± 0.09 _d	5.43 ± 0.20 ^f	5.57 ± 0.09 ^e	35.51 ± 0.49 _c	37.44 ± 1.20 _a	35.68 ± 0.53 _b
Carbohydrates	38.75 ± 0.39 _a	31.29 ± 0.69 _e	29.49 ± 1.63 ^f	34.89 ± 0.55 _b	32.25 ± 2.10 _d	34.05 ± 0.49 _c

Loc = Location (1, 2, and 3).

35,42]. On the other hand, *M. oleifera* petiole protein values are similar to those reported in Lombardy, Michoacán and San Pedro, Coahuila, Mexico [42] and in Jordan with *M. peregrina* [2]. These higher values in leaflets compared to petioles are attributed to the fact that petioles need a higher proportion of fiber in its structure in order to provide greater support and elasticity to support leaf weight, characteristics provided by the cellulose content present in the fibers [26].

Ash values were higher than those reported in previous studies [11], and similar to those reported by Valdez-Solana et al., [42]. The variation in the nutritional content of *M. oleifera* obtained in this research, and other similar studies, maybe due to: development stages of the plant, genotypes, environmental, climatic, and edaphic variations, the geographical area where the plant is cropped, fertilizers, industrialization process, agronomic practice, and storage conditions once harvested, ground and sieved (Gontes [16,42]), as well as the time of year, and the techniques used to collect leaf samples before analysis. This is one of the first studies where the chemical compounds of leaflets and petioles are analyzed separately. It is important to consider the differences that exist in the content of the elements between moringa tissues to have better control of their consumption.

Techno-functional properties

The analysis of variance for functional properties detected significant differences for plant tissue types and locations. On average, leaflets showed a higher WHC and SC higher WHC (water-holding capacity) and SC (swelling capacity) (with average values of 5.03 ± 0.04 mL/g and 7.28 ± 0.48 cm³/g, respectively), while petioles showed higher OHC (oil-holding capacity) and OMAC (organic molecule absorption capacity) (2.67 ± 0.16 g oil/g and 2.91 ± 0.21 mL oil/g and 2.91 ± 0.21 mL oil/g, respectively). In particular, leaflets did not show significant differences in WHC (with values between 5.00 - 5.07 mL/g), OHC (with values between 1.66 - 1.71 g oil/g) and OMAC (with values between 1.75 and 1.80 mL oil/g) and showed significant differences in SC with higher values in leaflets from location 1 (Zaragoza) (with values of 7.83 ± 0.29 cm³/g). On the other hand, petioles showed significant differences in WHC, OHC and OMAC values where the highest WHC values were in the petioles of location 2 (with values of 3.40 ± 0.00 mL/g), OHC and OMAC in the petioles of location 1 (with values of 2.82 ± 0.06 g oil/g and 3.16 ± 0.20 mL oil/g, respectively). Finally, SC values (with

values between 4.67 and 6.50 cm³/g) showed no significant difference.

Water-holding capacity was higher (average of 5.03 mL/g) than those reported by Umaru et al. [41] who found a water-holding capacity of 1.88 ± 0.13 mL/g. In the same way, compared to the quelite plant, presents similar values with a 5.56 g mL/g sample [33]. No reports were found in the literature related to the functional properties of Moringa, but based on these results, it is attributed that the protein constitution exerts a positive effect on water-holding capacity (WHC), and Swelling capacity (SC). Since it has a higher content of water-soluble proteins or hydrophilic nature which allows the interaction and absorption of water, on the other hand, the high values of OHC and OMAC could be related to the content and type of fibers present [13], having higher values in the PM compared to LM, which is attributed to the capacity of absorption and interaction of the vegetable fibers with oily matrices [31]. The techno-functional properties are characteristics of interest in the study of a complex ingredient or food matrix, since they are related to the capacity for hydration, volume increase and binding of fatty molecules in the matrix, this is dependent on the protein, fibrous and carbohydrate composition of the matrix [13], likewise, these properties allow for an improvement in softness, physical stability, oxidation stability, and the capacity to retain oils, as well as a prebiotic effect in the intestinal section [43].

Table 2

The behavior of the techno-functional properties can be attributed to different factors, mainly to their physicochemical composition. Fig. 1 shows two correlation matrices considering the values of the techno-functional analysis together with the physicochemical characterization of each tissue. Where a positive correlation is observed in the leaflet fiber with the Swelling capacity values (0.81), which could indicate that the type of fiber showed in this tissue allows the incorporation of water in the matrix, which provides an increase in volume. In addition, a high correlation was shown in the moisture content with the carbohydrate content (0.99), which could be attributed to the presence of hydrophilic molecules in the composition. Finally, the techno-functional property OMAC (Organic molecule absorption capacities) correlated with fat content (0.70) and OHC (Oil-holding capacity) (0.99), which indicates that the conformation and bonding with oily materials may be due to the properties of the molecular fiber chains that allow this interaction.

On the other hand, the correlation analysis using petioles indicated a high correlation with fat and fiber content (0.93), which is attributed to the properties of these fibers to interact with oily molecules, thus allowing them to maintain this type of molecules in their structure. In addition, there was a correlation of the WHC (water-holding capacity) property with fiber content (0.83), which indicates that the fibers in this tissue can influence the water absorption capacity, which could be due to the hydrophilic characteristics of the fiber, which is used to carry water in the plant structure. Finally, carbohydrate content with moisture content showed a good correlation (0.70), which is attributed to the presence of water-soluble carbohydrates that allow water retention in the plant.

Table 2

Functional properties in two types of *Moringa oleifera* tissue from three localities.

Properties	Moringa leaflets			Moringa petioles		
	Loc 1	Loc 2	Loc 3	Loc 1	Loc 2	Loc 3
WHC (mL/g)	5.03 ± 0.12 ^b	5.07 ± 0.06 ^a	5.00 ± 0.00 ^c	2.73 ± 0.23 ^e	3.40 ± 0.00 ^d	2.57 ± 0.21 ^f
SC (cm ³ /g)	7.83 ± 0.29 ^b	7.00 ± 0.87 ^c	7.00 ± 0.00 ^a	6.50 ± 0.00 ^f	4.67 ± 2.75 ^e	6.33 ± 1.04 ^d
OHC (g oil/g)	1.67 ± 0.11 ^e	1.71 ± 0.03 ^d	1.66 ± 0.29 ^f	2.82 ± 0.06 ^a	2.50 ± 0.09 ^c	2.69 ± 0.07 ^d
OMAC (mL oil/g)	1.75 ± 0.08 ^e	1.80 ± 0.06 ^d	1.75 ± 0.25 ^e	3.16 ± 0.20 ^a	2.77 ± 0.14 ^c	2.81 ± 0.25 ^b

WHC = Water-holding capacity. SC = Swelling capacity. OHC = Oil-holding capacity. OMAC = Organic molecule absorption capacities. Loc = Location (1, 2, and 3).

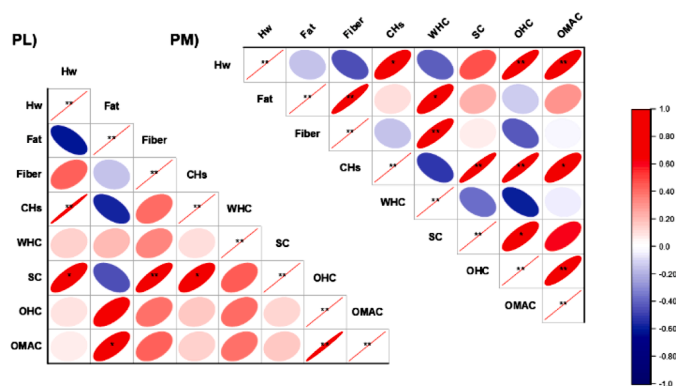


Fig. 1. Correlation matrix of techno-functional properties and physicochemical properties of *moringa oleifera*. LM = Moringa leaflets. PM = Moringa petioles. (*) = 0.05 of significance. (**) = 0.01 of significance. Hw = Moisture. CHs = Carbohydrates. WHC = Water-holding capacity. SC = Swelling capacity. OHC = Oil-holding capacity. OMAC = Organic molecule absorption capacities.

Soil analysis

After conducting soil study, it was revealed that the soils have favorable conditions for plant growth, including a relatively high organic matter content, medium alkalinity, and non-saline properties. Specifically, the soil at Location 1 contained 4.5 % organic matter, with a pH of 8.2, electrical conductivity (EC) of 1.0 mmhos/cm³, and a texture classified as “Cry.” At Location 2, organic matter was 3.2 %, pH was 8.4, EC reached 1.5 mmhos/cm³, and soil texture was “Crumb.” Similarly, Location 3 had 5.3 % organic matter, a pH of 8.1, an EC of 1.0 mmhos/cm³, and a “Crumb” texture. These soil conditions are suitable for moringa cultivation, as nitrogen availability, essential for protein and amino acid synthesis, can be improved in alkaline soils [9].

Determination of mineral content

Table 3 shows the mineral analysis, which revealed presence of 43 chemical elements in the soil sections analyzed in the three locations, where the majority elements were Ca, Si, Al, K and Fe, where the Ca values were found in a range between 18.25 and 46.97 %, Si between 33.28 and 56.14 % and Al between 7.78 and 9.97 %.

Table 4 shows 43 chemical elements identified by X-Ray fluorescence. Minerals play an important role within the organism, such as prevention of anemia, formation, and maintenance of bones and teeth, secretion of insulin, etc. [14,22]. The element determined in the highest amount in leaflets was Ca with 6.08, 5.64, and 5.85 % in samples from Location 1, 2, and 3, respectively while in the petioles it was lower, with an average of 3.74 %. Ca is the most abundant chemical element in the human body, it helps during the formation of bones and teeth and prevents osteoporosis [22]. The second most abundant element was K with a higher concentration in the petioles (with a range of 3.27–3.46 %) than in the leaflets (with a range of 3.50–5.38 %), unlike Ca, where its highest concentration was in the leaflets. The third major element present in moringa was S, with average values between 1.05 and 1.96 % in the leaflets, and average values between 0.39 and 0.64 % in the petioles. These chemical elements together with Na and Mg are nutritionally important for health, as well as for physiological processes (Fe, Mn, Co, Cu, I, S, and Se) [14,22]. The function of K within the human body is to help the proper functioning of the brain and nerves, preventing cerebrovascular accidents, in the acid-base and water regulation in the blood and tissues, it helps to prevent blood pressure and osteoporosis [22].

Something interesting is the identification of Se in both moringa tissues from all locations, but this element was not detected in the soil of the three locations. These results coincide with those of Lyons et al. [23], who found high levels of Se in moringa plants, developed in soils poor in

Table 3Content of chemical elements identified in soils where *Moringa oleifera* plants were obtained.

Element	Soil			Element	Soil		
	Loc-1	Loc-2	Loc-3		Loc-1	Loc-2	Loc-3
Mg (%)	0.00 ± 0.00 ^c	1.96 ± 0.20 ^a	1.54 ± 0.13 ^b	Pb	28.62 ± 3.12 ^b	37.75 ± 4.00 ^b	92.81 ± 9.30 ^a
Al (%)	7.78 ± 0.69 ^b	9.97 ± 1.00 ^a	9.71 ± 0.79 ^a	Cr	43.88 ± 5.88 ^b	75.50 ± 8.20 ^a	45.46 ± 5.20 ^b
Si (%)	33.28 ± 3.33 ^c	56.14 ± 5.61 ^a	40.01 ± 3.27 ^b	Ni	58.86 ± 4.50 ^c	65.49 ± 6.20 ^b	73.35 ± 5.98 ^a
K (%)	2.42 ± 0.22 ^c	3.86 ± 0.36 ^b	4.29 ± 0.35 ^a	Ga	13.55 ± 1.00 ^c	15.58 ± 1.20 ^b	17.00 ± 1.20 ^a
Ca (%)	46.97 ± 4.70 ^a	18.25 ± 1.80 ^b	29.56 ± 2.41 ^c	As	13.59 ± 1.2 ^b	8.42 ± 1.00 ^c	28.93 ± 1.98 ^e
Fe (%)	3.56 ± 0.33 ^c	4.43 ± 0.40 ^b	4.74 ± 0.39 ^a	Y	47.37 ± 0.40 ^a	46.42 ± 0.30 ^b	45.41 ± 0.40 ^c
P	2289.60 ± 230.16 ^c	7260.00 ± 720.90 ^a	5871.40 ± 479.40 ^b	Nb	8.78 ± 2.25 ^c	15.63 ± 2.40 ^a	12.97 ± 2.40 ^b
S	2098.80 ± 210.12 ^c	3968.80 ± 380.50 ^a	3219.80 ± 262.90 ^b	Mo	1.96 ± 0.08 ^c	3.68 ± 0.40 ^b	4.74 ± 0.54 ^a
Cl	667.80 ± 65.78 ^b	387.20 ± 37.90 ^c	1704.60 ± 139.18 ^a	Tc	0.14 ± 0.00 ^c	0.29 ± 0.00 ^b	0.33 ± 0.02 ^a
Sc	190.80 ± 20.12 ^a	0.00 ± 0.00 ^b	189.40 ± 15.46 ^a	Ru	0.10 ± 0.00 ^c	1.31 ± 0.02 ^b	0.38 ± 0.02 ^a
Ti	5437.80 ± 540.00 ^b	6098.40 ± 600.20 ^a	5113.80 ± 470.54 ^c	Rh	0.00 ± 0.00 ^b	1.21 ± 0.02 ^a	1.18 ± 0.02 ^a
V	95.40 ± 9.55 ^b	193.60 ± 19.00 ^a	94.70 ± 97.50 ^b	Pd	0.00 ± 0.00 ^b	0.39 ± 0.02 ^b	2.98 ± 0.02 ^a
Mn	858.60 ± 84.90 ^b	871.20 ± 85.90 ^b	1041.70 ± 101.90 ^a	Sn	62.58 ± 0.24 ^b	68.39 ± 0.26 ^a	60.04 ± 0.04 ^c
Co	95.40 ± 9.20 ^c	290.40 ± 25.50 ^a	189.40 ± 20.60 ^b	Sb	17.41 ± 0.02 ^b	29.81 ± 1.80 ^a	31.01 ± 2.20 ^a
Cu	47.46 ± 5.00 ^c	51.55 ± 6.10 ^b	60.51 ± 6.10 ^a	Te	40.12 ± 4.20 ^c	83.83 ± 5.54 ^a	70.17 ± 5.48 ^b
Zn	95.40 ± 8.50 ^b	96.80 ± 9.20 ^b	284.10 ± 18.55 ^a	I	23.61 ± 4.20 ^b	34.65 ± 4.80 ^a	33.19 ± 2.88 ^a
Br	40.31 ± 3.97 ^a	26.57 ± 2.52 ^b	40.39 ± 3.70 ^a	Cs	28.24 ± 3.00 ^b	43.75 ± 6.28 ^a	19.46 ± 3.54 ^c
Rb	95.40 ± 22.32 ^b	96.80 ± 12.10 ^b	189.40 ± 24.12 ^a	Hf	5.63 ± 0.80 ^b	27.93 ± 3.20 ^a	28.69 ± 3.26 ^a
Sr	667.80 ± 50.50 ^b	871.20 ± 88.00 ^a	852.30 ± 88.12 ^a	W	0.24 ± 0.00 ^c	2.08 ± 0.30 ^b	3.27 ± 0.32 ^a
Zr	381.60 ± 40.45 ^b	580.80 ± 60.00 ^a	378.80 ± 36.52 ^b	Hg	3.29 ± 0.03 ^b	1.21 ± 0.05 ^c	3.88 ± 0.05 ^a
Ba	190.80 ± 25.66 ^b	484.00 ± 50.42 ^a	473.50 ± 46.55 ^a	Bi	2.24 ± 0.18 ^c	3.53 ± 0.40 ^a	2.70 ± 0.30 ^b
				Po	0.67 ± 0.05 ^b	1.40 ± 0.05 ^a	0.00 ± 0.00 ^c

Loc = Location (1, 2, and 3). Mg, Al, Si, K, Ca, and Fe expressed as a percentage (%), the rest of the values expressed in parts per million (ppm).

this element, while studies carried out by Tumax Chiroy et al. [40] in nine plants including moringa, reported Se only in *Amaranthus hybridus*, even when the soil contained small amounts of this element. In this regard, Lyons et al. [24] mentioned that the plant has a great capacity to absorb chemical elements, even when soils are poor in these elements, Gontes Perez et al. [16] also notes that the presence of these compounds and their availability may depend on the type of crop as well as site-specific factors or soil physiochemistry. These findings may be due to accumulation and bioconcentration mechanisms present in some plants with hyperaccumulator capabilities, which can absorb and concentrate trace elements such as Se from very low concentrations in the soil through efficient root transport and translocation to leaf tissues (Lyons et al., 2009; Vurayai et al., 2020). The Se is an essential trace element for human health, it helps to produce antioxidant enzymes, acts as an anti-inflammatory and chemo-preventive, because of presence of 25 selenoproteins [40].

On the other hand, elements reported as toxic to the human body such as arsenic (As), lead (Pb), and cadmium (Cd) were found in both moringa tissues and in all locations, which may be due to the absorption of the plant from the soil because the soil contained these elements.

The highest concentration of arsenic (As) was found in the leaflets of locality 1 with values of 0.83 ppm, followed by the petiole sample of locality 2 with 0.73 ppm (Table 5). Likewise, higher lead (Pb) concentrations were presented in petioles from locality 1 with values of 2.57 ppm. and in leaflets from leaflets from locality 2 with values of 2.32 ppm, values similar to those reported in studies conducted in plants produced in Michoacan Mexico, with values of 0.055 and 2.1 ppm, respectively, and San Pedro, Coahuila with values of 2.8 and 2.5 ppm, respectively, [42]. The presence of these elements in the plant indicates its capacity for absorption, and retention of metals and toxic agents in the plant.

Fig. 2 shows a principal component analysis (PCA) showing the elements found for both tissue types and locations. Fig. 2 shows two components in the model where CP1 explains 41.61 % of the total variance and CP2 explains 24.74 %. In the biplot, it can be observed the formation of two large groups grouped by tissue type, in the group of leaflets, there is a greater presence and diversity of elements compared to petioles. Likewise, the presence of different minerals in each tissue indicates that the plant has the capacity to migrate minerals, according to the type of cellular or tissue structure present.

Within the group of minerals most frequently found in leaflets (LM) were Rb, Cd, S, P, Se, V, Ca, Mo, Mn, Sc, Co, Ru, Pd, Zn, Cu, Sb, Sn, Te, Fe, Si, Cr, Os, Tc, Rh, I, and Hg. On the other hand, the most frequently found minerals in petioles (PM) were Cl, K, In, Br, Al, Bi, Br, and Pt. Finally, partial positioning Pb, Ga, AS, Ti, Nb, Cs, Y, Hf, and K elements was observed between leaflet (LM) and petiole (PM) groups, which could be due to the plant's ability to assimilate minerals and their positioning in its different tissue [9].

Finally, Table 5 shows a correlation analysis of minerals present in the soil related to the minerals present in leaflets (LM) and petioles (PM), where leaflets showed a positive correlation in the elements Ca (0.87), Sc (0.83), Fe (0.98), Zn (0.86), Sr (0.92), Te (0.93), Pd (0.97), and Sb (0.94), likewise petioles showed a positive correlation with the elements Mg (0.98), Ca (0.97), Co (0.87), Fe (0.72), Zn (0.98), Sr (0.87), Sb (0.93), Cr (0.96), Ga (0.97), and Rh (0.93), which indicates the absorption of these elements by these sections of the plant, a phenomenon whose final concentration in the plant would depend mainly on the concentration of these minerals or elements in the soil. Research reveals the ability of *M. oleifera* to absorb and accumulate many chemical elements in its leaves even when the soils are poor in these elements. These results also allow the visualization of moringa as a soil bioremediation agent with high loads of the aforementioned metals after being assimilated from the soil to its [32]. Finally, based on the results, its capacity for mineral absorption and retention is observed, which may have nutritional and functional importance, as well as the distribution in edible tissues, the presence of possible toxic agents, and their relationship with soil concentration, in order to evaluate quality, safety, and absorption in *Moringa oleifera*.

Amino acid profile

Table 6 shows the amino acids found in moringa tissues. In general, leaflets showed a higher content of amino acids compared to petioles, likewise, the major amino acid in leaflets (LM) was aspartic acid (with values between 82.55 and 37.45 mg/L), serine (with values between 37.95 and 9.0 mg/L) and glutamic acid (values between 3.35 and 10.90 mg/L). On the other hand, the amino acids at the highest concentration in petioles (PM) were aspartic acid (with values between 9.70 and 23.50 mg/L), glutamic acid (with values between 3.35 and 10.55 mg/L) and serine (with values between 3.25 and 5.05 mg/L). Both types of moringa

Table 4
Determination of the mineral profile of two *Moringa oleifera* tissues grown from three locations.

Element	Moringa leaflets			Moringa petioles			Element	Moringa leaflets			Moringa petioles		
	L-1	L-2	L-3	L-1	L-2	L-3		L-1	L-2	L-3	L-1	L-2	L-3
Mg (%)	0.27 ± 0.02 ^c	0.27 ± 0.02 ^c	0.25 ± 0.02 ^d	0.23 ± 0.02 ^e	0.32 ± 0.02 ^a	0.31 ± 0.02 ^b	Ga	0.33 ± 0.02 ^e	0.48 ± 0.03 ^a	0.32 ± 0.02 ^f	0.34 ± 0.02 ^c	0.39 ± 0.03 ^d	0.44 ± 0.03 ^b
K (%)	3.46 ± 0.24 ^d	3.28 ± 0.23 ^e	3.27 ± 0.23 ^f	5.38 ± 0.30 ^a	4.32 ± 0.22 ^b	3.50 ± 0.27 ^c	As	0.16 ± 0.01 ^f	0.57 ± 0.05 ^d	0.83 ± 0.06 ^a	0.58 ± 0.04 ^c	0.76 ± 0.05 ^b	0.42 ± 0.03 ^e
Ca (%)	6.08 ± 0.43 ^a	5.64 ± 0.39 ^c	5.85 ± 0.41 ^b	4.31 ± 0.30 ^d	3.10 ± 0.22 ^f	3.81 ± 0.27 ^e	Y	1.94 ± 0.14 ^a	0.68 ± 0.05 ^f	1.35 ± 0.09 ^d	1.85 ± 0.13 ^b	0.77 ± 0.05 ^e	1.67 ± 0.12 ^c
S (%)	1.96 ± 0.14 ^a	1.05 ± 0.07 ^c	1.31 ± 0.09 ^b	0.46 ± 0.03 ^f	0.39 ± 0.03 ^e	0.64 ± 0.04 ^d	Nb	3.50 ± 0.25 ^a	2.33 ± 0.16 ^f	2.91 ± 0.20 ^d	3.37 ± 0.24 ^b	2.34 ± 0.16 ^e	2.92 ± 0.21 ^c
Fe	346.36 ± 24.25 ^f	580.32 ± 40.62 ^b	664.10 ± 64.49 ^a	368.61 ± 25.80 ^e	371.46 ± 26.00 ^d	421.59 ± 29.51 ^c	Mo	4.73 ± 0.33 ^c	4.44 ± 0.31 ^d	6.68 ± 0.47 ^a	3.49 ± 0.24 ^e	2.71 ± 0.19 ^f	4.90 ± 0.38 ^b
P	3030.65 ± 212.15 ^b	2856.96 ± 199.99 ^c	3160.20 ± 221.21 ^a	2837.18 ± 198.60 ^d	2029.44 ± 142.06 ^f	2386.02 ± 167.02 ^e	Tc	0.59 ± 0.04 ^b	1.16 ± 0.08 ^a	0.24 ± 0.02 ^f	0.29 ± 0.02 ^d	0.28 ± 0.02 ^e	0.36 ± 0.03 ^c
Al	0.00 ± 0.00 ^d	0.00 ± 0.00 ^d	0.00 ± 0.00 ^d	279.25 ± 19.55 ^a	54.36 ± 3.81 ^c	98.67 ± 6.91 ^b	Ru	0.48 ± 0.03 ^b	0.51 ± 0.04 ^a	0.26 ± 0.02 ^c	0.19 ± 0.01 ^e	0.24 ± 0.02 ^d	0.15 ± 0.01 ^f
Si	420.58 ± 29.44 ^d	1060.20 ± 74.21 ^a	1007.60 ± 70.53 ^b	290.42 ± 20.33 ^f	416.76 ± 29.17 ^e	466.44 ± 32.65 ^c	Rh	0.51 ± 0.04 ^b	1.63 ± 0.11 ^a	0.22 ± 0.02 ^e	0.00 ± 0.00 ^f	0.27 ± 0.02 ^d	0.42 ± 0.03 ^c
Cl	977.23 ± 68.41 ^f	2432.88 ± 170.30 ^d	1099.20 ± 76.94 ^e	3261.64 ± 228.31 ^b	5263.86 ± 368.47 ^a	2448.81 ± 171.42 ^c	Pd	2.03 ± 0.14 ^c	2.27 ± 0.18 ^b	2.81 ± 0.20 ^a	1.68 ± 0.12 ^e	1.76 ± 0.12 ^d	1.13 ± 0.08 ^f
Sc	123.70 ± 8.66 ^b	111.60 ± 7.81 ^c	137.40 ± 9.62 ^a	44.68 ± 3.13 ^f	45.30 ± 3.17 ^e	80.73 ± 5.65 ^d	Sn	12.37 ± 0.87 ^z	22.32 ± 1.56 ^z	22.90 ± 1.64 ^z	11.17 ± 0.78 ^z	9.06 ± 0.63 ^z	17.94 ± 1.26 ^z
Ti	24.74 ± 1.73 ^e	33.48 ± 2.34 ^d	34.35 ± 2.40 ^c	22.34 ± 1.56 ^f	45.30 ± 3.17 ^a	35.88 ± 2.51 ^b	Sb	7.67 ± 0.54 ^d	9.00 ± 0.63 ^b	8.73 ± 0.61 ^a	4.90 ± 0.34 ^e	5.85 ± 0.41 ^f	6.51 ± 0.46 ^c
V	4.33 ± 0.30 ^a	3.12 ± 0.22 ^b	3.09 ± 0.22 ^c	1.45 ± 0.10 ^e	0.36 ± 0.03 ^f	1.61 ± 0.11 ^d	Te	12.37 ± 0.87 ^d	22.32 ± 1.56 ^b	22.90 ± 1.60 ^a	11.17 ± 0.78 ^e	9.06 ± 0.63 ^f	17.94 ± 1.26 ^c
Mn	408.21 ± 28.57 ^a	379.44 ± 36.56 ^b	332.05 ± 23.24 ^c	122.87 ± 8.60 ^e	90.60 ± 6.34 ^f	134.55 ± 9.42 ^d	I	2.84 ± 0.24 ^d	7.26 ± 0.43 ^a	5.62 ± 0.34 ^b	1.57 ± 0.10 ^f	4.42 ± 0.31 ^c	1.59 ± 0.11 ^e
Co	24.74 ± 1.73 ^a	22.32 ± 1.56 ^c	22.90 ± 1.60 ^b	11.17 ± 0.78 ^f	18.12 ± 1.27 ^d	17.94 ± 1.26 ^e	Cs	5.70 ± 0.37 ^a	0.00 ± 0.00 ^e	0.00 ± 0.00 ^e	0.88 ± 0.07 ^d	1.71 ± 0.12 ^c	2.31 ± 0.16 ^b
Cu	24.74 ± 1.73 ^c	33.48 ± 2.34 ^b	34.35 ± 2.40 ^a	22.34 ± 1.56 ^d	18.12 ± 1.27 ^e	17.94 ± 1.26 ^f	Hf	1.90 ± 0.13 ^a	0.45 ± 0.03 ^f	1.75 ± 0.12 ^b	1.40 ± 0.10 ^d	1.67 ± 0.12 ^c	1.06 ± 0.05 ^e
Zn	86.59 ± 6.06 ^c	100.44 ± 7.03 ^b	114.50 ± 8.02 ^a	44.68 ± 3.13 ^f	45.30 ± 3.17 ^e	80.73 ± 5.56 ^d	W	2.66 ± 0.19 ^a	1.22 ± 0.09 ^f	1.73 ± 0.12 ^d	2.21 ± 0.15 ^c	2.37 ± 0.17 ^b	1.24 ± 0.09 ^e
Br	61.85 ± 4.33 ^e	100.44 ± 7.03 ^b	45.80 ± 3.21 ^f	100.53 ± 7.04 ^a	99.66 ± 6.98 ^c	62.79 ± 4.40 ^d	Hg	0.42 ± 0.03 ^e	2.11 ± 0.15 ^a	1.30 ± 0.10 ^b	0.39 ± 0.03 ^f	0.71 ± 0.05 ^d	0.74 ± 0.05 ^c
Rb	12.37 ± 0.87 ^a	11.16 ± 0.78 ^d	11.45 ± 0.80 ^b	11.17 ± 0.78 ^c	9.06 ± 0.63 ^e	8.97 ± 0.63 ^f	Bi	0.86 ± 0.06 ^c	0.59 ± 0.04 ^f	0.70 ± 0.05 ^e	0.95 ± 0.07 ^a	0.89 ± 0.06 ^b	0.81 ± 0.06 ^d
Sr	296.88 ± 20.78 ^e	1305.72 ± 91.40 ^a	824.40 ± 57.71 ^b	268.08 ± 18.77 ^f	679.50 ± 47.60 ^c	448.50 ± 0.31 ^d	Po	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a
Zr	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	Cd	2.10 ± 0.12 ^b	1.27 ± 0.09 ^d	1.67 ± 0.12 ^c	0.67 ± 0.05 ^e	0.29 ± 0.02 ^f	2.26 ± 0.16 ^a
Ba	2.91 ± 0.20 ^c	0.00 ± 0.00 ^f	3.36 ± 0.24 ^b	5.53 ± 0.39 ^a	1.85 ± 0.12 ^e	2.63 ± 0.18 ^d	In	0.00 ± 0.00 ^f	0.24 ± 0.02 ^c	0.16 ± 0.01 ^e	0.21 ± 0.01 ^d	1.04 ± 0.07 ^a	0.58 ± 0.16 ^b
Pb	1.17 ± 0.08 ^f	2.32 ± 0.16 ^b	2.24 ± 0.16 ^c	2.57 ± 0.18 ^a	1.38 ± 0.10 ^e	2.09 ± 0.15 ^d	Se	1.60 ± 0.11 ^c	0.72 ± 0.05 ^d	2.56 ± 0.18 ^a	0.49 ± 0.03 ^e	0.24 ± 0.02 ^f	1.83 ± 0.13 ^b
Cr	2.60 ± 0.18 ^c	2.12 ± 0.15 ^d	3.55 ± 0.26 ^a	0.00 ± 0.00 ^f	3.35 ± 0.23 ^b	1.08 ± 0.08 ^e	Os	0.89 ± 0.06 ^b	1.46 ± 0.10 ^a	0.71 ± 0.05 ^d	0.83 ± 0.06 ^c	0.63 ± 0.04 ^e	0.41 ± 0.03 ^f
Ni	4.21 ± 0.30 ^a	3.79 ± 0.27 ^b	2.63 ± 0.18 ^f	2.79 ± 0.20 ^e	3.53 ± 0.26 ^c	3.14 ± 0.22 ^d	Pt	0.51 ± 0.04 ^a	0.11 ± 0.01 ^d	0.00 ± 0.00 ^e	0.50 ± 0.04 ^b	0.42 ± 0.04 ^c	0.00 ± 0.00 ^e

(continued on next page)

Table 4 (continued)

Element	Moringa leaflets			Moringa petioles			Element	Moringa leaflets			Moringa petioles		
	L-1	L-2	L-3	L-1	L-2	L-3		L-1	L-2	L-3	L-1	L-2	L-3
							Au	0.00 ± 0.00 ^f	0.76 ± 0.05 ^b	0.26 ± 0.02 ^d	0.61 ± 0.04 ^c	0.86 ± 0.06 ^a	0.11 ± 0.00 ^e

L = Location (1, 2, and 3). Mg, K, Ca, and S expressed as a percentage (%), the rest of the values expressed in parts per million (ppm).

Table 5

Correlation coefficients of concentration of elements present in soil and elements present in leaflets and petioles from *Moringa oleifera*.

Tissue	Mg	Ca	Co	Sc	Fe	Zn	Sr	Te	Pd	Sb	Cr	Ga	Rh
LM	-0.25	0.87	-0.88	0.83	0.98	0.86	0.92	0.93	0.97	0.94	-0.72	0.05	0.34
PM	0.98	0.97	0.87	0.48	0.72	0.98	0.87	-0.15	-0.96	0.93	0.96	0.97	0.93

LM= Moringa leaflets. PM = Moringa petioles.

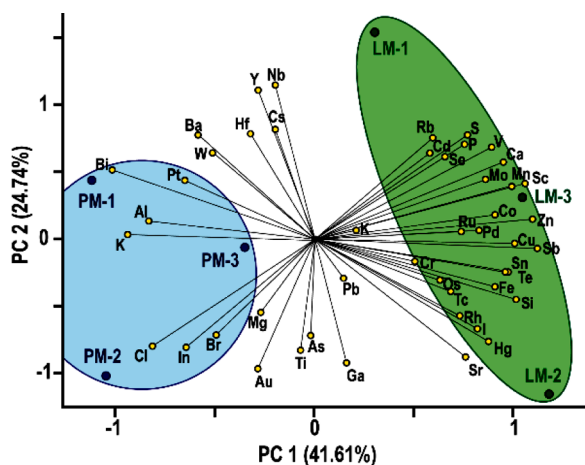


Fig. 2. Biplot of principal component analysis. Proximal analysis and identification of chemical elements in soil from three localities and two types of tissue. LM = Moringa leaflets. PM = Moringa petioles. Numbers (1, 2, and 3) = Locations (1, 2, and 3, respectively).

tissues showed higher contents in location 2 (Ramos Arizpe) in comparison to locations 1 and 3 (Zaragoza and Saltillo). Finally, the amino acids that showed the lowest concentration as well as the highest

Table 6

Amino acid (mg/L) profile in leaflets and petioles from *Moringa oleifera* grown at three locations.

NEAA	Moringa leaflets			Moringa petioles			EAA	Moringa leaflets			Moringa petioles		
	L-1	L-2	L-3	L-1	L-2	L-3		L-1	L-2	L-3	L-1	L-2	L-3
Aspartic acid	57.15 ± 4.00 ^b	82.55 ± 5.78 ^a	37.45 ± 2.62 ^c	9.70 ± 0.68 ^f	23.50 ± 1.65 ^d	22.75 ± 1.59 ^e	Arginine	6.01 ± 0.42	6.75 ± 0.47	4.45 ± 0.31	0.65 ± 0.05	8.10 ± 0.57	3.55 ± 0.22
Glutamic acid	9.30 ± 0.65 ^d	9.35 ± 0.60 ^c	10.90 ± 0.76 ^a	3.35 ± 0.23 ^f	4.60 ± 0.032 ^e	10.55 ± 0.74 ^b	Threonine	4.40 ± 0.31	10.2 ± 0.71	5.25 ± 0.37	0.95 ± 0.07	1.60 ± 0.11	1.90 ± 0.13
Serine	9.40 ± 0.66 ^b	37.95 ± 2.66 ^a	9.00 ± 0.63 ^c	3.25 ± 0.23 ^f	4.35 ± 0.30 ^e	5.05 ± 0.35 ^d	Valine	4.35 ± 0.30	7.25 ± 0.51	6.50 ± 0.50	1.25 ± 0.09	1.70 ± 0.12	2.20 ± 0.15
Alanine	5.90 ± 0.41 ^c	16.3 ± 1.15 ^a	6.00 ± 0.42 ^b	2.00 ± 0.14 ^f	2.35 ± 0.15 ^e	2.40 ± 0.17 ^d	Phenylalanine	4.05 ± 0.28 ^c	5.00 ± 0.35 ^a	4.60 ± 0.32 ^b	0.00 ± 0.00 ^d	0.00 ± 0.00 ^d	0.00 ± 0.00 ^d
Glycine	1.97 ± 0.14 ^a	1.70 ± 0.14 ^a	1.97 ± 0.15 ^a	1.97 ± 0.14 ^a	1.97 ± 0.16 ^a	1.97 ± 0.13 ^a	Isoleucine	2.85 ± 0.20 ^c	4.40 ± 0.31 ^a	4.25 ± 0.30 ^b	0.35 ± 0.02 ^e	0.20 ± 0.01 ^f	0.60 ± 0.04 ^d
Tyrosine	1.25 ± 0.09 ^b	5.25 ± 0.37 ^a	1.05 ± 0.07 ^c	0.15 ± 0.01 ^e	0.20 ± 0.01 ^d	0.15 ± 0.01 ^e	Leucine	2.20 ± 0.15 ^c	3.65 ± 0.26 ^a	3.05 ± 0.21 ^b	0.35 ± 0.02 ^f	0.45 ± 0.03 ^e	0.60 ± 0.04 ^f
Asparagine	1.15 ± 0.08 ^b	3.30 ± 0.23 ^a	0.70 ± 0.05 ^c	0.25 ± 0.01 ^f	0.50 ± 0.01 ^e	0.60 ± 0.01 ^d	Histidine	0.10 ± 0.00 ^a	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b
Glutamine	0.21 ± 0.01 ^a	0.21 ± 0.01 ^a	0.21 ± 0.01 ^a	0.21 ± 0.01 ^a	0.21 ± 0.01 ^a	0.21 ± 0.01 ^a	Tryptophan	0.10 ± 0.00 ^a	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b
Cysteine	0.05 ± 0.00 ^a	0.00 ± 0.00 ^b	0.05 ± 0.00 ^a	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b	0.00 ± 0.00 ^b							

LM = Moringa leaflets. PM = Moringa petioles. NEAA = Non-essential amino acids. EAA = Essential amino acids.

absence in all tissues and locations were cysteine, histidine and tryptophan, while phenylalanine was not present in petioles.

The amino acids found in this research agree with those reported by Isitua et al. [17] and Castillo-López et al. [11], who identified 16 and 14 amino acids in moringa leaves, respectively. While Chelliah et al. [12], and State et al. [38] reported in the root, seed, and leaves of moringa, 16 and 15 amino acids, respectively, found a large amount in the seed. However, there are reports that indicate that moringa has a large amount of free amino acids [28] and essential amino acids [1].

Fig. 3 shows a principal component analysis (PCA) showing the elements found in both moringa tissue and locations. Fig. 3 shows two components in the model where CP1 explains 63.59 % of the total variance and CP2 explains 19.60 %. In the biplot it can be observed the formation of two main groups, grouped by tissue type, in the group of leaflets there is greater presence and diversity of amino acids (EAA and NEAA) compared to petioles.

In general, leaflets showed a higher quantity and diversity of both essential and non-essential amino acids compared to petioles, which can be directly linked to the protein content and protein quality in each of the moringa tissues. Methionine was the only amino acid that was not found in any of the moringa tissues collected in three locations, this differs from that reported in the literature. In the same way, the tryptophan amino acid was only identified in a very small amount in the leaflets from Zaragoza, its report being null in other investigations [1,11,17,38]. Variation in the content of the amino acids and some in particular, such as methionine and tryptophan, is probably due to the

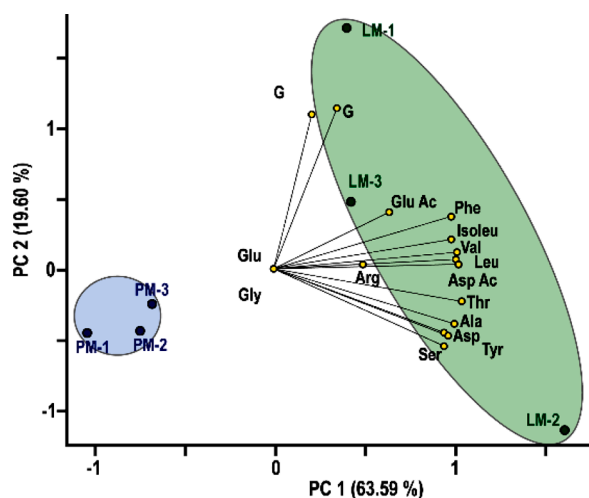


Fig. 3. Biplot of principal component analysis. Proximal analysis and identification of amino acids in two types of moringa collected from three localities. LM = Moringa leaflets. PM = Moringa petioles. Numbers (1, 2, and 3) = Localities (1, 2, and 3, respectively).

leaves nutritional content since this depends on several factors: plant variety and phenological state, soil and climate conditions, pH, the season of the year, extraction method, identification procedure, etc. (Gontes [16]).

Conclusions

Moringa is a plant rich in nutrients, which indicates that both leaflets and petioles have immense nutritional value. In general, the leaflets showed a higher content of protein, fat, ash, water retention capacity and swelling capacity, while the petioles presented a higher content of fiber, oil retention capacity and absorption capacity of organic molecules. In addition, leaflets showed a greater diversity and concentration of chemical elements whose presence can be attributed to their absorption, and retention from soil. Finally, the content of essential and nonessential amino acids was higher in leaflets than in petioles. In general, the analysis by tissues allowed to determine how quality and physicochemical, techno-functional, elemental and amino-acid profile are affected by tissue and location.

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Ethics statement

The authors declare that they have no conflicts of interest and adhere to the ethical guidelines for research.

CRediT authorship contribution statement

Martha Gómez-Martínez: Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jesús David García-Ortiz:** Writing – review & editing, Validation, Supervision, Investigation, Formal analysis, Data curation. **Susana Gómez-Martínez:** Validation, Supervision. **Mariela R. Michel:** Validation, Supervision. **Claudia M. López-Badillo:** Validation, Supervision. **Manuela Pintado:** Validation, Supervision. **Raúl Rodríguez-Herrera:** Writing – review & editing, Visualization, Validation, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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