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# Morphological characterization of *Moringa oleifera* seeds from different crops of Mexico

**Ruiz-Hernández, Rafael[1*]; Hernández-Rodríguez Martha[2]; Cruz Monterrosa Rosy G.[3]; Díaz-Ramírez Mayra[3]; Jiménez-Guzmán Judith[3]; León-Espinosa Erika B.[3]; García- Garibay Mariano[3]; Fabela-Morón Miriam F.[3]; Pérez-Ruiz Rigoberto V.[3]; Rayas-Amor Adolfo A.[3*]**

[1] Universidad Autónoma Metropolitana, Unidad Lerma, Catedrático COMECyT. Departamento de Ciencias de la Alimentación, División de Ciencias Biológicas y de la Salud. Lerma de Villada, Estado de México C.P. 52005.

[2] Postgrado de Recursos Genéticos y Productividad-Genética, Colegio de Postgraduados, Campus Montecillo. Municipio de Texcoco, Estado de México, México. C.P. 56230.

[3] Universidad Autónoma Metropolitana Unidad Lerma, Departamento de Ciencias de la Alimentación, División de Ciencias Biológicas y de la Salud. Lerma de Villada, Estado de México. C. P. 52005.

* Correspondence: a.rayas@correo.ler.uam.mx; ralfddz@gmail.com

**ABSTRACT**

**Objective**: to characterize the seeds of *Moringa oleifera* present in various crops in Mexico morphologically.

**Design/Methodology/Approach**: An analysis of variance, principal components, and conglomerates of qualitative morphological descriptors (shape, color, presence of wings and wing color) and quantitative (length, width, and weight) were carried out.

**Results**: Significant statistical differences ($P<0.05$) were found in the seeds' length, width, weight, and almonds. The principal component analysis indicated that components 1 (70.58%) and 2 (25.59%) contributed 96.17% of the variation, and the cluster analysis identified four groups. The evaluated populations showed qualitative variation (shape, color, presence of wings, and color of wings) and quantitative (length, width, and weight).

**Study limitations/implications**: the germination percentage could not be evaluated because no information was obtained on the age of the seed and the storage conditions.

**Result/Finding/Conclusion**: This information enriches the knowledge of *Moringa oleifera* in Mexico and serves as a basis for selecting materials of most significant interest.

**Keywords**: characterization, seed, *Moringa oleifera*.

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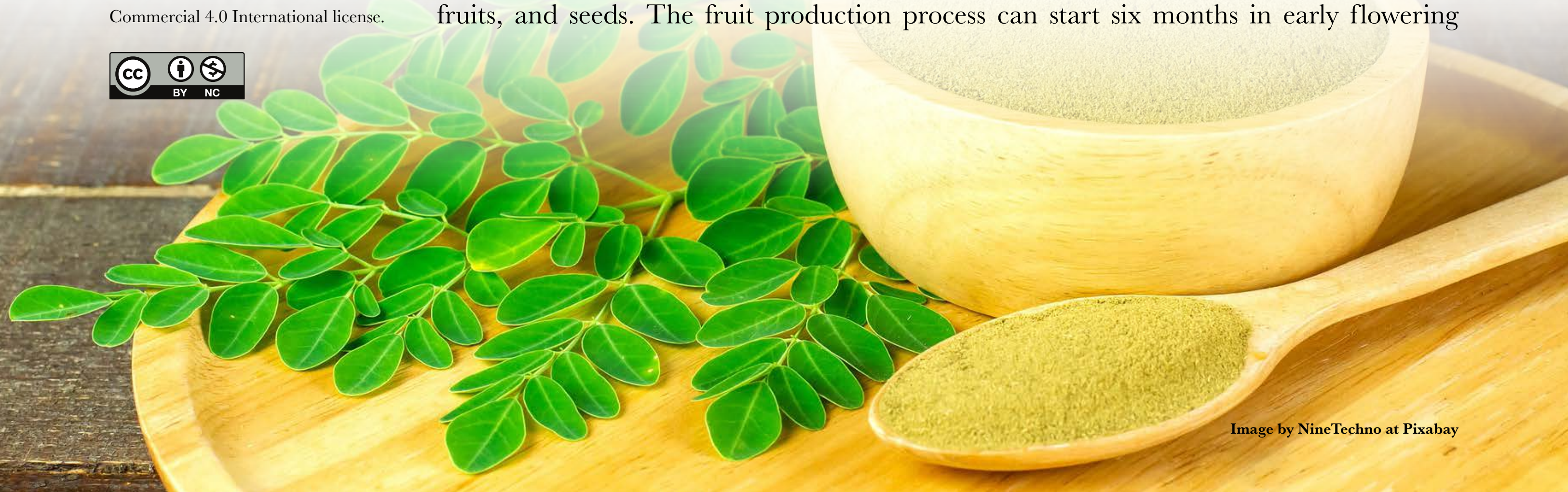
## INTRODUCTION

*Moringa oleifera* Lam. is a species that is currently cultivated in different types of ecosystems worldwide. It tolerates high temperatures, low humidity conditions, and soils with low nutrients (Paliwal *et al.*, 2011). It presents high production of biomass, flowers, fruits, and seeds. The fruit production process can start six months in early flowering



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varieties and more than one year in late varieties (Leone *et al.*, 2015). In addition, flowering is also influenced by different humidity levels in the soil (Muhl *et al.*, 2011). It has been reported that it can flower once or twice a year, and in optimal humidity conditions, it can produce fruits throughout the year (Zaku *et al.*, 2015). Fruit production can reach up to 411 plant$^{-1}$ fruits with a yield of 51.3 t ha year$^{-1}$ (Ndubuaku *et al.*, 2014). The fruits can be 30 to 120 cm long (Paliwal *et al.*, 2011), have a diameter of 1.49 to 2.55 cm, and have 12 to 23.5 seeds (Zhigila *et al.*, 2015). The tender fruits are green and pale green, ripe brown, dark brown, or golden (Ramos *et al.*, 2010; Popoola *et al.*, 2016). The seeds can be oval, round, or triangular, brown or dark brown, and with or without the presence of wings. The length of the seed can be from 1.0 to 1.5 cm, with 0.8 to 1.1 cm wide (Zhigila *et al.*, 2015). The weight of the seed fluctuates between 0.101 and 0.274 g (Shaltout, 2017). Each moringa tree could produce between 15,000 and 25,000 seeds plant$^{-1}$ (Makkar & Becker, 1997). These seeds contain a high content of oil, protein, and chemical compounds that can be used for flocculation, elimination of heavy materials in the water, biodiesel production, and prevention of chronic diseases such as obesity, diabetes, hypertension, and cancer (Pirrò *et al.*, 2016).

Studies previously carried out by Ramos *et al.* (2010), Zhigila *et al.* (2015), and Popoola *et al.* (2016) showed that there is a high degree of morphological variation in moringa seed and environmental and edaphic factors modulate the diversity. In Mexico, there is little information about the degree of morphological variation in moringa seeds. This lack of information limits the development of projects focused on the integral use of the seed and the genetic improvement of the existing populations. Therefore, the objective of this research was to determine the morphological diversity of *M. oleifera* seeds from different crops in Mexico.

## MATERIALS AND METHODS

During the months of May and June 2021, moringa seeds were collected from 22 crops located in the states of Chiapas, Guanajuato, Guerrero, Hidalgo, Michoacán, Nuevo León, Oaxaca, San Luis Potosí, Veracruz and Yucatán (Table 1, Figure 1).

Edaphology, climatology, vegetation, and land use files were downloaded from the CONABIO pages (http://www.conabio.gob.mx/informacion/gis/) and UNIATMOS (http://uniatmos.atmosfera.unam.mx/) to determine the climatic and edaphic variables.

The ArcGIS version 10.5 was used to obtain the variables that influence the morphology of moringa seeds. Table 2 shows the minimum, average, and maximum temperature values, annual precipitation, type of climate, altitude, humidity range, dominant soil, and soil moisture regime in each geographical area sampled.

### Biological material

Five hundred grams of moringa seeds were collected to determine the morphological descriptors; 75 healthy seeds were randomly selected from each sampled crop. Quantitative descriptors: The length and width of the seeds were obtained with a vernier. The individual weight, almond weight, and weight of 100 seeds were quantified with an analytical balance of the Ohaus Adventurer® brand. Quantitative descriptors: the variables of seed color,

**Table 1**. Geographical locations of the *M. oleifera* crops evaluated.

| Crop | State | Municipality | Community | Longitude | Latitude |
|---|---|---|---|---|---|
| CHI1 | Chiapas | Tuzantán | Villa Hidalgo | −92.374722 | 15.108056 |
| CHI2 | Chiapas | Tuxtla Gutiérrez | Colonia La Salle | −93.0868889 | 16.7429444 |
| GRO1 | Guerrero | Acapulco de Juárez | Bejuco | −99.6977778 | 16.8216667 |
| GRO2 | Guerrero | Acapulco de Juárez | Parrotillas | −99.61558371 | 16.8787834 |
| GRO3 | Guerrero | Acapulco de Juárez | Concepción | −99.66028879 | 16.8799601 |
| GRO4 | Guerrero | Tecpán de Galeana | Mitla | −99.89343517 | 16.87894246 |
| GTO1 | Guanajuato | Soledad de Gasca | Celaya | −100.8146904 | 20.502528 |
| HGO1 | Hidalgo | San Felipe Orizatlán | Ahuatitla | −98.6660845 | 21.1630165 |
| MICH1 | Michoacán | Benito Juárez | El Rodeo | −100.4708226 | 19.3055772 |
| MICH2 | Michoacán | Múgica | Múgica | −102.180997 | 18.928047 |
| NL1 | Nuevo León | Escobedo | Francisco I. Madero | −100.2847444 | 25.7854473 |
| OAX1 | Oaxaca | Santa Cruz Xoxocotlán | San Juan Bautista | −96.7280556 | 16.9791667 |
| OAX2 | Oaxaca | Santa María Huatulco | La Herradura | −96.3658333 | 15.7772222 |
| OAX3 | Oaxaca | Mariscala de Juárez | Guadalupe la Huertilla | −98.1088889 | 17.8513889 |
| OAX4 | Oaxaca | Tuxtepec | San Juan Bautista | −96.1286697 | 18.087694 |
| SLP1 | San Luis Potosí | Tanlajas | Guayajox | −98.73666667 | 21.7144444 |
| VER1 | Veracruz | Soledad de Doblado | El Progreso | −96.4022719 | 19.0818742 |
| VER2 | Veracruz | Paso del Macho | Loma Pelada | −96.5398368 | 18.9258796 |
| YUC1 | Yucatán | Tzucacah | Tzucacah | −89.0391111 | 20.0720278 |
| YUC2 | Yucatán | Mérida | Frac. el Parque | −89.5872222 | 20.9711111 |
| YUC3 | Yucatán | Peto | Teshan | −88.62125 | 20.1486389 |
| YUC4 | Yucatán | Baca | Felipe Carrillo Puerto | −89.60700993 | 20.9954688 |

wing color, presence of wings, the fragility of the wings, and hardness of the seeds were determined.

### Statistical analysis

An analysis of variance was performed to identify significant differences ($P<0.05$) among the states where seeds were collected, and then the Tukey test ($P<0.05$) was performed for the quantitative descriptors using the Infostat version 2020e software. The correlation coefficient, principal component analysis, and cluster analysis were performed through hierarchical clustering with a coefficient of variation in the unweighted pair group (Euclidean distance). The two-dimensional scatter diagram was performed using the percentage of variation in the first two principal components. The PAST 3.0 software was used.

## RESULTS AND DISCUSSIONS

### Climatic variables

An average temperature of 24.71 °C was identified, with a minimum of 10.46 °C and a maximum of 34.80 °C. Moringa cultures tolerate temperatures of 12 to 48 °C (Roloff *et*

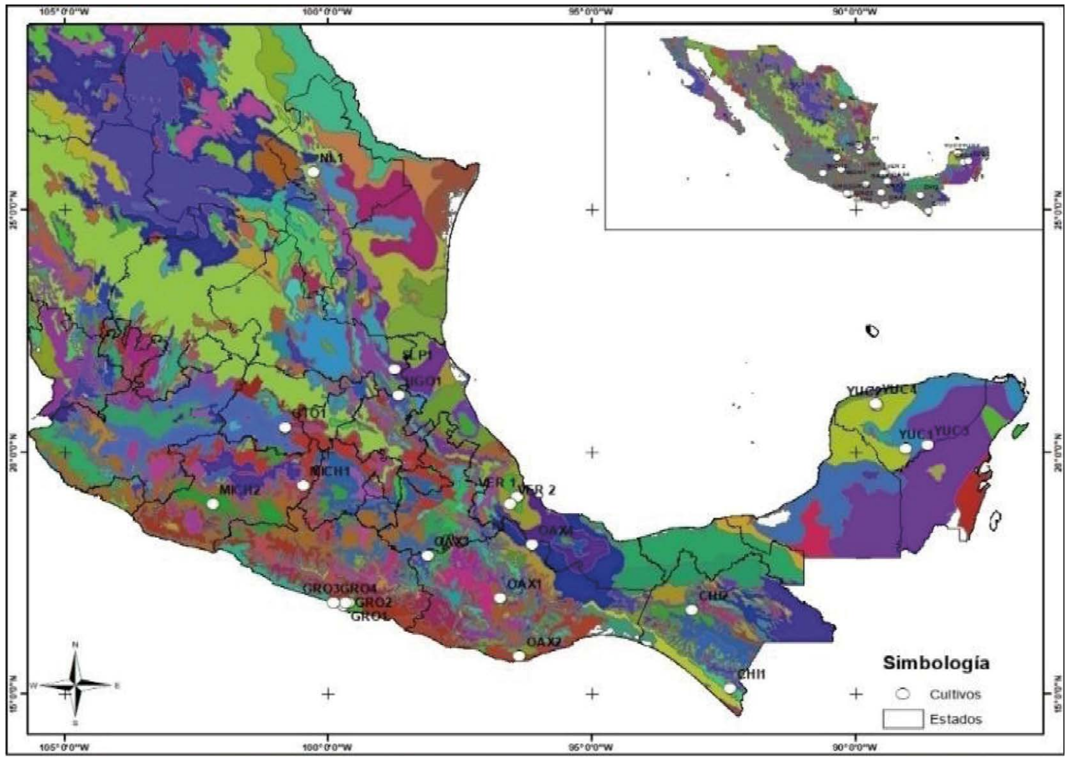


**Figure 1**. The geographical location of *M. oleifera* crops sampled. The types of climates present in the Mexican Republic are observed.

*al.*, 2009). However, temperatures below 16 °C affect pollen viability (Radice & Giordani, 2018) and lower than 10 °C prevent flowering; therefore, they require a range of 25 to 35 °C to guarantee the production of biomass and fruits (Pandey *et al.*, 2011). Moringa responds positively under this temperature range because winter is not so cold and favors flowering and seed production (Adebayo *et al.*, 2011). The minimum and maximum precipitation regimes identified were 521 and 3005 mm year$^{-1}$. These values are within the range (250 to 2000 mm per year) for its establishment (Adikuru *et al.*, 2011). However, the water requirement is a function of each phenological stage of the plant, being 1000 mm the optimal precipitation for seed production (Olson and Alvarado, 2016). The climate with the most significant predominance in the sampled crops was the Awo, which is warm-humid with an average annual temperature greater than 22 °C and the humidity range most frequent was subhumid (w1). Muhl *et al.* (2011) mention that moringa predominates in sub-humid tropical climates because it is the most recommended for production purposes.

Regarding altitude, the minimum value identified was 11m, and the maximum was 1,755 m. Olson and Alvarado (2016) pointed out that crop performance decreases as altitude increases being 500 m the maximum altitude for the establishment of crops (Velázquez-Zavala *et al.*, 2016). Despite having excellent acclimatization capacity, factors such as precipitation, humidity range, wind speed, and altitude affect morphological variations in moringa (Martínez *et al.*, 2014). Förster *et al.* (2015) mentioned that environmental factors influence morphometric traits, phenology, and production. Ledea-Rodríguez *et al.* (2018)

**Table 2**. Climatic data of the *M. oleifera* crops sampled.

| Crop | Meant* (°C) | Mint (°C) | Maxt (°C) | Rainfall (mm) | Climate type | Humidity | Altitude (m) | Dominant soil | Soil moisture regime |
|---|---|---|---|---|---|---|---|---|---|
| CHI1 | 27.03 | 20.69 | 33.37 | 3005 | Am | humid (m) | 169 | Acrisol | Udico 270 to 330 DDH* |
| CHI2 | 25.32 | 18.84 | 31.80 | 985 | Awo | Subhumid (w0) | 529 | Leptosol | Xerico 90 to 180 DDH |
| GRO1 | 26.63 | 20.83 | 32.43 | 1207 | Awo | Subhumid (w1) | 30 | Arenosol | Xerico 90 to 180 DDH |
| GRO2 | 26.85 | 20.78 | 32.92 | 1162 | Awo | Subhumid (w1) | 39 | Arenosol | Xerico 90 to 180 DDH |
| GRO3 | 26.78 | 20.81 | 32.74 | 1179 | Awo | Subhumid (w1) | 56 | Arenosol | Xerico 90 to 180 DDH |
| GRO4 | 26.22 | 20.88 | 31.56 | 1253 | Aw1 | Subhumid (w1) | 217 | Arenosol | Xerico 90 to 180 DDH |
| GTO1 | 18.74 | 10.46 | 27.02 | 638 | BS1hw | Semiarid (BS1) | 1755 | Vertisol | Ustico 180 to 270 DDH |
| HGO1 | 23.45 | 17.80 | 29.10 | 1737 | A(f) | Humid (m) | 249 | Regosol | Udico 270 to 330 DDH |
| MICH1 | 21.81 | 14.38 | 29.23 | 961 | Aw1 | Subhumid (w1) | 1196 | Feozem | Udico 270 to 330 DDH |
| MICH2 | 27.29 | 19.77 | 34.80 | 717 | BS1(h')w | Árid (BS0) | 265 | Vertisol | Xerico 90 to 180 DDH |
| NL1 | 21.83 | 15.18 | 28.48 | 521 | BS1hw | Semiarid (BS1) | 478 | Vertisol | Xerico 90 to 180 DDH |
| OAX1 | 20.26 | 11.99 | 28.53 | 688 | BS1(h')w | Subhumid (w0) | 1518 | Regosol | Ustico 180 to 270 DDH |
| OAX2 | 25.86 | 19.38 | 32.34 | 1119 | Awo | Subhumid (w0) | 183 | Arenosol | Aridico less than90 DDH |
| OAX3 | 23.92 | 15.59 | 32.25 | 699 | BS1(h')w | Subhumid (w0) | 1102 | Leptosol | Xerico 90 to 180 DDH |
| OAX4 | 24.91 | 19.86 | 29.96 | 2242 | Am | Humid (m) | 32 | Cambisol | Udico 270 to 330 DDH |
| SLP1 | 24.32 | 18.47 | 30.16 | 1316 | Aw1 | Subhumid (w1) | 98 | Vertisol | Ustico 180 to 270 DDH |
| VER 1 | 25.23 | 19.53 | 30.93 | 1143 | Awo | Subhumid (w1) | 68 | Vertisol | Xerico 90 to 180 DDH |
| VER 2 | 24.72 | 19.07 | 30.37 | 1144 | Awo | Subhumid (w1) | 216 | Vertisol | Ustico 180 to 270 DDH |
| YUC1 | 25.53 | 18.44 | 32.62 | 1085 | Awo(x') | Subhumid (w0) | 36 | Luvisol | Xerico 90 to 180 DDH |
| YUC2 | 25.78 | 19.09 | 32.47 | 1053 | Awo | Subhumid (w0) | 11 | Leptosol | Aridico less than90 DDH |
| YUC3 | 25.34 | 18.46 | 32.22 | 1178 | Aw1(x') | Subhumid (w1) | 29 | Leptosol | Xerico 90 to 180 DDH |
| YUC4 | 25.79 | 19.15 | 32.44 | 1030 | Awo | Subhumid (w0) | 12 | Leptosol | Aridico less than90 DDH |

T*: temperature, DDH*: number of humid days.

highlighted the importance of knowing the environmental conditions when studying aspects of the moringa seed, mainly to guarantee seed production under temperature conditions and optimal irrigation.

**Quantitative descriptors**. Significant statistical differences (P<0.05) were obtained in the seed length of the 22 populations evaluated (Table 3). The OAX1 and CHI2 populations obtained 0.98 and 1.54 cm, respectively. The value of the CHI2 population is similar to the 1.5 cm reported by Zhigila *et al.* (2015), where he evaluated 30 accessions of moringa and higher than the 1.03 of Ramos *et al.* (2010) and 1.16 of López *et al.* (2018). Significant differences (P<0.05) were found in the width of the seed, and the range was 0.74 (VER2) to 1.11 cm (VER1) between the evaluated populations. These values are lower than the minimum (0.88 cm) and maximum (1.11 cm) reported by Zhigila *et al.* (2015) and similar to the 1.00 cm of Ramos *et al.* (2010) and 1.09 cm from López *et al.* (2018).

Significant differences (P<0.05) in length, wide and weight were observed among the evaluated materials. The 0.420 g observed in CHI2 is higher than the 0.300 g of Makkar and Becker (1997), 0.280 of López *et al.* (2018), 0.197 from Ramos *et al.* (2010), 0.274 g from Shaltout *et al.* (2017), and 0.305 from Popoola *et al.* (2016). Bezerra *et al.* (2004) mentioned that heavier seeds produced vigorous seedlings, and medium-weight seeds showed higher growth speed. This characteristic allows discarding materials of lower weight and thus guarantee each individual's gemination and survival processes (Popoola *et al.*, 2016). The quantitative variation identified in the seed weights it is the product of each crop's environmental effect and agronomic management, in addition to the individual potential of each genetic material modulated by environmental conditions (Ledea-Rodríguez *et al.*, 2018). The average weight of 100 seeds was 29.08 g with a minimum and a maximum of 21.29 and 38.60 g. The average value is similar to the 29.94 g reported by López *et al.* (2018) and less than 30.59 g of (Popoola *et al.*, 2016). The almond weight percentage related to the total weight was in the range of 62.63 and 77.02% for the YUC1 and GRO4 populations, respectively. Makkar and Becker (1997) mentioned that the almond occupies 75% of the total weight of the seed, and Valdés *et al.* (2018) identified that the almond occupies 71% of the total weight of the seed. This attribute indicates that the seed can be favored in the germination process and serve as an elite material for improvement.

**Correlation analysis**. The strongest positive correlation was observed between the mean weight of 100 seeds, seed weight and Almond weight (%), the length and weight of the seed, and seed weight and almond weight (r=0.84) (Table 4). A correlation of r=0.41 was found between the mean temperature and the weight of the seed. Moreover, a correlation of r=0.43 between the maximum temperature and the weight of the seed. The multiple introductions of moringa material in the country, the genetic diversity, and its high tolerance to different types of stress may be influencing this low relationship (Olson and Fahey, 2011; Tian *et al.*, 2015). Dao and Kabore (2015) mentioned the non-existence of a significant correlation between geographic location, altitude, and precipitation on moringa morphology. However, this aspect can be clarified by evaluating the same material in different environments.

**Table 3**. Morphometry of *M. oleifera* seeds from different crops in Mexico.

| Crop | Length(cm) | Width (cm) | Weight(g) | Weight of 100 seeds(g) | Almond weight (g) | Almond Weight (%) |
|---|---|---|---|---|---|---|
| CHI1 | 1.32$^{G}$ ± 0.02 | 1.02$^{HIJ}$ ± 0.01 | 0.380$^{J}$ ± 0.01 | 37.96 | 0.290 | 70.65 |
| CHI2 | 1.54$^{H}$ ± 0.02 | 1.07$^{JK}$ ± 0.01 | 0.420$^{K}$ ± 0.01 | 38.60 | 0.320 | 70.36 |
| GRO1 | 1.02$^{ABC}$ ± 0.02 | 0.87$^{BC}$ ± 0.01 | 0.240$^{A}$ ± 0.01 | 22.55 | 0.190 | 74.41 |
| GRO2 | 0.99$^{AB}$ ± 0.02 | 0.85$^{B}$ ± 0.01 | 0.240$^{A}$ ± 0.01 | 21.29 | 0.180 | 72.88 |
| GRO3 | 1.00$^{AB}$ ± 0.02 | 1.07$^{JK}$ ± 0.01 | 0.310$^{EFG}$ ± 0.01 | 29.56 | 0.250 | 72.16 |
| GRO4 | 1.17$^{F}$ ± 0.02 | 1.06$^{J}$ ± 0.01 | 0.370$^{J}$ ± 0.01 | 35.68 | 0.310 | 77.02 |
| GTO1 | 1.04$^{ABC}$ ± 0.02 | 0.91$^{CD}$ ± 0.01 | 0.250$^{AB}$ ± 0.01 | 24.75 | 0.200 | 70.24 |
| HGO1 | 1.04$^{ABC}$ ± 0.02 | 0.88$^{BCD}$ ± 0.01 | 0.250$^{AB}$ ± 0.01 | 24.49 | 0.230 | 74.79 |
| MICH1 | 0.99$^{AB}$ ± 0.02 | 0.89$^{BCD}$ ± 0.01 | 0.250$^{AB}$ ± 0.01 | 22.99 | 0.190 | 69.15 |
| MICH2 | 1.16$^{EF}$ ± 0.02 | 0.98$^{FGH}$ ± 0.01 | 0.340$^{HI}$ ± 0.01 | 31.53 | 0.260 | 72.74 |
| NL1 | 1.10C$^{DEF}$ ± 0.02 | 0.93$^{DEF}$ ± 0.01 | 0.290$^{CDE}$ ± 0.01 | 26.76 | 0.200 | 71.79 |
| OAX1 | 0.98$^{A}$ ± 0.02 | 0.89$^{BCD}$ ± 0.01 | 0.260$^{ABC}$ ± 0.01 | 26.19 | 0.230 | 74.93 |
| OAX2 | 1.14$^{DEF}$ ± 0.02 | 1.00$^{GHI}$ ± 0.01 | 0.320$^{FGHI}$ ± 0.01 | 29.70 | 0.240 | 71.28 |
| OAX3 | 1.30$^{G}$ ± 0.02 | 1.03$^{IJ}$ ± 0.01 | 0.320$^{EFGH}$ ± 0.01 | 29.64 | 0.220 | 69.82 |
| OAX4 | 1.03$^{ABC}$ ± 0.02 | 0.91$^{CD}$ ± 0.01 | 0.260$^{AB}$ ± 0.01 | 27.24 | 0.260 | 76.21 |
| SLP1 | 1.06$^{BC}$ ± 0.02 | 0.92$^{DE}$ ± 0.01 | 0.270$^{BCD}$ ± 0.01 | 27.08 | 0.220 | 71.95 |
| VER1 | 1.31$^{G}$ ± 0.02 | 1.11$^{K}$ ± 0.01 | 0.380$^{J}$ ± 0.01 | 37.71 | 0.290 | 70.4 |
| VER2 | 0.97$^{A}$ ± 0.02 | 0.74$^{A}$ ± 0.01 | 0.300$^{DEF}$ ± 0.01 | 30.30 | 0.240 | 70.4 |
| YUC1 | 1.07$^{BCD}$ ± 0.02 | 1.07$^{JK}$ ± 0.01 | 0.280$^{BCD}$ ± 0.01 | 27.41 | 0.160 | 62.63 |
| YUC2 | 1.00$^{AB}$ ± 0.02 | 0.90$^{CD}$ ± 0.01 | 0.260$^{AB}$ ± 0.01 | 25.12 | 0.210 | 74.99 |
| YUC3 | 1.09$^{CDE}$ ± 0.02 | 0.97$^{EFG}$ ± 0.01 | 0.340$^{GHI}$ ± 0.01 | 30.67 | 0.240 | 69.89 |
| YUC4 | 1.15$^{EF}$ ± 0.02 | 1.00$^{GHI}$ ± 0.01 | 0.350$^{IJ}$ ± 0.01 | 32.49 | 0.260 | 70.61 |

CHI: state of Chiapas, GRO: state of Gerrero, GTO: state of Guanajuato, HGO: state of Hidalgo, MICH: state of Michoacan, NL: state of Nuevo Leon, OAX: state of Oaxaca: SLP: state of San Luis Potosi, VER: state of Veracruz, YUC: state of Yucatan; 1,2,3,4: collection sites within each mexican state; ±: estandar error.

**Table 4**. Correlation matrix of the quantitative descriptors of *M. oleifera* seeds.

| | Seed length (cm) | Seed width (cm) | Seed weight (g) | Almond weight (%) | Mean temperature (°C) | Minimum temperature (°C) |
|---|---|---|---|---|---|---|
| Seed width(cm) | 0.68* | | | | | |
| Seed weight(g) | 0.85* | 0.7* | | | | |
| Almond weight (%) | 0.67* | 0.48* | 0.84* | | | |
| Mean weightof 100 seeds(g) | 0.81* | 0.68* | 0.97* | 0.88* | | |
| Altitude (m) | | | | | −0.85* | -0.92* |

*: P-value <0.05.

**Qualitative descriptors**. Three forms of seed were identified in the evaluated populations: triangular, spherical, and oval. Four colors in the seeds were observed: light brown, brown, dark brown, and black, with wings and semi-winged (Table 5).

A higher frequency of spheric and oval shape seeds was identified. The triangular shape seeds were identified only in four populations. Zhigila *et al.* (2015) identified oval and isometric seeds with predominant wings, while Makkar and Becker (1997) mentioned that the seeds are spheric with a semi-permeable layer of brown to black color with three white wings spaced at 120°. In this investigation, a higher frequency of brown and dark brown seeds was found. However, other works have reported dark brown (Palada, 1996), brown (Makkar and Becker, 1997; Ramos *et al.*, 2010), brown to black (Parrotta, 2009), pale yellow to creamy, and white seeds (Anwar *et al.*, 2006: Anwar and Rashid, 2007). Makkar and Becker (1997) mentioned that white seeds have low viability, representing a negative aspect of germination. White wings were identified in most of the evaluated crops; the above is in line with the results of Zhigila *et al.* (2015) when identifying the presence of white wings in their evaluation. Ramos *et al.* (2010) mentioned that the wings were light brown.

## Principal component analysis

The principal component analysis demonstrated the morphological variability of the seed in the 22 moringa populations (Table 6).

In the dispersion figure of components, four groups were observed. Group 1 integrated the GRO1, GRO2, GTO1, HGO1, MICH1, NL1, OAX1, OAX4, SLP1, and YUC2. Group 2 integrated the GRO3, MICH2, OAX2, OAX3, VER2, YUC3, and YUC4 crops. In group 3, only the YUC1 crop was included, and group 4 included GRO4, CHI1, CHI2, and VER1 cultures (Figure 2).

## Cluster analysis

The cluster analysis identified four groups. Group 1 integrated subgroup A (GTO1 and MICH1) and subgroup B (HGO1, YUC2, OAX1, OAX4, NL1, SLP1, GRO1, and GRO2).

**Table 5**. Qualitative descriptors were used to evaluate the morphological diversity in *M. oleifera* seeds.

<table>
<tr><th>Crop</th><th>Seedshape</th><th>Color of testa</th><th>Seeds</th><th>Color of wings</th><th>Brittle wings</th><th>Seedcoat</th><th>Almond color</th><th>Pest presence</th></tr>
<tr><td>CHI1</td><td>Oval</td><td>Brown</td><td>Winged</td><td rowspan="18">Brownish</td><td>Yes</td><td rowspan="14">Hard</td><td rowspan="22">White</td><td rowspan="14">No</td></tr>
<tr><td>CHI2</td><td>spherical</td><td>Brown</td><td>Winged</td><td rowspan="4">No</td></tr>
<tr><td>GRO1</td><td>Oval</td><td>Brown</td><td>Semi-winged</td></tr>
<tr><td>GRO2</td><td>Spherical</td><td>Brown</td><td>Winged</td></tr>
<tr><td>GRO3</td><td>Triangular</td><td>Brown</td><td>Semi-winged</td></tr>
<tr><td>GRO4</td><td>Spherical</td><td>Brown</td><td>Semi-winged</td><td>Yes</td></tr>
<tr><td>GTO1</td><td>Oval</td><td>Light brown</td><td>Semi-winged</td><td>No</td></tr>
<tr><td>HGO1</td><td>Spherical</td><td>Brown</td><td>Winged</td><td rowspan="5">Yes</td></tr>
<tr><td>MICH 1</td><td>Spherical</td><td>Brown</td><td>Winged</td></tr>
<tr><td>MICH 2</td><td>Spherical</td><td>Dark Brown</td><td>Winged</td></tr>
<tr><td>NL1</td><td>Spherical</td><td>Brown</td><td>Winged</td></tr>
<tr><td>OAX1</td><td>Oval</td><td>Black</td><td>Semi-winged</td></tr>
<tr><td>OAX2</td><td>Triangular</td><td>Brown</td><td>Winged</td><td>No</td></tr>
<tr><td>OAX3</td><td>Triangular</td><td>Dark Brown</td><td>Semi-winged</td><td rowspan="2">Yes</td></tr>
<tr><td>OAX4</td><td>Oval</td><td>Dark Brown</td><td>Semi-winged</td><td rowspan="2">Membranous</td><td>Yes</td></tr>
<tr><td>SLP1</td><td>Spherical</td><td>Brown</td><td>Winged</td><td rowspan="2">No</td><td rowspan="3">No</td></tr>
<tr><td>VER 1</td><td>Oval</td><td>Brown</td><td>Winged</td><td rowspan="2">Hard</td></tr>
<tr><td>VER 2</td><td>Spherical</td><td>Brown</td><td>Semi-winged</td><td rowspan="3">Yes</td></tr>
<tr><td>YUC1</td><td>Triangular</td><td>Dark Brown</td><td>Winged</td><td>Brown</td><td>Membranous</td><td>Yes</td></tr>
<tr><td>YUC2</td><td>Oval</td><td>Brown</td><td>Winged</td><td rowspan="3">Brownish</td><td rowspan="3">Hard</td><td rowspan="3">No</td></tr>
<tr><td>YUC3</td><td>Spherical</td><td>Brown</td><td>Winged</td><td rowspan="2">No</td></tr>
<tr><td>YUC4</td><td>Spherical</td><td>Dark Brown</td><td>Winged</td></tr>
</table>

Group 2 integrated the GRO3, OAX2, OAX3, VER2, YUC3, MICH2, and YUC4 populations. Group 3 only to the YUC1 population and group 4 to the VER1, CHI1, and CHI2 populations (Figure 3). Tian *et al.* (2015) mentioned that morphological diversity is associated with genetic diversity.

The identification of morphological diversity allows the selection of characters of greater adaptive and productive importance. The information obtained through morphological descriptors helps breeders select materials with desirable traits for farmers and consumers (Gitonga *et al.*, 2008).

## CONCLUSIONS

There was significant morphological variation in Moringa oleifera seeds grown in Mexico. The qualitative and quantitative descriptors used were highly informative to clarify

**Table 6**. Principal component analysis of morphological characters of *M. oleifera* seeds.

| Characteristic | CP* 1 | CP 2 | CP 3 | CP 4 | CP 5 | CP 6 | CP 7 |
|---|---|---|---|---|---|---|---|
| Seed length (cm) | 0.023 | −0.002 | −0.002 | 0.016 | 0.021 | 0.024 | 0.068 |
| Seed width (cm) | 0.013 | −0.005 | −0.016 | −0.026 | 0.026 | 0.053 | 0.005 |
| Seed weight (g) | 0.010 | 0.000 | −0.011 | 0.002 | 0.008 | −0.001 | 0.016 |
| Almond weight (%) | 0.007 | 0.007 | −0.001 | −0.001 | 0.005 | 0.004 | 0.000 |
| Percentage of the almond weight inrelation to the total weight (%) | −0.118 | 0.982 | −0.060 | −0.077 | 0.020 | 0.094 | 0.041 |
| Mean weight of 100 seeds (g) | 0.992 | 0.118 | 0.011 | −0.021 | −0.002 | 0.007 | −0.006 |
| Seed shape | −0.009 | 0.109 | 0.771 | 0.595 | −0.112 | −0.107 | −0.112 |
| Color of testa | −0.009 | −0.056 | 0.544 | −0.489 | 0.356 | 0.215 | 0.533 |
| Seeds | 0.015 | −0.053 | −0.215 | 0.458 | −0.246 | 0.608 | 0.552 |
| Color wings | −0.001 | −0.049 | 0.032 | −0.091 | −0.125 | 0.136 | −0.138 |
| Brittle wings | 0.008 | −0.017 | −0.127 | 0.330 | 0.855 | 0.259 | −0.242 |
| Seed coat | 0.009 | 0.028 | −0.123 | 0.167 | 0.143 | −0.587 | 0.468 |
| Almond color | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Pest presence | 0.006 | 0.027 | −0.163 | 0.211 | 0.176 | −0.362 | 0.308 |
| Eigenvalue | 25.498 | 9.245 | 0.435 | 0.356 | 0.261 | 0.164 | 0.131 |
| % variance | 70.581 | 25.590 | 1.204 | 0.984 | 0.722 | 0.453 | 0.363 |

CP*: Principal Components.

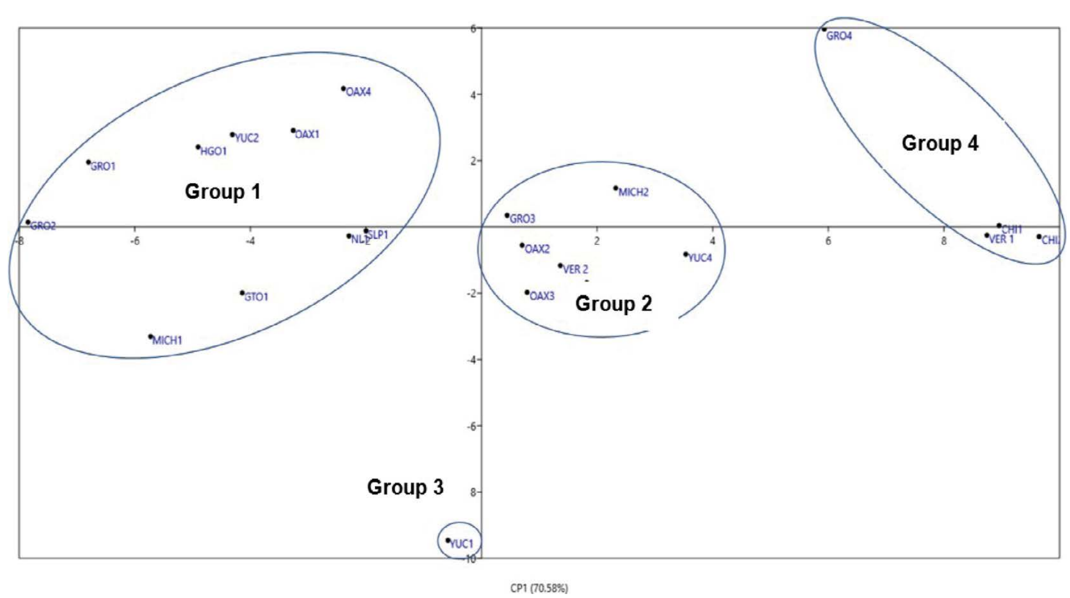


**Figure 2**. Dispersion of components 1 and 2 for the 22 cultures of *M. oleifera*.

the variation among the *Moringa oleifera* populations; in this sense, the seeds from the state of Chiapas (sites 1 and 2) and Veracruz (site 1) showed the highest weight suggesting that heavier seeds produced vigorous seedlings, and medium-weight seeds have shown higher

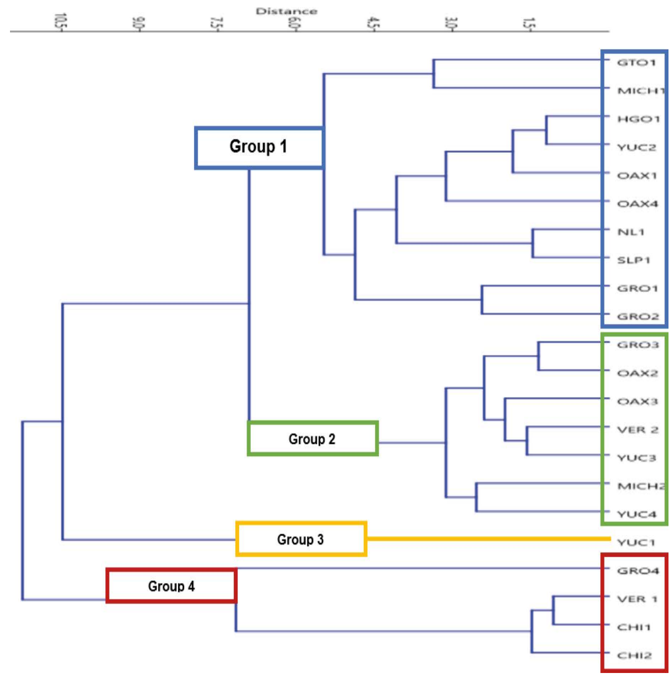


**Figure 3**. Cluster analysis based on the morphological descriptors of *M. oleifera* seeds

growth speed. This information contributes to the knowledge of this multipurpose species and serves as the basis for creating conservation and genetic improvement programs.

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