AP AGRO PRODUCTIVIDAD

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Characterization of mamey [*Pouteria sapota* (Jacq.) Moore & Stearn] in the Totonacapan Poblano of Puebla, Mexico

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ABSTRACT

Objective: The objective of this study was to morphologically characterize mamey in 10 municipalities of the Sierra Nororiental of Puebla (Totonacapan Poblano), Mexico.

Design/methodology/approach: In the study, 206 accessions obtained from simple random sampling using qualitative and quantitative morphological descriptors were evaluated, using an analysis of variance, principal components and hierarchical cluster analysis with the Gower distance and the Ward grouping method.

Results: Quantitative descriptors had high coefficients of variability (12.66% to 43.40%). The principal components analysis indicated that components 1 (41.66%), 2 (19.97%) and 3 (16.62%) accounted for 78.25% of the variance and the cluster analysis identified eight groups; the tree and leaf variables turned out to be the most important to group the samples.

Limitations on study/implications: For greater accuracy on the morphological diversity of mamey, it is necessary to include more descriptors of the fruit and the flower.

Findings/conclusions: The descriptors that contributed the most to the grouping were those related to the shape, height and size of the tree, and the weight, size and shape of the leaf; in relation to the fruit, the descriptor that contributed the most was the shape. These results could be useful in programs of conservation, improvement, and use of the mamey.

Keywords: morphological diversity, conglomerates, Sierra Norte of Puebla, Sapotaceae.

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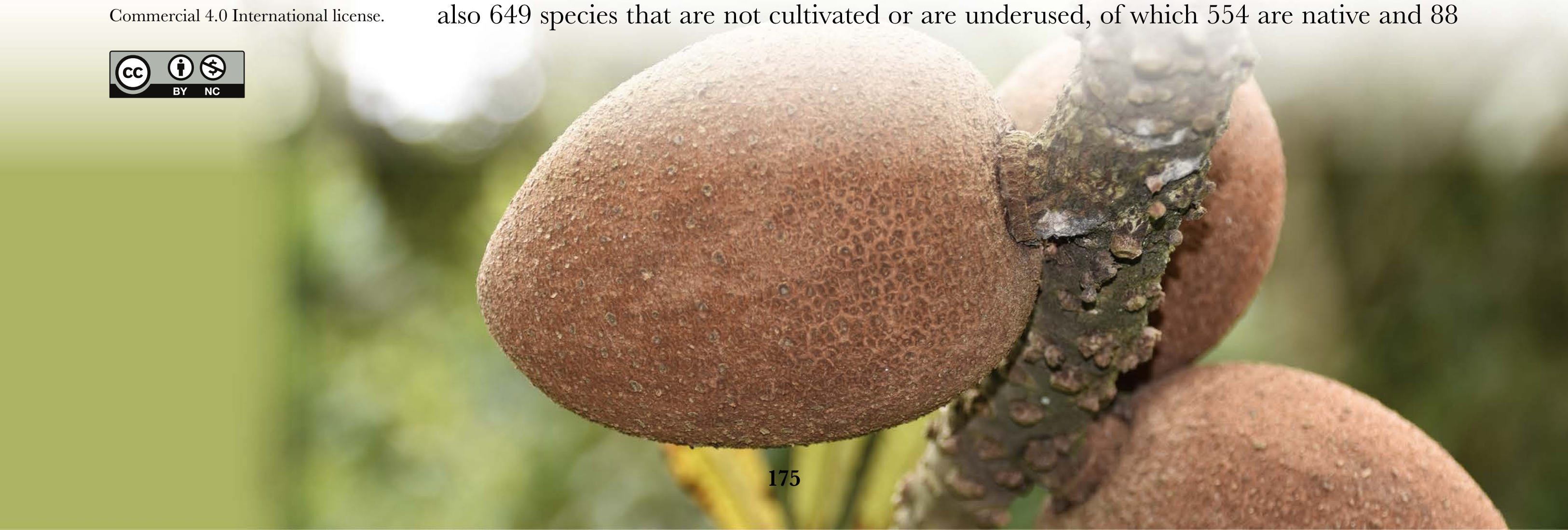
INTRODUCTION

Segura *et al.* (2018) mention that 762 species of edible fruits are cultivated in Mexico, which are distributed into 87 families and 288 genera; in addition, they mention that there are 113 species of fruit trees cultivated, of which 53 are native and 60 introduced; there are also 649 species that are not cultivated or are underused, of which 554 are native and 88



introduced. One of these underused species is mamey [*Pouteria sapota* (Jacq.) Moore and Stearn] from the Sapotaceae family and native to the country, which together with other species from the families Myrtaceae, Cactaceae, Annonaceae and Fabaceae were already consumed by the native peoples of Mesoamerica (González & Del Amo, 2012). Presently, *P. sapota* is valuable for its fruit because it presents several nutritional properties such as fiber, fat, iron, calcium, proteins, sodium, vitamins and healthy carbohydrates for human beings (Velázquez *et al.*, 2015).

Mamey is a species native to tropical and subtropical zones of Central America and southeastern Mexico, which is considered to be its possible center of domestication (Martínez-Castillo *et al.*, 2019). This species is distributed from the south of Sinaloa to Chiapas and in the Gulf of Mexico, from Tamaulipas to Tabasco, as well as in the Yucatán Peninsula and central states such as Morelos, Guanajuato, Estado de México, San Luis Potosí, Hidalgo, Querétaro and Puebla; some of the states mentioned have zones with tropical and subtropical climates (Núñez-Colín *et al.*, 2017). Mexico is the principal mamey producer in the world, with a surface sown of 1,731.71 hectares and a production of 21,800.42 tons, and more than 87.87% of national production is concentrated in the states of Yucatán with 62.28%, Guerrero 12.23%, Veracruz 6.09%, Michoacán 3.87% and Puebla 3.40% (SIAP, 2021).

In Mexico there are studies about the morphological characterization of mamey (Bayuelo-Jimenez & Ochoa, 2006; Gaona-García *et al.*, 2008), focused on maturation of fruits in ecotypes (Domínguez *et al.*, 2010), characterization of post-harvest management (Villarreal-Fuentes *et al.*, 2015), characteristics of mamey quality (Espinosa-Zaragoza *et al.*, 2016), and tolerance to forced warm air in the fruits (Ariza *et al.*, 2018). On the other hand, Villegas-Monter *et al.* (2016) analyzed aspects about the diversity and uses of mamey, while Carpio *et al.* (2015) studied the phenology of mamey. However, there are few studies regarding variations of growth habits, tree shape, and leaf shape (Calderón *et al.*, 2011). The morphological characterization of plant genetic resources is a procedure used to measure and know the genetic variability of a population, to differentiate plants, and to conserve genetic resources (Hernández, 2013). This study had the objective of morphologically characterizing mamey (*P. sapota*), using morphological variables of trees, leaves and fruits in 10 municipalities of the Totonacapan Poblano region, with the purposes of improvement and conservation.

MATERIALS AND METHODS

Study area and sampling

A total of 206 accessions were collected in 10 municipalities of the Totonacapan Poblano region, located in the Sierra Nororiental of Puebla (Figure 1). The climate in these municipalities is warm with rainfall nearly all year long, with altitudinal zones that range from 90 m to 1020 m of altitude with annual rainfall of 800 mm to 2000 mm, zones of up to 4000 mm and a mean annual temperature between 18 °C and 26 °C (Barrera-Rodríguez *et al.*, 2009).

The field phase was carried out from November to December 2020 and February to March 2021. The sampling was simple random, five leaves were included per tree, labeled

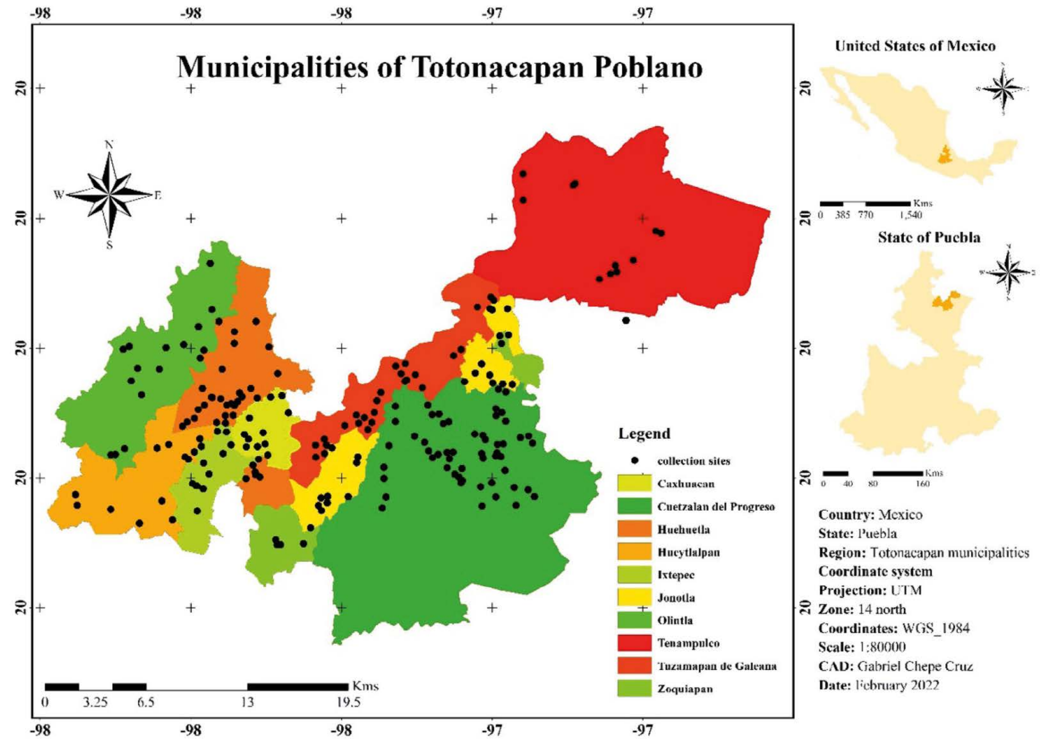


Figure 1. Geographical location of the 206 accessions of *P. sapota* in 10 municipalities of the Totonacapan Poblano region.
Source: Prepared by the authors with vectorial data from INEGI (2020).

and stored in a cooler with average temperature of 4 °C to later store them at −20 °C. For the morphological characterization, quantitative and qualitative descriptors adapted to mamey were obtained as presented by Azurdia *et al.* (1997) to characterize mamey fruits and trees (Table 1).

The length, width and weight of the leaf were measured from each sample using a Mitutoyo brand Vernier. The weight was determined with an analytical scale Velab VE-204. The qualitative descriptors of the tree, leaf and fruit were determined visually.

Statistical analysis

The Principal Components Analysis (PCA) and the conglomerate analysis were conducted with the software RStudio version 4.1.1 (RStudio Team, 2021). For the Pearson's coefficients and descriptive statistics, the functions used were summary and corr; the principal components analysis was done with the prcomp function, of the factoextra package (Kassambara & Mundt, 2020). For the Conglomerate analysis (Cluster) the daisy and hclust functions from the cluster package were used (Maechler *et al.*, 2021). To determine the number of conglomerates, the function used was kgs, of the maptree package (White & Gramacy, 2012).

The PCA was obtained with standardized data through the function scale of R, and then the traits that contributed most to differentiate mamey materials were identified. To determine the number of principal components (PC), the Cliff (1988) criterion and the

Table 1. Morphological descriptors used to characterize mamey.

Descriptor	Code	Unit of measure or state of the descriptor
Tree		
Height	ATL	Meter (m)
Height to the first branch	APR	Meter (m)
Diameter at chest height	DAP	Centimeter (cm)
Sample status	EM	1) Inserted, 2) Native, 3) Wild
Type of vegetation or production system	TV/SP	1) Acahual, 2) Kuojtakiloyan, 3) Pepper, 4) Paddock, 5) High evergreen forest, 6) Cedar agroforestry system, 7) Shade coffee system, 8) Citrus system, 9) Milpa system, 10) Backyard
Tree habit	HA	1) Columnar, 2) Pyramidal, 3) Rectangle, 4) Round, 5) Irregular
Canopy shape	FC	1) Pyramidal, 2) Round, 3) Irregular
Leaf		
Leaf blade length	LL	Centimeter (cm)
Leaf blade width	AL	Centimeter (cm)
Leaf Length/width ratio	RL/A	Dimensionless
Leaf blade area	AF	Square centimeter (cm^2)
Leaf blade weight	P	Gram (g)
Leaf shape	FH	1) Cuneate, 2) Linear, 3) Oblanceolate, 4) Obovate, 5) Ovate
Fruit		
Fruit shape	FF	1) Ellipsoid, 2) Spheroid, 3) Ovoid
Fruit tip shape	FA	1) Curved, 2) Straight

Kaiser (1960) criterion were used. In the cluster analysis, a dendogram based on both quantitative and qualitative descriptors, was constructed; pondering was based on Gower (1971) distances. Grouping was based on Ward's (1963) hierarchical method. The number of conglomerates was estimated using the penalization function by Kelley-Gardner-Sutcliffe through the KGS statistics (Kelley *et al.*, 1996).

RESULTS AND DISCUSSION

Descriptive statistics

The descriptive statistics of the eight quantitative descriptors measured in the 206 accessions of mamey in ten municipalities of the Sierra Nororiental of Puebla are shown in Table 2. In this study the traits had high coefficients of variability (CV) (12.66% to 43.40%); according to Hidalgo (2003), the traits that present CV lower than 20% indicate low variability, although this is not a decision criterion to identify the use of traits in the analysis.

The frequencies of scoring of each qualitative descriptor of *P. sapota* are described next: in the state of sampling, 54.9% are native and 44.2% are introduced. In type of vegetation or production system, it was found that 28.2% corresponded to acahual, 23.8% to a shade coffee sustem, 18% to backyard, 9.7% to the milpa system, 7.3% to the system called Kuoujtakiloyan, 5.3% to the citrus system, 3.4% to pastureland, 2.4% to the pepper system, and lastly the tall sub-evergreen forest and cedar agroforestry system only presented

Table 2. Quantitative descriptors and statistical parameters in mamey samples.

Code	Average*	S	R	Minimum	Maximum	CV (%)
ATL	12.65	4.32	25.21	5.22	30.43	34.13
APR	3.15	1.37	9.43	0.56	9.99	43.40
DAP	44.16	16.38	90.35	1.16	91.52	37.10
LL	34.28	6.85	34.94	18.96	53.89	19.99
AL	9.97	2.35	20.94	4.50	25.44	23.53
RL/A	3.48	0.44	3.64	1.28	4.92	12.66
AF	180.94	69.67	396.81	49.86	446.67	38.50
P	5.84	1.93	13.92	1.37	15.30	33.03

S=standard deviation; R=range of variation; CV=coefficient of variation. ATL=tree height, APR=height of the first branch, DAP=diameter at chest height, LL=laminar length, AL=laminar width, RL/A=length:width ratio of the leaf, AF=leaf area, P=weight, *n=206.

1%. Regarding the tree's growth habit, the results were: pyramidal 46.6%, round 41.7%, without shape 8.7%, rectangular 2.4% and columnar 0.5%. In the descriptor crown shape, it was found that 47.1% was pyramidal, 44.7% semi-circular and 8.3% without shape. For leaf shape, it was found that 71.4% were oblanceolate, 19.4% obovate, 5.3% cuneate, 3.4% linear and 0.5% oval. In fruit shape, the results were: ellipsoidal 54.4%, spheroid 24.3% and ovoid 21.4%, with straight apex in 99% and 1 % curve.

Correlation between the descriptors

Pearson's correlation coefficients for the eight quantitative descriptors are shown in Table 3. Most of the correlations (15) between the descriptors were significant ($p<0.05$) and 13 were not. The highest correlations were found in the morphological descriptors of the leaf, the strongest positive correlations were found between AF and AL (0.91), between AF and LL (0.88), between P and LL (0.76), and P and AF (0.74). These correlations mean that the leaf width and length are directly related with the leaf area and weight. On the other hand, RL/A were negatively correlated with AL (−0.41); this signals that as the leaf

Table 3. Matrix of Pearson's correlation coefficients of the quantitative descriptors of 206 mamey samples.

	ATL	APR	DAP	LL	AL	RL/A	AF	P
ATL	1.00							
APR	0.33***	1.00						
DAP	0.45***	0.16*	1.00					
LL	0.16*	0.10	0.14*	1.00				
AL	0.08	0.08	0.15*	0.63***	1.00			
RL/A	0.07	0.02	−0.01	0.36***	−0.41***	1.00		
AF	0.12	0.10	0.16*	0.88***	0.91***	−0.07	1.00	
P	−0.02	0.02	0.09	0.76***	0.58***	0.06	0.74***	1.00

*, **, *** indicate statistical significance in the p value of 0.05, 0.01 and 0.001, respectively. ATL=tree height, APR=height at first branch, DAP=diameter at chest height, LL=leaf length, AL=leaf width, RL/A=leaf length:width ratio, AF=leaf area, P=weight.

width decreases, the leaf length/weight ratio will increase. The minimal correlations were present in the following descriptors: ATL and LL (0.16), APR and DAP (0.16) and in turn DAP and LL (0.14), DAP and AL (0.15) and lastly DAP and AF (0.16). This shows that there is a minimal relation between the descriptors of height of the first branch with leaf width and length.

Principal components analysis

The principal components analysis indicated that PC1, PC2 and PC3 explain 41.66%, 19.97% and 16.62% of the variability, and together they explain 78.30% (Table 4). PC1 explained 41.66% of the variance, including the descriptors AF, LL, AL, P, which are leaf variables. PC2 contribute 19.97% of the variance, where the descriptors that contributed most were: ATL, DAP and APR. Finally, PC3 explained 16.62% of the variance, where descriptors RL/A and LL stood out.

In general, the descriptors evaluated contributed to a large extent to the variance (Figure 2), which agrees with results from Bayuelo-Jimenez & Ochoa, (2006), Gaona-García, Tejacal-Alia *et al.*, (2008) and Rodríguez-Gaytán *et al.*, (2021) who used some similar desciptors; this suggests that these descriptors are useful to carry out the characterization of mamey. The PCA presented high levels of variability, which helped to identify the groups that were generated through the cluster analysis.

Hierarchical conglomerate analysis

Eight groups were identified at a Gower distance of 1.3 (Figure 3). The characteristics of each group are summarized next. Conglomerate one grouped 21 individuals, most from the municipality of Tuzamapan de Galeana, with trees of low height (16.62 m to 6.03 m), with

Table 4. Results from the PCA of the quantitative descriptors used to characterize the mamey accessions.

Components	1	2	3
Eigen value	3.33	1.6	1.33
Variance percentage	41.66	19.97	16.62
Cumulative variance percentage	41.66	61.63	78.25
Descriptors	Eigen values		
ATL	0.208	−0.817	−0.080
APR	0.167	−0.597	−0.096
DAP	0.260	−0.665	−0.179
LL	0.903	0.009	0.387
AL	0.862	0.172	−0.414
RL/A	−0.013	−0.214	0.962
AF	0.976	0.112	−0.052
P	0.827	0.210	0.180

ATL=tree height, APR=height to the first branch, DAP=diameter at chest height, LL=leaf blade length, AL=leaf blade width, RL/A=leaf blade length to width ratio, AF=leaf blade area, P=leaf blade weight.

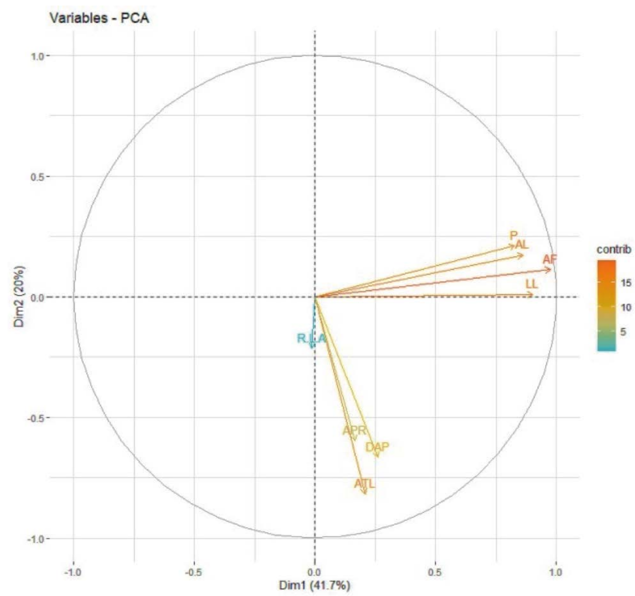


Figure 2. Contributions of the mamey descriptors according to what is determined in PC1 and PC2. ATL=tree height, APR=height at first branch, DAP=diameter at chest height, LL=leaf length, AL=leaf width, RL/A=leaf length:width ratio, AF=leaf area, P=weight.
Source: Prepared by the authors with Rstudio v.4.1.1.

large leaves of average leaf area of 189.16 cm^2, with a tree growth habit and crown without shape and ellipsoidal fruit; these results can be due to the management by producers since the municipality is known for producing mamey, among other fruits. Cluster two showed 32 accessions from the municipalities of Jonotla, Ixtepec, Cuetzalan del Progreso, Olintla and Huehuetla, with the lowest height at first branch with an average of 2.70 m and a high length/width ratio of the leaves, which can result from management practices; most of the accessions were found in a shade coffee system. Group three had 23 samples from the municipalities of Hueytlalpan, Huehuetla, Caxhuacan, Cuetzalan del Progreso and Tenampulco, the trees presented a high height with average of 15.53 m; this group had the highest DAP (56.65 cm), with round tree growth habit and semi-circular crown, the trees were found in the acahual vegetation which implies low human intervention, generating the conditions for greater development. Conglomerate four presented 32 individuals from the municipalities of Tuzamapan de Galeana, Cuetzalan del Progreso and Olintla, and in the descriptors related to the tree presented averages of: ATL (12.92 m), APR (3.33 m), DAP (53.18 m) and in those related to the leaves: LL (33.68 cm), AL (9.68 cm), R L/A (3.49), AF (174.97 cm^2), P (5.69 g); they are present in acahual vegetation or shade coffee system, with fruit of spheroid shape and two accessions presented a round apex, this group is similar to a group reported by Gaona-García, Alia-Tejacal *et al.* (2008) in the southwest region of the state of Morelos.

Conglomerate 5 had 19 accessions from the municipalities Caxhuacan, Cuetzalan del Progreso and Huehuetla; this conglomerate presented the highest data in ATL (16.02 m), APR (3.67 m), LL (40.68 cm), AL (11.39 cm), AF (238.99 cm^2) and P (7.34 g), the accessions were found in the shade coffee system with pyramidal tree growth habit

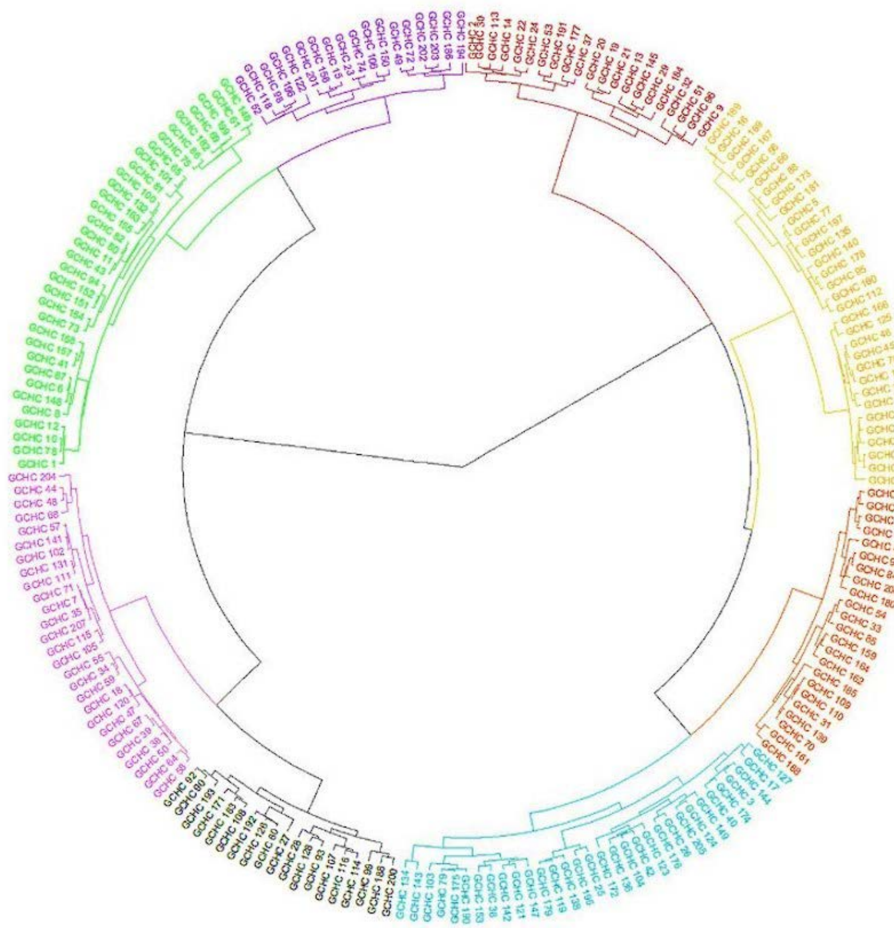


Figure 3. Dendogram constructed through Ward's accumulative hierarchical algorithm and Gower distances of 15 morphological variables in *P. sapota*, eight conglomerates are observed.
Source: Prepared by the authors with Rstudio v.4.1.1.

and shape of the crown, with obovate shaped leaves and spheroid fruits; these growth conditions of the tree can be influenced by the management of the system where they belong and favor the conditions such as nutritional state, relative opening of the crown, initial height of the seedling, and size of the seed (Ricker *et al.*, 2000)secondary forest, and open pasture in Los Tuxtlas (Veracruz, Mexico. Conglomerate six had 27 samples from the municipalities of Huehuetla, Tuzamapan de Galeana, Jonotla and Cuetzalan del Progreso; in this group the lowest data in LL (30.33 cm), RL/A (3.23), AF (156.58 cm^2) and P (4.9 g) were found, with native accessions in acahual vegetation with pyramidal tree growth habit and crown shape, with leaves of oblanceolate shape and ellipsoidal fruit. Conglomerate seven presented 34 individuals from the municipalities Huehuetla, Ixtepec, Cuetzalan del Progreso and Tenampulco; this group presented the lowest data of DAP (31.28 cm), and in addition they are of low growth habit with ATL of 10.93 m with an APR of 3.05 m; they are accessions introduced to acahual vegetation with pyramidal growth habit and crown shape, oblanceolate leaves, and ellipsoid fruits. Conglomerate eight presented 18 individuals from the municipalities of Huehuetla and Cuetzalan del Progreso; this conglomerate had the lowest data in descriptors ATL (10.12 m) and AL (9.44 cm), with samples introduced in backyard productive systems of pyramidal growth tree habit and crown shape, oblanceolate leaves, and spheroid fruits; this last trait is similar to what was reported by Bayuelo-Jimenez & Ochoa (2006) in some genetic materials of *P. sapota* from the center-west of Michoacán, and because of their nature of being introduced they can be scarcely adapted to the conditions of these two municipalities with a low height.

CONCLUSIONS

In the Sierra Norte of Puebla, in the Totonacapan Poblano region, a high morphological variability was detected in *P. sapota* where eight conglomerates of mamey were differentiated. The descriptors that contributed most to the grouping were those related to the shape, height and size of the tree, as well as the weight, size and shape of the leaf; regarding the fruit, the descriptor that contributed most was the shape. These results could be useful in programs for conservation, improvement and exploitation of mamey.

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