Article

Identification and morphological characterization of agaves in agroforestry systems with metepantle in peasant lands

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Abstract

Agave varieties were identified in 11 classes of peasant lands in Tepetlaoxtoc de Hidalgo, State of Mexico; as well as; its morphological characterization of what are popularly known as magueyes pulqueros; through the analysis of clusters and the main component. 7 varieties were found: Manso (*Agave salmiana* Otto ex Salm.), Verde (*Agave americana* L.), Ayoteco (*Agave salmiana* Otto ex Salm.), Carrizo (*Agave mapisaga* Trel.) and Pua larga (*Agave* sp.). The varieties of maguey Manso and Verde are found in all classes of peasant lands, inducing that all evaluated individuals are phenotypically similar or closely related, in contrast, the Pua larga was found only in three classes of land. The Ayoteco and Carrizo varieties were found in five soil classes, both with phenotypic characteristics closely related to the maguey Manso. The greatest morphological development was found in the yellow soil class, where the maguey Verde, Pua larga, Carrizo and Ayoteco obtained their best development in crown diameter and height. The maguey Manso had a crown diameter (distance between leaf and open leaf) of between 1.15 to 3.5 m and a height of 1.2 at 2.8 m. In contrast, the Carrizo presented 1.7 to 2.37 m in crown diameter and a height of 1.23 to 2.1 m respectively. The farmers of Tepetlaoxtoc have conserved this diversity of varieties of maguey pulquero due to the diversity of multiple uses that they provide and continue in their domestication process, influencing their morphology.

Keywords: agroforestry, maguey pulquero, peasant lands.

Reception date: March 2020
Acceptance date: May 2020

Introduction

In Mesoamerican agroforestry systems, the use of metepantle, a concept formed by the Nahuatl words «metl», maguey or agave, and «pantli», flag or division (Montemayor, 2009), is an ancestral agricultural practice, which refers to cultivation of maguey in rows perpendicular to the slope of the terrain. In the municipality of Tepetlaoxtoc de Hidalgo, State of Mexico, this ancestral agricultural practice is in force, because the cultivation of the agave pulquero persists in the ecological conditions of the region, reflected in social and productive practices determined by the historical articulation of its technological and cultural processes, as well as its impact on the region, privileged as a center of origin and diversity of the agave by natural selection for 9 000 years, for the domestication, management and multiple uses that the native peoples have developed. However, at the same time it is a strategy for the conservation of biodiversity and the food security of communities (Koohafkan and Altieri, 2011; Flores-Sánchez *et al*., 2012).

The cultivation and culture of agave pulquero is a sample of the complex management of soil and vegetation resources; ancestral knowledge, which has been preserved with slight changes in their names or adapted to technological innovations (Aguilar *et al*., 2014). The product of the maguey, since pre-Hispanic times, more renowned is the pulque, in Nahuatl «octli», the essential drink in ritual life as a drink in ceremonies related to different deities such as Quetzalcoatl and Mayahuel; in addition to being present in countless symbols, myths, traditions, images, sounds, textures, habitats, food, clothing, games and colloquial language (Olivier, 2012). However, these agricultural systems are not necessarily productive, due to the social-environmental problems triggered by the change in the use and management of natural resources and the consumption habits of peasant communities, coupled with a general deterioration in capacity productive land, which has progressively fractured the millennial man-agave relationship.

In the search to generate joint strategies of characterization, revaluation and improvement of this ancestral agricultural practice of land management with metepantle, in Tepetlaoxtoc, the objective of this work was to identify the pulp agave varieties and their morphological structure, based on the scientific and popular knowledge, which will allow its subsequent comprehensive management, recognizing its usefulness to conserve the agro-diversity of the communities that practice it, since together with the cultivation of corn, it was fundamental for the life of the peoples of central Mexico throughout its history, due to the cultivation conditions between rows, its form of use, its production processes and the culture of the agave (Godoy *et al*., 2003).

Materials and methods

Geographical description of the study area

The study area in Tepetlaoxtoc, is located between the coordinates 19° 35’ 54’’ and 19° 24’ 30” north latitude, 98° 50’ 02” and 98° 46’ 34’’ west longitude and an elevation between 2 300 and 2 469 m, in a diversity of geological structures of the volcanic-tectonic process between the end of the Paleozoic period and during the Mesozoic, which resulted in landscapes of hills and alluvial planes (Gutiérrez *et al*., 2017). It belongs to the Panuco basin, the Moctezuma river sub-basin, with the intermittent currents of the Hondo river and the Sila river (INEGI, 2010).

The climate corresponds to the Bs(c)wk'g type, according to the Köppen classification, modified by García (1973), with an annual average temperature of 15.5 °C, a maximum of 26.9 °C and a minimum of 3.9 °C . The soils reported are Phaeozem, Vertisol (Gutiérrez *et al*., 2017), Andosol and Umbrisol (INEGI, 2010), where agave pulquero is grown in rows perpendicular to the slope of the land and mainly corn, beans, squash and broad beans between rows under seasonal agriculture with some introduced crops such as oats.

Varieties of agave pulquero

The characterization was made in a total of 33 sample units distributed in the 11 classes of peasant land: tepetatuda roja (tr), tepetatuda parda (tp), barro blanco (bb), barro pardo (bp), tepetatuda blanca (tb), barro oscuro (bo), amarilla (am), barro (ba), amarilla arenosa (aa), tepetatuda amarilla (tm) and amarilla barruda (ab). Which were named in terms that peasants use daily to refer to them with respect to certain features of the arable layer of the soil.

Such as the color, texture, wet consistency, dry consistency, moisture retention, opportunity for tillage and soil fertility, which occur on Regosols, Anthrosols (terraces) and Fluvisols (alluvial plane) class soils. The common names of the agave pulquero varieties present and the age were determined in the field in the company of the key informants, and the taxonomic identification was obtained according to the database of technical names or commonly used in the use of agaves in Mexico, subject to the International Botanical Nomenclature Code (Colunga-García, 2006) and its herbarium identification.

Morphological structure of agave pulquero varieties

Morphological characteristics established in the technical guide for the varietal description of Agave sp., from the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) and the National Seed Inspection and Certification Service (SNICS)-(2014) were evaluated, with a convenience sampling, in the plots that the key informants considered representative of the agroforestry systems with metepantle, because the land classes have more uses, urban, mining, livestock.

The transects were 30 meters long, perpendicular to the terrain slope, with a width that depended on the largest distance of the diameter of the open shaft of the maguey and the widest of the transect, and they were also left 2 m at the beginning of each transect to avoid the shore effect and the random choice of three plants per transect. Each plant was evaluated for height (m), total number of pencas (leaves unfolded), basal area (m, %), crown diameter, which for practical purposes was named the diameter of pencas to open pencas, (m, %), the coverage (m,%) in two orientations N-S and E-W.

The morphology of the leaves was evaluated by the random choice of three leaves per plant, which were measured: length (m), width of the middle part of the leaf (m), number of lateral spines, length of the spine terminal (mm) and the separation between lateral spines (mm) with the use of the vernier. In addition, the plantation density (number of agaves/variety/transect) was quantified.

Quantitative evaluation of agave pulquero varieties in the peasant land classes

This analysis was based on the Euclidean distance; starting from the morphological characteristics evaluated by each variety of agave pulquero in the 11 classes of peasant lands, which allowed the clusters to be distinguished with the use of the Statgraphics Centurion© XVI version 1.11 statistical program.

Conglomerate analysis (cluster analysis) and principal component analysis were applied based on the methodology suggested by Dallas (2004) to quantitatively evaluate hierarchical levels that served as the basis for classifying the morphological structure of agave pulquero varieties, in such a way that the distribution of the values of the variables was the most homogeneous and between clusters the most different from each other.

Results and discussion

Varieties of agave pulquero

The varieties that are popularly known as maguey Manso, maguey Verde, maguey Ayoteco, maguey Carrizo, maguey Pua largo, which are in the group of species of the genus agave reported for the production of fermented and distilled beverages, were distinguished (Gentry, 1982). According to taxonomic studies (Rzedowski and Rzedowski, 2005), both Manso and Ayoteco maguey are classified as *Agave salmiana*, while reed as *Agave mapisaga* Trel (Alfaro, 2007).

The distribution of agave pulquero varieties in the peasant land classes is shown in Table 1. Maguey Manso and Verde were present in all land classes, the Ayoteco was found in classes tb, tm, aa, am, ba and ab, the Carrizo in classes tb, tm, aa, ba and bb and the Pua larga only in classes tr, aa and am.

Table 1. Varieties of agave pulquero present in the peasant land classes in Tepetlaoxtoc, State of Mexico.

Land class	Abbreviation	Varieties of agave pulquero
Tepetatuda roja	tr	1, 2 and 5
Tepetatuda parda	tp	1 and 2
Tepetatuda barruda	tb	1, 2, 3 and 4
Tepetatuda Amarilla	tm	1, 2, 3 and 4
Amarilla arenosa	aa	1, 2, 3, 4 and 5
Amarilla	am	1, 2, 3 and 5
Barro pardo	bp	1 and 2
Barro	ba	1, 2, 3 and 4
Barro obscuro	bo	1 and 2
Amarilla barruda	ab	1, 2 and 3
Barro blanco	bb	1, 2 and 4

1= maguey Manso; 2= maguey Verde; 3= maguey Ayoteco; 4 maguey Carrizo; and 5= maguey Pua larga.

The agaves pulqueros *A. salmiana* Otto ex Salm. and *A. americana* L. that are present in all land classes, according to Colunga-García (2006), are found in the group of magueyes that continue to have regional and potential relevance, which have been cultivated since pre-hispanic times and that they are currently more widely disseminated (Alvárez *et al.*, 1998; Valadez, 2014; Vázquez *et al*., 2016; Vela, 2018).

Authors such as García-Mendoza (1995) report that agave pulquero develops in a wide variety of soils, in the study area it was observed that they range from tepetatuda to mud-type lands, whose label corresponds to descriptive terminology It involves the criteria of color, texture and presence of tepetate, in relation to both characteristics of opportunity for tillage and the peculiarities of the design of the metepantle.

Research carried out by Alfaro *et al*. (2007) indicate that this type of distribution is the product of specific selections of producers in the search to obtain defined and differentiated morphological materials related to the characteristics of quality and quantity of mead, among many others, since they originate new phenotypes with a greater adaptability and response to extreme environments, which can contribute to success in nature or in its selection and use in agriculture (García-Mendoza, 2011).

The presence of two types of *A. salmiana* (Manso and Ayoteco) is due to their plasticity; that is, genetic infiltration of the forms cultivated with wild ones (García-Mendoza, 2011) and the morphological variability is due to human intervention (Mora-López *et al*., 2011). Due to this ancient and intense relationship between humans and agave, there are variants with regional, national and international importance, of which there is considerable ancestral knowledge and high morphological variation (Colunga-García *et al*., 1996).

Morphological structure of agave pulquero varieties

From the morphological point of view the varieties of agave pulquero found are different (Table 2); however, according to Alfaro *et al*. (2007) genetically the maguey Manso and the Ayoteco are similar, since they are selections that have originated from a common ancestor and that at some point separated and gave rise to the species that are currently known.

Table 2. Morphological structure of maguey varieties in the peasant land classes in Tepetlaoxtoc, Mexico.

Varieties	Land class	E	DC	C	C%	Db	Ab	Ab%	A
Manso	tr	5	1.79	2.52	4.66	0.5	0.19	0.36	1.38
	tp	8	3.5	9.62	8.91	0.8	0.5	0.47	1.92
	tb	12	3.25	8.3	6.91	1.25	1.23	1.06	2.8
	tm	15	2.12	3.53	5.47	0.77	0.46	0.71	2.2
	aa	16	3.2	8.02	8.35	0.42	0.14	0.14	1.22
	am	5	1.26	1.25	1.26	0.61	0.29	0.3	1.65
	bp	4	1.15	1.04	2.47	0.4	0.12	0.3	1.45
	ba	9	1.44	1.63	2.52	0.27	0.06	0.09	1.6

Varieties	Land class	E	DC	C	C%	Db	Ab	Ab%	A
	bo	9	1.85	2.69	4.07	0.62	0.3	0.46	1.4
	ab	10	1.95	2.99	4.33	0.53	0.22	0.31	1.6
	bb	8	1.55	1.89	3.14	0.48	0.18	0.3	1.4
Verde	tr	5	1.6	2.01	3.72	0.46	0.17	0.31	1.11
	tp	10	2.53	5.01	6.42	0.34	0.09	0.12	2.78
	tb	10	2.62	5.37	5.77	0.69	0.37	0.4	2.25
	tm	15	2.01	3.17	4.92	0.40	0.12	0.19	2.1
	aa	7	3.09	7.47	8.04	0.37	0.1	0.12	2.1
	am	7	2	3.14	2.99	0.65	0.33	0.32	2.3
	bp	5	1.75	2.41	3.82	0.5	0.19	0.31	1.26
	ba	10	1.79	2.52	4.3	0.49	0.18	0.32	1.75
	bo	15	1.69	2.24	3.94	0.55	0.24	0.42	1.7
	ab	10	1.83	2.62	4.71	0.51	0.2	0.37	2
	bb	7	1.44	1.62	3.59	0.34	0.09	0.2	1.2
Ayoteco	bb	8	3	7.07	7.6	0.47	0.17	0.18	1.71
	tm	15	1.96	3.02	4.68	0.42	0.14	0.21	2
	aa	7	2.78	6.05	6.5	0.26	0.05	0.06	2.03
	am	7	2.04	3.27	3.11	0.59	0.27	0.26	1.77
	ba	9	1.65	2.13	3.3	0.33	0.09	0.13	1.64
	ab	9	1.81	2.57	4.64	0.53	0.22	0.39	1.67
Carrizo	bb	5	2.37	4.41	4.74	0.69	0.37	0.4	1.93
	tm	10	1.42	1.57	3.49	0.23	0.04	0.09	2.1
	aa	7	2.59	5.27	5.49	0.39	0.12	0.12	1.45
	ba	10	1.7	2.26	3.86	0.52	0.21	0.36	1.54
	tb	4	1.71	2.3	5.89	0.34	0.09	0.23	1.25
Pua larga	tr	5	1.75	2.41	4.45	0.47	0.17	0.32	1.3
	aa	7	2.59	5.27	5.49	0.39	0.12	0.12	1.45
	am	5	1.15	1.04	1.05	0.66	0.34	0.34	2.15

E= Plant age (years); DC= crown diameter (m); C= coverage (m^2); C%= coverage (%); Db= basal diameter (m); Ab= basal area (m^2); Ab%= basal area (%); A= height (m).

The maguey Manso presented a variation in the crown diameter (from penca to open penca) from 1.15 to 3.5 m, with a coverage of 1.04 to 9.62 m and the basal diameter from 0.27 to 1.25 m, the basal area was from 0.06 to 1.23 m^2 and a height of 1.22 to 2.8 m. However, in the brown tepetatuda land class it was where it presented the greatest crown diameter (3.5 m) at an age of 8 years and a height of 1.92, in contrast to the same age in the white mud class it presented the least development (1.55 m and 1.4 m respectively).

These characteristics of plant height, basal area, number of leaves and leaf length are of particular importance for obtaining mead and obtaining barbecue penca (regional dish) (Alfaro *et al*., 2007). The maguey Verde was found in all the peasant classes of land, being in the yellow class where it presented the largest crown diameter (3.09 m) at an age of 7 years and a height of 2.1 m, in contrast in the white mud it presented a crown diameter of 1.44 m and a height of 1.2 m at the same age.

The maguey Ayoteco presented plantation ages from 7 to 15 years, the class of land where the largest crown diameter (3 m) was presented was white mud, however, the highest height was found in the yellow (2.03 m) in an age of 7 years. The relationship between plant height and leaf length indicates that the greater the height, the greater the length of leaves is expected, similarly to what was reported by Alfaro *et al*. (2007).

The maguey Carrizo was found in plantations with ages from 4 to 10 years, reaching its highest height in tepetatuda amarilla (2.2 m) and the maximum crown diameter of 2.59 m in the yellow soil class at an age of 7 years. In the long spike, plantation ages of 5 to 7 years and heights of 1.3 to 2.25 m were observed, with crown diameters from 1.15 to 2.41 m, crown coverage from 1.04 to 2.41 m^2, basal diameter from 0.39 to 0.66 m with a number of leaves unfolded from 10 to 18. The class of peasant land where it presented its best morphological development was yellow (Table 3).

Table 3. Morphological structure of the leaf of the maguey varieties in the peasant land classes in Tepetlaoxtoc, Mexico.

Variety	Land class	NTH	Lh	Aph	LET	NEL	SEL
Manso	Tr	18	1.15	0.2	73.1	10	29.95
	Tp	17	1.22	0.19	64.92	33	57.2
	Tb	20	1.79	0.3	53.5	50	40.5
	Tm	22	1.89	0.25	53	44	49.1
	Aa	13	2	0.32	74.7	40	68.29
	Am	12	1.1	0.27	62.92	30	60.42
	Bp	10	0.94	0.22	76.3	33	45.5
	Ba	10	1.1.1	0.22	80.9	30	66.6
	Bo	14	1.3	0.26	60.37	20	62.05
	Ab	15	1.57	0.23	81.33	19	75.57
	Bb	18	1.15	0.2	73.1	10	29.95
Verde	Tr	12	1.09	0.16	77.11	28	38.8
	Tp	12	1.09	0.17	77.11	28	38.8
	Tb	19	1.33	0.3	51.29	44	70.5
	Tm	20	1.79	0.31	53.5	50	40.5
	Aa	12	1.09	0.17	77.11	28	38.8
	Am	11	1.1	0.23	81.4	27	79.7
	Bp	11	0.93	0.18	58.88	30	46.42
	Ba	12	1.08	0.22	76.7	25	55.4

Variety	Land class	NTH	Lh	Aph	LET	NEL	SEL
	Bo	11	1.1	0.23	79.1	27	78.7
	Ab	11	1.1	0.23	79.1	27	78.7
	Bb	11	1.1	0.23	79.1	27	78.7
Ayoteco	Bb	19	1.33	0.3	51.29	44	70.2
	Tm	20	1.79	0.31	53.5	50	40.5
	Aa	10	1.1.1	0.22	80.9	31	66.6
	Am	12	1.1	0.27	62.92	30	60.42
	Ba	15	1.58	0.21	74.59	38	44.12
	Ab	17	1.22	0.19	64.92	33	57.2
Carrizo	Bp	18	1.49	0.31	63.07	39	71.63
	Tm	20	2.32	0.38	57.68	44	42.94
	Aa	14	0.89	0.21	67.3	31	44.4
	Ba	16	1.1	0.23	79.1	27	78.7
	Tb	15	1	0.23	84.53	22	87.44
Pua larga	Tr	18	1.15	0.2	73.1	10	29.95
	Aa	13	2	0.32	74,7	40	68.29
	Am	10	1.1	0.23	79.1	27	78.7

NTH= total number of leaves unfolded; Lh= leaf length (m); Aph= width middle part of the leaf (m); LET= length of terminal spine (mm); NEL= number of lateral spines; SEL= separation between lateral spines (mm).

The mean values of the morphological characteristics of the maguey Manso leaf showed a length of 0.94 to 2 m, the middle part of the leaf varied 0.19 to 0.32 m, the length of the terminal spine from 53 to 81.33 mm, the number of spines sides from 10 to 50 and the separation between lateral spines from 29.95 to 75.57 mm. while the length of the leaves of the green maguey varied from 0.93 to 1.79 m, the middle part of the leaf from 0.16 to 0.31 m, the length of the terminal spine from 51.29 to 81.4 mm.

The number of lateral spines ranged from 25 to 50 with a lateral separation of 40.5 to 79.7 mm. This is attributed to the effect of the environment on the phenotype of plants, since the green and tame variants are genetically very different, but phenotypically similar (Alfaro *et al*., 2007). The maguey Ayoteco presented a number of unfolded leaves from 10 to 20, with a length of 1.1 to 1.79 m, the middle part of the leaf from 0.19 to 0.31 m, the length of the terminal spine of 51.29 and 80.9 mm, the number of lateral spines from 30 to 50 and the separation between lateral spines from 40.5 to 79.7 mm.

In agaves it has been documented that one of the elements of the domestication syndrome is gigantism (Colunga-García *et al*., 1996), the results of the study by Mora-López *et al*. (2011) indicate that the Ayoteco variety has large rosettes over three meters high. The tallest maguey pulquero plants were also the ones with more leaves, longer leaves and more lateral spines. The morphological characters evaluated did not allow establishing the existing genetic relationship between reed and green, since in the field these magueys are very different from each other, as mentioned by Alfaro *et al*. (2007).

The maguey Pua larga variety was found only in the tr, aa and am lands, with a total number of unfolded leaves from 10 to 18, leaf length from 1.1 to 2 m and width of the middle part with an interval of 0.2 to 0.32 m, number of spines from 10 to 40 and separation between spines from 29.95 to 8.7 mm. The morphological characteristics that made it possible to better distinguish the species and variants of magueyes pulquero were the length of the main spine and the number of lateral spines. The tallest magueyes pulquero plants are those with the highest number of leaves, longest leaves and the largest number of lateral spines.

The plants with the highest height are also those with the highest number of leaves, as in the case of maguey Manso, which are in agreement with the results of Rzedowski and Rzedowski (2005) since both are *Agave salmiana*. The morphological characterization contributes to the legal protection of varieties or cultivars in common use of this type of agave endemic to Mexico, and thereby promote its conservation and sustainable use (Avendaño-Arrazate *et al*., 2015).

Quantitative evaluation of the Structure of agave pulquero varieties and peasant land classes. Five dendrograms were obtained in the cluster analysis; from the morphological structure of each variety of maguey pulquero identified in the peasant land classes (Figure 1).

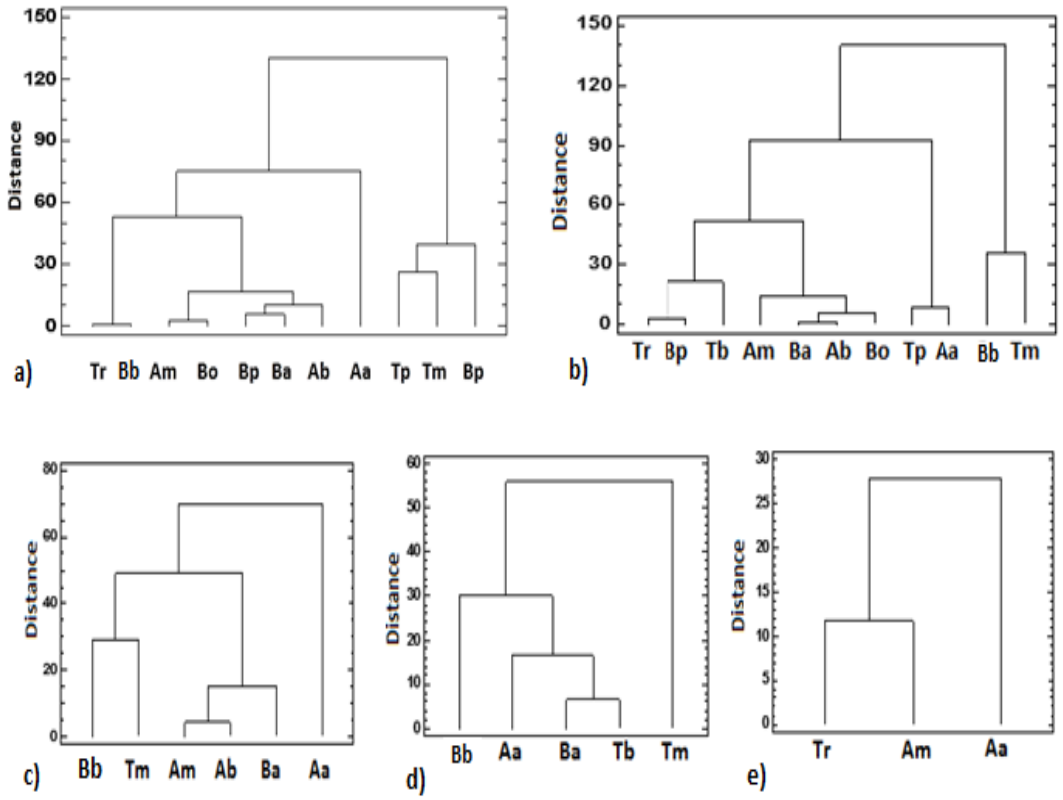


Figure 1. Dendrogram of the conglomerate analysis of the morphological structure of the maguey a) Manso; b) Verde; C) Ayoteco; d) Carrizo; and e) Pua larga in the peasant land classes where they are distributed in Tepetlaoxtoc, State of Mexico.

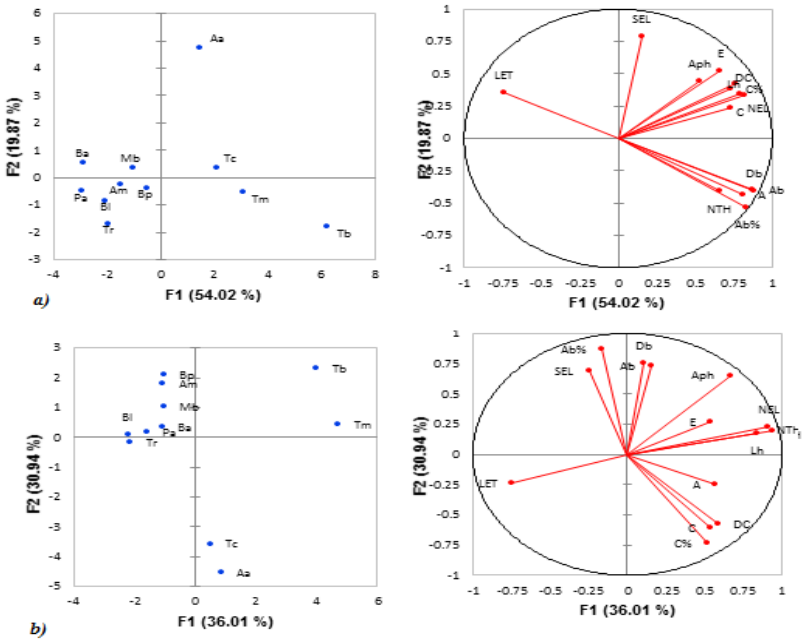
They were quantitatively evaluated with respect to the properties of the general structure of the plant and particularly of the leaf, which was an alternative to differentiate and group the soil classes where the agaves have similar characteristics, which will allow defining the agricultural potential since, as Alfaro *et al*. (2007), both complement each other. Bowley (1999) emphasizes that detecting the most important land classes in the differentiation of the generated groups is very useful since adaptation is seen in different classes.

The magueyes Manso and Verde are distributed in all classes because all the evaluated individuals are phenotypically equal or closely related, in contrast, with the maguey Ayoteco and the Carrizo were observed in five classes, so that both botanical varieties have phenotypic characteristics closely related to the maguey Manso, in contrast there is less closeness to the characteristics of the Pua larga since it was only found in three land classes.

Therefore, it is possible to distinguish the selections generated by producers in the degree of association between the morphological characteristics of agaves pulqueros and land classes, which according to Gaspar and Pérez (2009) is determined by the angular separation formed by their projections; it also considers the distance of each variable; starting from the origin and the process of humanization mentioned by Mora-López *et al*. (2011).

The analysis of the main component allowed establishing that the number of lateral spines and the length of the main spine represent 74% of the variability in the morphological structure of the magueyes. In addition, a correlation between plant height and number of lateral spines was detected, because in taller plants

The leaves tend to be larger and have more lateral spines. Mora-López *et al*. (2011) evaluated 48 morphological attributes in the *Salmianae* Section, of which, the highest coefficients of variation were presented in the characters: rosette height, stem length, tooth length, rosette diameter, thickness of cuticle, number of teeth and distance between teeth (Figure 2).



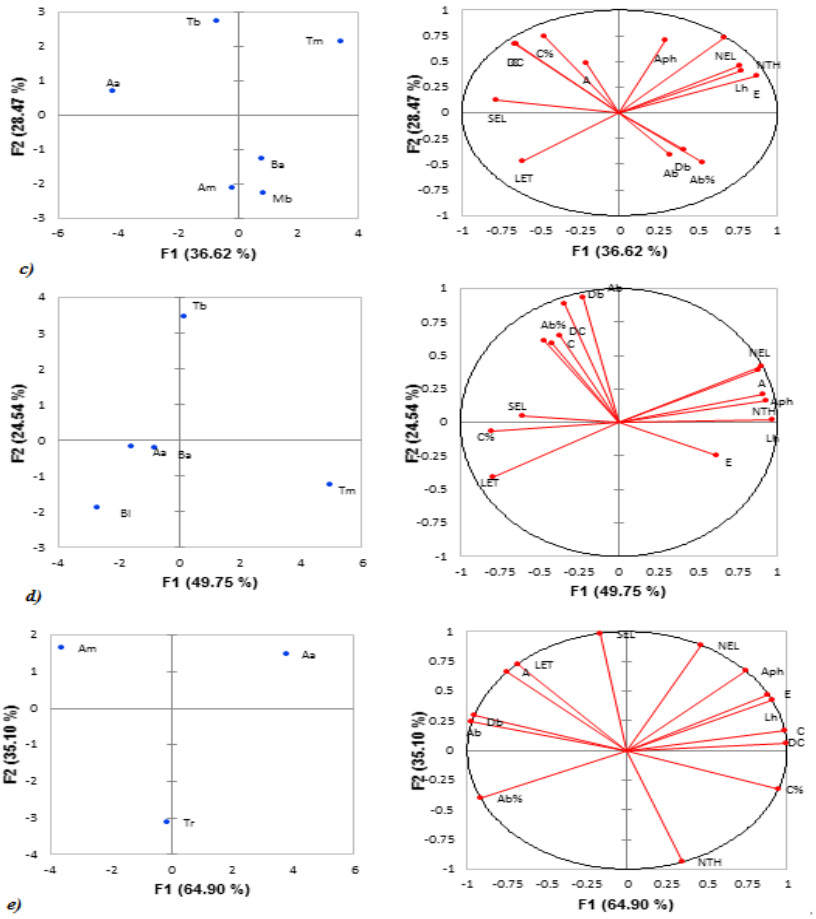


Figure 2. Analysis of the main component of the morphological structure of Maguey a) Manso; b) Verde; C) Ayoteco; d) Carrizo; and e) Pua Larga, in the peasant land classes are distributed in Tepetlaoxtoc, Mexico.

Conclusions

It was possible to identify 5 varieties of agave pulquero and their morphological structure in 11 types of peasant land, highlighting the tame and green that were found in all kinds of land. However, the greatest development occurred in the yellow soil class, where the maguey Verde, Pua larga, Carrizo and the Ayoteco obtained their best development in crown diameter and height.

Producers from the Tepetlaoxtoc region have selected these varieties of maguey that have provided them with a diversity of multiple uses, which have a degree of association between the morphological characteristics of agaves pulqueros and the benefits they provide, thereby conserving agro-diversity of this community that together with the cultivation of corn have been fundamental throughout its history for the life of the peoples of central Mexico.

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