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Article

# Agro-morphological characterization in *Aloe vera* genotypes in two states of Mexico

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## Abstract

In the last decade, the pharmaceutical industry has shown great interest in the cultivation of aloe vera [*Aloe vera* (L.) Burm. F.]. In Mexico, it is grown in different states and agroecological conditions. This study aimed to characterize *in situ* the agro-morphological characteristics of aloe vera at two sites in the states of Puebla and Veracruz, Mexico. In the 2019 agricultural cycle, two-year-old aloe vera plants were collected in both agroecological regions during both the dry and rainy seasons. The agro-morphological variables recorded were: leaf length, width, contour, thickness and weight, useful leaf weight, residue weight, gel weight, and skin weight. The edaphic variables analyzed were: pH, electrical conductivity, organic matter, texture, bulk density, total nitrogen, phosphorus, and potassium. In addition, the altitude and average temperature and precipitation of each site were recorded. The variables were analyzed through an analysis of variance, principal components and Pearson's correlation using the Rstudio program and the Statistical Analysis System. Significantly higher values ($p \leq 0.05$) were found in 60% of the agro-morphological variables of materials 1P, 2P, and 2V compared to 1V. According to the principal component analysis, the first two principal components accounted for 98.22% of the total morphological variability in the materials evaluated by site. There was a correlation between one geophysical variable, two climatic variables, two edaphic variables and morphological variables, except for leaf width. It is concluded that there is a significant relationship between the agro-morphological characteristics of aloe vera and the agroecological conditions of the site.

## Keywords:

agroecosystems, aloe vera, drought, agroecological zones.

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## Introduction

Aloe vera [*Aloe vera* (L.) Burm. F.] is a succulent plant that is grown in countries with semiarid climates; it belongs to the family Asphodelaceae (Liliaceae) (Surjushe *et al*., 2008) and thrives preferentially in dry climates (Bs), between 18 and 40 °C of temperature. In general, the *A. vera* plant grows in any type of soil with a high content of organic matter and good drainage, it does not resist low temperatures below 18 °C or very high solar radiation (Pedroza and Gómez, 2006).

Mexico ranks fourth in the world among the main producing countries of *A. vera*. At the national level, Tamaulipas ranks first with 4 044.7 ha, followed by Veracruz with 700 ha, and Puebla with 170 ha. In Veracruz, *A. vera* is grown under rainfed conditions, while in Puebla under irrigated and rainfed conditions (SIAP, 2017).

Several studies with *A. vera* show that edaphoclimatic and geographical conditions affect its development and growth (Flück, 1995; Saks and Ish-shalom-Gordon 1995; Páez *et al*., 2000; Tawfik *et al*., 2001; Acosta, 2003; Franco-Salazar *et al*., 2012).

Research such as that of Kumar *et al*. (2019) determined the morphological and biochemical diversity in 74 accessions of *A. vera* from the arid zone of India, with precipitation intervals of 100 to 400 mm, and found that morphological and biochemical characteristics are relevant descriptors to differentiate the genetic diversity of *A. vera* germplasm to be used in genetic improvement programs.

Since the agro-morphological variability present in the areas of highest production of *A. vera* in Mexico has not been systematized, the present study aimed to characterize *in situ* the agro-morphological characteristics of four genotypes of *A. vera* in the different sites in the states of Puebla and Veracruz, Mexico.

## Materials and methods

The climatic and geographical conditions of the sites where the evaluated *A. vera* materials were collected were: site 1P (18° 28 # 47.8” north latitude, 98° 35’ 24.0” west longitude, altitude 1 096 m, climate $AW_0$, precipitation 827 mm, and temperature 16.9 °C); site 2P (18° 26’ 18.1” north latitude, 98° 39’ 40.6” west longitude, altitude 1 102 m, climate $AW_0$, precipitation 827 mm, and temperature 16.9 °C); site 1V and site 2V (19° 18’ 30.1” north latitude, 96° 28’ 52.5” west longitude, altitude 136 masl, climate $AW_1$, precipitation 1 516 mm, and temperature 25.4 °C) (García, 2004).

The biological material corresponded to randomly selected commercial plantations of *A. vera*, considering the type of agronomic management. In 2019, 36 two-year-old plants were collected for each site and transported to the Agro-industrial Processes Pilot Plant of the College of Postgraduates, Veracruz *Campus* to carry out handling, cleaning, disinfection, and measurement operations. To record morphological variables and gel content, mature leaves of each plant were selected.

The agro-morphological variables recorded were: leaf length (LeLen, in Spanish LarHo ), width (LeWid, in Spanish AncHo) and contour (LeCon, in Spanish ConHo), with a tape measure (1 ±0.1 cm) (Hoechstmass®; Germany). The following was weighted: whole leaf (LeafW, in Spanish Phoja), useful leaf (ULeafW, in Spanish PhojaU), which corresponds to the part of the leaf used by agribusiness, gel weight (GelW, in Spanish Pgel), residue weight (LereW, in Spanish PreHo), stem weight, and root weight.

The weight (g) was obtained using an ES-3000H balance with a precision of 0.01 g (JD3000®; USA). Leaf thickness (LeThi, in Spanish EspHo) was measured with a digital vernier (0.1 mm) (Mitutoyo®; Kawasaki, Japan). The experimental design was completely randomized, using 36 experimental units (aloe vera plants) for each site.

The soil analysis was determined with the NOM-SEMARNAT-2000 standard. The AS-02 method was used for pH; the AS-16 for electrical conductivity (EC); organic matter (orM) using Walkley and Black’s AS-07 method. For bulk density (Bd), the formula used was:

$D=\frac{M}{V}$ (equation 1).

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Where: D= the density of the soil (g $cm^{-3}$); M= mass (g); and V= the occupied volume ($cm^3$). Total nitrogen (N) was determined by the AS-25 method by digestion. Phosphorus (P) and potassium (K) were determined by the Grow Master method for nutrient analysis in agriculture.

With the data obtained, an analysis of variance (Anova) was performed to detect significant differences in the morphological variables among the materials of *A. vera* and the means were compared using Tukey's test ($p\leq$ 0.05). In addition, a principal component analysis (PCA) was performed based on the correlation matrix of the averages of the agro-morphological variables, using the PRINCOMP procedure of the Statistical Analysis System, and the distribution of aloe vera materials was visualized in a Biplot graph (Gabriel, 1971).

Edaphic variables were analyzed in duplicate. Additionally, Pearson's correlation analysis was performed to determine the relationship between agro-morphological and agroecological variables, such as altitude (ALT), mean temperature (TEMP), and mean precipitation (PREC), the latter two corresponding to the last two years. Statistical analyses were analyzed using Rstudio (version 3.6.1) and SAS® V.9.0, NTSYSpc® V.2.21 software (Rohlf, 2009).

# Results and discussion

## Agro-morphological characteristics

Table 1 shows the mean and standard deviation of the agro-morphological variables of the *A. vera* genotypes studied. Genotypes 1P, 2P, and 2V had the highest values (>60 cm) in LeLen, in contrast to 1V (37.4 cm). For the LeWid variable, it was found that genotype 1P was the best (13 cm, $p\leq$ 0.05), compared to 2V with 8.6 cm. In the case of LeCon, no statistical difference was found between genotypes 1P and 2P, obtaining better values than 1V.

**Table 1. Statistical differences in the means of agro-morphological variables of *A. vera* plants from Puebla and Veracruz.**

| Variable | Puebla | | Veracruz | |
|---|---|---|---|---|
| | 1P | 2P | 1V | 2V |
| LeLen (cm) | 63.9 ±7.5a | 64.8 ±3.8a | 37.4 ±14.3b | 67.2 ±5.5a |
| LeWid (cm) | 13 ±17.5a | 10 ±1ab | 6.1 ±1ab | 8.6 ±0.7b |
| LeCon (cm) | 21.2 ±1.8a | 21.9 ±1.1a | 13.7 ±2.1c | 19.7 ±1.6b |
| LeThi (cm) | 2.3 ±0.5ab | 2.1 ±0.5b | 1.5 ±0.5c | 2.4 ±0.1a |
| LeafW (g) | 609.5 ±193.4a | 574.3 ±95.9a | 205.4 ±70.1b | 617.3 ±71.5a |
| ULeafW (g) | 509 ±179.9a | 476.9 ±108.9a | 166.7 ±59.1b | 472.8 ±68.1a |
| LereW (g) | 349.4 ±115.2a | 330.3 ±69.4a | 129.2 ±50b | 351 ±63.2a |
| GelW (g) | 260 ±86.3a | 244 ±38.6a | 76.2 ±36.7b | 266.3 ±82a |
| Stem (g) | 658.6 ±140.6a | 625 ±60.1a | 530 ±73.8b | 454.3 ±198.6b |
| Root (g) | 556.4± 163a | 572 ±201.2a | 416.6 ±166.5b | 312.3 ±95c |

Average value of thirty-six mature leaves ± standard deviation. Means with equal letters in rows are not statistically different (Tukey, $p\leq$ 0.05). The acronyms of the variables are described in materials and methods.

The highest value of LeThi was obtained by genotype 2V, with 2.4 cm. Materials 1P, 2P, and 2V had higher means ($p\leq$ 0.05) in LeafW, ULeafW, LereW, GelW, and stem weight. Alagukannan and Ganesh (2006) evaluated the morphological variables of *A. vera* plants collected in different soil and climatic conditions in India and found values similar to the present work, with values (minimum and maximum) of LeLen between 40.8 to 63.1 cm, 4.4 to 10.9 cm of LeWid, 1.5 to 2.7 cm of LeThi, 187.7 to 434.3 g of LeafW, and 112.6 to 282.5 g of GelW.

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Authors such as Kumar *et al*. (2019) obtained a range of variation between 30 to 57.5 cm in LeLen, 3 to 9.8 cm in LeWid, and 9.2 to 17.3 cm in LeThi, in *A. vera* plants collected only in the arid zone of India, where rainfall conditions from 100 to 400 mm prevail. The values reported by the authors cited above are similar to the values obtained in the present study. Some differences may be due to the availability of water in the different producing areas or to the genetic component.

The first three principal components (PC) accounted for 100% of the total agro-morphological variation among the genotypes studied (Table 2). The characteristics associated with PC1 were LeLen, LeWid, LeCon, LeThi, LeafW, ULeafW, LereW, and GelW, while stem and root weight were related to PC2.

**Table 2. Eigenvectors, eigenvalues, and proportion of the explained variation of the first three principal components (PC) of the agro-morphological characteristics of *Aloe vera*.**

| Variable | PC1 | PC2 | PC3 |
|---|---|---|---|
| LeLen (cm) | 0.97 | 0.22 | 0.1 |
| LeWid (cm) | 0.85 | -0.4 | -0.31 |
| LeCon (cm) | 0.97 | -0.09 | 0.18 |
| LeThi (cm) | 0.92 | 0.36 | -0.09 |
| LeafW (g) | 0.98 | 0.17 | 0.01 |
| ULeafW (g) | 0.99 | 0.05 | 0.01 |
| LereW (g) | 0.98 | 0.16 | 0.01 |
| GelW (g) | 0.98 | 0.19 | 0 |
| Stem weight (g) | 0.38 | -0.92 | -0.04 |
| Root weight (g) | 0.36 | -0.91 | 0.15 |
| Eigenvalue | 7.67 | 2.15 | 0.17 |
| Explained variation (%) | 76.71 | 21.51 | 1.77 |
| Accumulated variation (%) | 76.71 | 98.22 | 100 |

Based on the quantitative variables of the plants, aloe vera genotypes 1P, 2P, and 2V were dispersed in PC1 as they showed higher LeThi, LeLen, LeafW, LeCon, LeWid, LereW, and GelW, with values of 2.3 cm, 65.3 cm, 486.2 g, 20.9 cm, 10.5 cm, 343.5 g, and 256.8 g, respectively. In PC2 were materials 1V, 1P, and 2P as they had greater stem and root weights (604.5 g and 515.0 g, respectively), compared to genotype 2V (454.3 g and 312.3 g, respectively) (Figure 1).

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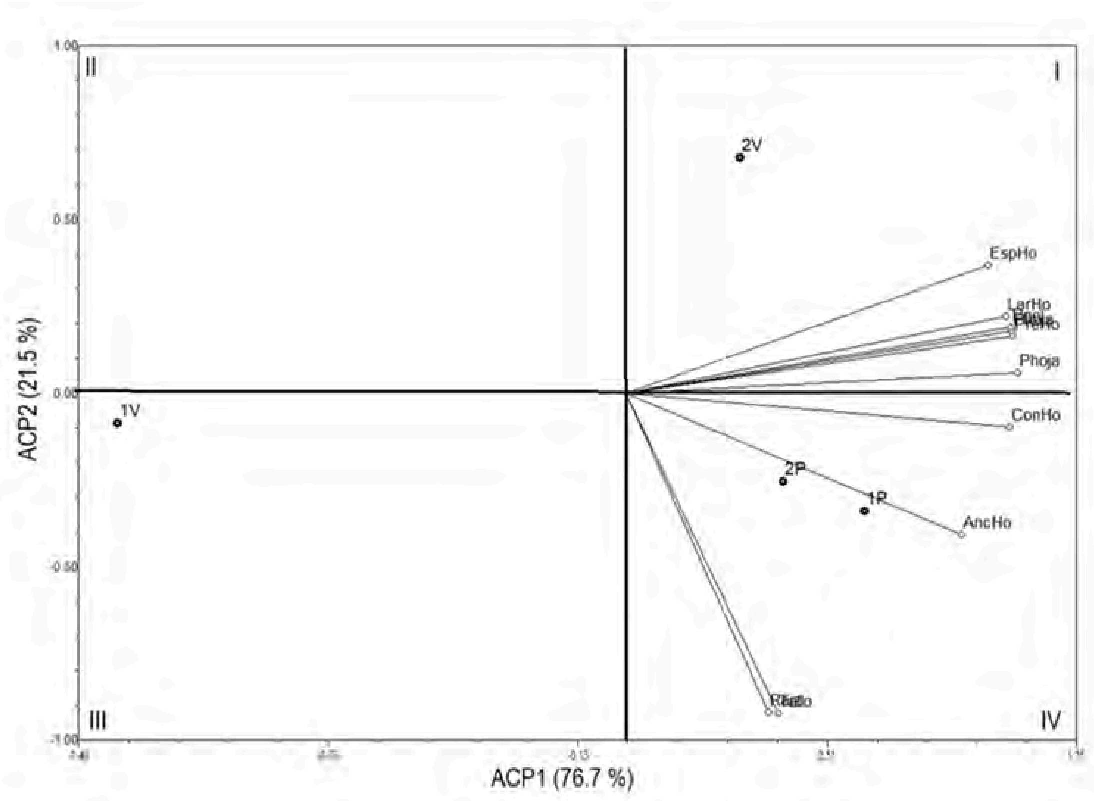
**Figure 1. Biplot of *A. vera* from Puebla and Veracruz, constructed with the first two PCs of 10 agro-morphological variables. For the acronyms of the variables (Table 1).**




Regarding the dispersion of genotypes according to morphological variables, it was observed that the plants from Puebla were in the fourth quadrant, which denotes reduced morphological diversity. On the other hand, aloe vera materials from the state of Veracruz were distributed in quadrants 1 and 3 (Figure 1).

This variability in the agro-morphological characteristics of plants in Veracruz may be due to the difference in the agronomic management of the producer. In this regard, Cristiano *et al*. (2016) points out that agronomic management can positively or negatively affect aloe vera crops, such as planting techniques and even postharvest management.

According to Añez and Vásquez (2005), some practices such as planting distance do not affect the growth of aloe vera plants, but they do affect the number of suckers they produce. However, if the suckers are not properly controlled, they can compete with the main plant for water and nutrients in the soil, negatively affecting its growth.

## Soil analysis

The soils of aloe vera plantations in Table 3 showed that the pH in Puebla was moderately alkaline (7.4 and 8), while for Veracruz, it was moderately acidic (5.4 and 6.3) (SEMARNAT, 2002). The EC in Puebla indicates a moderately saline soil (2.1 and 4 dS $m^{-1}$) compared to Veracruz, where it had negligible salinity effects (0.1 and 0.2 dS $m^{-1}$). On the other hand, very high percentages of N were recorded for the four aloe vera plantations. The soils of site 1V had very high orM values (13.1%) in contrast to those of sites 1P, 2P, and 2V, which are within the range of 1.9 to 2.6%, classified as medium values (SEMARNAT, 2002).

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**Table 3. Edaphic variables of four sites with *A. vera* in Puebla and Veracruz.**

| Variable | Puebla | | Veracruz | |
|---|---|---|---|---|
| | Site 1* | Site 2* | Site 1* | Site 2* |
| pH | 7.4 | 8 | 5.4 | 6.3 |
| EC (dS $m^{-1}$) | 2.1 | 1.8 | 0.2 | 0.1 |
| orM (%) | 1.9 | 2.3 | 13.1 | 2.5 |
| Type of soil | Sandy-clayey loam | Clayey-loam | Clayey | Clayey-loam |
| Bd (g $ml^{-1}$) | 1.1 | 1.1 | 1 | 1.2 |
| N (%) | 5.7 | 8 | 5.8 | 12.9 |
| P (mg $L^{-1}$) | 4.2 | 1.3 | 3.5 | 0.5 |
| K (mg $L^{-1}$) | 20 | 13 | 8 | 5 |

* = average value of three repetitions. Acronyms are described in materials and methods.

The significant correlation values between the agro-morphological and agroecological characteristics of the four aloe vera genotypes are shown in Table 4, where a significant association (*p*# 0.05) was found between the agroecological variables: ALT, TEMP, PREC, and soil EC with the agro-morphological variables of stem and root weight.

**Table 4. Agro-morphological correlations in aloe vera plant genotypes and their agroecological condions.**

| | LeLen | LeWid | LeCon | LeThi | LeafW | ULeafW | LereW | GelW | Stem | Root |
|---|---|---|---|---|---|---|---|---|---|---|
| LeCon | 0.95* | 0.82 | | | | | | | | |
| LeThi | 0.96* | 0.67 | 0.85 | | | | | | | |
| LeafW | 0.99** | 0.77 | 0.95* | 0.97* | | | | | | |
| ULeafW | 0.98** | 0.83 | 0.97* | 0.94* | 0.99** | | | | | |
| LereW | 0.99** | 0.77 | 0.95* | 0.97* | 0.99** | 0.99** | | | | |
| GelW | 0.99** | 0.76 | 0.94* | 0.97* | 0.99** | 0.99** | 0.99** | | | |
| Root | 0.16 | 0.63 | 0.47 | -0.01 | 0.19 | 0.31 | 0.2 | 0.18 | 0.97* | |
| ALT | 0.49 | 0.83 | 0.74 | 0.33 | 0.52 | 0.62 | 0.53 | 0.51 | 0.93* | 0.93* |
| TEMP | -0.49 | -0.83 | -0.74 | -0.33 | -0.52 | -0.62 | -0.53 | -0.51 | -0.93* | -0.93* |
| PREC | -0.49 | -0.83 | -0.74 | -0.33 | -0.52 | -0.62 | -0.53 | -0.51 | -0.93* | -0.94* |
| EC | 0.45 | 0.86 | 0.7 | 0.31 | 0.49 | 0.59 | 0.5 | 0.48 | 0.95* | 0.94* |
| orM | -0.98** | -0.79 | -0.98* | -0.94** | -0.99** | -0.99** | -0.99** | -0.99** | -0.3 | -0.29 |
| Bd | 0.92 | 0.41 | 0.76 | 0.94* | 0.89 | 0.84 | 0.89 | 0.9 | -0.21 | -0.2 |
| K | 0.26 | 0.85 | 0.49 | 0.19 | 0.33 | 0.43 | 0.34 | 0.32 | 0.94* | 0.87 |

Correlation significance level: *= $p \leq 0.05$, significant; **= $p \leq 0.01$, highly significant. The acronyms of the variables are described in materials and methods.

Edaphic variables with a high significant correlation ($p \leq 0.01$), but in a negative sense ($|r| \geq -0.94$), were recorded between the orM of the soil and some agro-morphological characteristics, which indicates that a soil rich in orM does not favor the development of attributes in the aloe vera plant. High concentrations of orM can reduce the growth and development of aloe vera plants, and thus negatively affect leaf size and weight (Chowdhury *et al*., 2020).

Bd had a significant correlation ($p \leq 0.05$) with the LeThi of aloe vera (r= 0.94), which has a direct impact on leaf quality attributes such as gel quantity and LeafW. K was significantly associated ($p \leq 0.05$) with stem weight (r= 0.94). The classification of the correlations presented in this study was in accordance with the criteria established in the study by Ruiz de Anda *et al*. (2019).

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High correlations |r|> 0.7; *p*≤ 0.01 between the agro-morphological and agroecological characteristics (climate and soil variables), cited in the present study, allow us to postulate that the PREC and TEMP variables of the planting site negatively influence the stem and root of the *A. vera* plant and the orM does not favor the development of the plant. In this regard, Gepts (2008) highlights that the climatic variables important in the physiological and developmental processes of plants are generally: solar radiation, average air temperature, temperature, and average annual precipitation.

## Conclusions

It was found that aloe vera genotypes 2V, 1P, and 2P had the highest values in most of the agro-morphological variables; genotype 1V is completely far from the dimensional plane of the rest, possibly attributed to the presence of high values of orM in the soil. Overall, the agroecological variable of precipitation has a high correlation with the agro-morphological characteristics in the four aloe vera genotypes, suggesting that site conditions have an important role in the genetic variation of the germplasm evaluated.

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