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Diversity variability of native corn cobs in the high zone of Totonacapan, mesoamerica

Diversidad morfológica de mazorcas de maíces nativos en la zona alta del Totonacapan, mesoamérica

Diversidade morfológica de espigas de milho nativo na zona alta de Totonacapan, mesoamérica

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Rev. Fac. Agron. (LUZ). 2024, 41(4): e244140
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v41.n4.09

Received: 27-09-2024
Accepted: 04-11-2024
Published: 18-11-2024

Crop production
Associate editor: Dr. Jorge Vilchez-Perozo
University of Zulia, Faculty of Agronomy
Bolivarian Republic of Venezuela

Keywords:
Mexico
Zea mays
Corn
Totomoxtles

Abstract

Mexico is considered one of the origins of corn (*Zea mays* L.), and in the Totonacapan area there are still native plant genetic resources that have not been characterized and are under threat by the introduction of improved genetic material and/or commercial seeds in traditional production systems. It was evaluatedthe morphological variability of native corn in the municipalities of Coahuitlán, Mecatlán and Filomeno Mata from the Totonacapan region. The experimental design implemented was non-balanced hierarchical, and principal component and correspondence analysis were also developed; six producers were visited per community within each municipality. The corn from Filomeno Mata was characterized by thick cobs, long leaves (totomoxtle) and large ears, while those from Coahuitlán and Mecatlán converge in heavy cobs with many long and heavy grains per row. The characteristics of the municipalities define the agricultural practices of the producers. Finally, significant differences ($P \leq 0.001$) were found in the length, perimeter and coverage of the leaf, cob, and grain between producers from different municipalities and from the same municipality. The morphological diversity of native corn between producers from different communities is fostered by differences in the productive practices they employ within each municipality.

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Resumen

México es considerado uno de los orígenes del maíz (*Zea mays* L.), y en la zona del Totonacapan se conserva aún recursos fitogenéticos nativos que no han sido caracterizados, y que se encuentran bajo amenazada por la introducción de material genético mejorado y/o semillas comerciales en los sistemas de producción tradicionales. Se evaluó la variabilidad morfológica de maíces nativos en los municipios Coahuitlán, Mecatlán y Filomeno Mata de la región del Totonacapan. El diseño experimental implementado fue jerárquico no equilibrado, desarrollándose además análisis de componentes principales y de correspondencia; se visitaron seis productores por comunidad dentro de cada municipio. Los maíces de Filomeno Mata se caracterizaron por mazorcas gruesas, hojas (totomoxtle) largas y olotes grandes; mientras que los de Coahuitlán y Mecatlán convergen en mazorcas pesadas con muchos granos largos y pesados por carreras. Las características de los municipios definen las prácticas agrícolas de los productores. Finalmente se obtuvieron diferencias significativas ($P \leq 0.001$) en la longitud, perímetro y cobertura de la hoja, de mazorcas, olote y grano entre productores de diferentes municipios y del mismo municipio. La diversidad morfológica de maíces nativos entre productores de las diferentes comunidades se fomenta por diferencias en las practicas productivas que emplean dentro de cada municipio.

Palabras clave: México, *Zea mays*, maíz, totomoxtles.

Resumo

O México é considerado uma das origens do milho (*Zea mays* L.), e na área de Totonacapan ainda se conservam recursos fitogenéticos nativos que não foram caracterizados e que estão ameaçados pela introdução de material genético melhorado e/ou sementes comerciais em sistemas de produção tradicionais. Foi avaliado variabilidade morfológica do milho nativo nos municípios de Coahuitlán, Mecatlán e Filomeno Mata da região de Totonacapan. O desenho experimental implementado foi hierárquico e desequilibrado, tendo sido também desenvolvidas análises de componentes principais e de correspondência; Foram visitados seis produtores por comunidade dentro de cada município. O milho Filomeno Mata caracterizou-se por espigas grossas, folhas longas (totomoxtle) e espigas grandes; enquanto os de Coahuitlán e Mecatlán convergem em espigas pesadas com muitos grãos longos e pesados em tiragens. As características dos municípios definem as práticas agrícolas dos produtores. Por fim, foram obtidas diferenças significativas ($P \leq 0,001$) no comprimento, perímetro e cobertura foliar das espigas, espigas e grãos entre produtores de diferentes municípios e de um mesmo município. A diversidade morfológica do milho nativo entre produtores de diferentes comunidades é promovida pelas diferenças nas práticas produtivas utilizadas dentro de cada município.

Palavras-chave: México, *Zea mays*, milho, totomoxtles.

Introduction

Mexico is considered one of the centres of origin of maize (*Zea mays* L.), hosting a great diversity of breeds adapted to different environmental conditions (altitude 0-3000 masl; rainfall <400 to >3000 mm), and agricultural systems, which promotes variability among breeds recognised by international organisations such as FAO (Santillán-Fernández *et al*., 2021) and botanical personalities such as the American Edgar Anderson (1897-1969) when he referred to Mexico as 'Aztec land, more than any other country in the New World, is a land of maize' (Anderson, 1946).

Mexico has 60 % of the world's corn genetic diversity with 64 breeds, of which 92.18 % are native (Sanchez *et al*., 2000). The great morphological variability of existing maize is an eco-geographical and cultural heritage of Mexico (Caballero-Salinas *et al*., 2023).

For sowing, 82 % of agricultural production units use native seeds and the rest use improved and/or certified genetic material (INEGI, 2019). In addition to being adapted to diverse climatic conditions and possessing genetic diversity for producers' technologies, native seeds have characteristics that allow them to satisfy the food tastes of people (SADER, 2023).

Such is the case of the Totonacapan area, Veracruz, Mexico, where native genetic material is still preserved, which is increasingly threatened in the interest of producing corn with higher-coverage cobs and thus take advantage of its leaf to market it, leaving the quality and quantity of grain in second place, which represents a threat that is increasingly advancing conditioned by socioeconomic, political, commercial, biotic and abiotic factors, and new forms of production based on technological changes (González-Cortés *et al*, 2017; Lazos-Chavero, 2014), promoting preferences and selection of indigenous varieties in conjunction with morphological traits.

Based on the above approach and the need to reference the characteristics of native maize in the upper Totonacapan area, the objective was to evaluate the morphological variability of native maize in the municipalities of Coahuitlán, Filomeno Mata and Mecatlán in the Totonacapan region of Veracruz, Mexico.

Materials and methods

Geographical location of sampling sites

Samples were taken in the municipalities of Coahuitlán (20°13'20.y 18 'N 97°39'97.46 "W), Filomeno Mata (20°10'20.16 "N and 97°38'97.45 "W) and Mecatlán (20°10'20.15 "N and 97°36'27 97.42 'W) located in the Totonacapan region, Veracruz, Mexico. Similar climatic conditions coexist between the municipalities (semi-warm humid and warm humid), as well as pest infestations (codling moth (*Helicoverpa armigera*) and grain weevil (*Sitophilus granarius*); in addition to similar altitudes ranging from 100 to 900 m above sea level (SIEGVER, 2020).

Application of the instrument

An instrument composed of 42 items that included social, productive, economic, and socioeconomic variables was applied to 80 producers from the municipalities under study, of which 16 producers were selected, six for each municipality, since they were the only ones that conserved within their practices, the production of native corn seeds without crossing or mixing with commercial or improved seeds; discarding producers whose seeds had been obtained from the wholesaler that commercialises the leaf (hereinafter totomoxtle) in the region. The instrument was validated using Cronbach's alpha (Cronbach, 1951) with a score of 0.865, using Fisher's confidence interval (Romano *et al*., 2011).

Maize harvests

Cobs were harvested in December 2021, corresponding to the June-December 2021 production cycle. Each producer donated between 14-16 cobs to constitute the sample for the study. Each sample was duly registered with the name of the producer, locality and type of material. The samples came from the planting area of 16 producers residing in the municipalities of Coahuitlán (6), Filomeno (6) and Mecatlán (4), and were taken randomly from plants ten linear metres apart at 190 days after planting (DDS) of maize, avoiding the selection of plants in the first 15 m on each side of the harvestable plot, which was considered as an edge effect. For the collection, transportation and conservation of the material, the same management as that used by native populations producing native maize was considered. The material collected directly from the plants was placed in sacks and transported to the city of Xalapa; from the third day onwards, the respective measurements were taken, and the plants were not subjected to any drying or post-harvest procedure that could alter their morphology.

Variables evaluated

The length of the totomoxtle (LTo) and cob (CobL) (cm), as well as the perimeter (CobPe) (cm) of the totmoxtle (PTo), cob (PMa), and cover of the totomoxtle (CTo) (cm) were considered. In the ear, the number of races (Carr) (U), number of grains per race (GraCarr) (U) and total weight of the ear (PeMa) (g) were also counted with a Rhino granatary balance (model Vins-5, precision 1 g, made in Mexico), and in the ear, length (LOL) (cm), perimeter (POL) (cm) and weight (PeOL) (g) were evaluated. The length (LGra) (mm) from the base of the kernel (pedicel) to the distal portion of the endosperm was considered, while the width (Agra) (mm) was considered as the longitudinal measurement in the middle portion of the pericarp, and the thickness (Egra) (mm) was considered in a longitudinal plane at the level of the soft endosperm. All measurements were performed with a digital vernier (Steren® 0.2 mm accuracy). The weight of 1000 seeds (P1000) (g) was quantified by randomly selecting and separating seeds in each of the collected cobs and subsequently weighed on a digital balance OAHUS® (model H-5276, made in Mexico, 0.001 g accuracy).

Experimental design and statistical analysis

The study was developed using an unbalanced hierarchical experimental design. The municipalities (Coahuitlán, Filomeno and Mecatlán) were identified as factor A, and the producers within each municipality were identified as factor B. Eight replicates were considered for each combination of levels (A and B), but the number of producers was different within each municipality.

Statistical analysis was carried out using Statistica v 12.0 software. An analysis of variance was performed using Tukey's criterion at a confidence level of 95 %, according to the mathematical model of the unbalanced hierarchical experimental design:

$$Y_{ij} = \mu + Mn_i + Pr(Mn)_{j\,(i)} + e_{(ij)_k}$$

Where: Y_{ijk} = observed phenotypic value of the trait for the i-th treatment of the j-th block, μ= overall mean, Mn_i= effect associated with the i-th municipality, Pr_j= effect of the j-th producer, $Pr(Mn)_{j(i)}$= the j-th level of the producer is nested in the i-th level of the municipality, $e_{(ij)k}$= normally distributed random error with zero mean and $sigma^2$ variance.

The multivariate principal components technique was used to define the factors that were determinant for the morphology of totomoxtle, cob, ear, ear and grain for each locality and the factors for which localities were determinant. Correlation assumptions were tested using KMO (Kaiser, 1974) and Bartlett's test of sphericity. Factors were extracted using an eigenvalue-based correlation matrix, and Kaiser's standardised Varimax method was used to rotate the database. For integration between the multi-categorical variables, multiple correspondence analysis was considered.

Results and discussion

Relationships among morphological variables of totomoxtle, grain, ear and ear between localities were analysed by principal component analysis (PCA) (figure 1). In the Coahuitlán locality, the variables Carr, GrCarr and LTo as a function of vector length, showed the least variability, while the amplitude of the cosine of the angle suggested that the variable Carr and PeMa were highly related, as were LGra with PMa, and surface area of the family planting unit (SUPupf) with GrCarr, as were LTo, POL and Agra, while LGra, P1000, PMa, LMa, and LOL showed the greatest variability, which together explained 64.7 % of the variance (figure 1-A). In the locality Filomeno Mata (figure 1-B) all the variables under study presented a great variability, while the closest relationships were located between the variables AGra and LTo, PeMa and AOL, POL together with PMa and LGra, as well as Ato with Carr, and finally P1000 with SUPupf, the contiguous of the variables explained 100 % of the variance. In Mecatlan P1000 was the variable with the lowest variability, while Carr, SUPupf and EGra were the variables most related, as were P1000 with LOL and LMa, Agra and POL, the latter with PMa, and PMa with LGra; followed by PeMa with Age, and LTo with CTo. Ato and AOl were not related to any variable (figure 1-C).

The differences obtained within each locality in the morphology of the cob, totomoxtle, kernel and ear may be related to common traits of creole maize, in the criteria of Hortelano-Santarosa *et al*. (2012); Oreamuno-Fonseca and Monge-Pérez, (2018) it was peculiar to find variability among the morphological characteristics of creole maize, due to the flow of germplasm that is generated among producers in addition to the agroecological conditions of the producing areas (González-Martínez *et al*., 2020), and contrasting variations between climatic and edaphic conditions of the localities under evaluation (Diego-Flores, *et al*., 2012).

Similar results to those obtained in this study and which gave rise to variations and heterogeneity among the maize populations that made up the groups within each locality, were reported in the studies of Castro-Nava *et al*., (2018), with these researchers alluding to a wide intra- and interspecific diversity, an aspect that is reiterative in research with native maize (Pérez-García, 2023).

The above was directly related to the recognised genetic variability among native maize varieties, in which traits such as the colour, shape, appearance of the totomoxtle, ear and kernel, constituted specific attributes of Mexican cuisine considered by local and urban producers when selecting the kernel for production (Lazos-Chavero, 2014), which exerts selection pressure in the field on native varieties at regional, local and productive levels, suggestive criteria as shown in figure 1A, B, C.

When considering the effect of localities and municipality on the way in which morphological variables (totomoxtle, grain, ear and cob) are related, it was obtained that the municipality influenced the expression of PsMa, GrCarr, LTo, and LGra; while the locality directly determined the weight of the ear (figure 2).

Aspects such as sociological complexity including the management and dynamic conservation of native maize agrobiodiversity together with social-productive organisation and cultivation practice, are notable aspects that influence the morphology of totomoxtle, olote, cob and grain, which may be related to the variability in the relationships and importance of the variables describing morphology

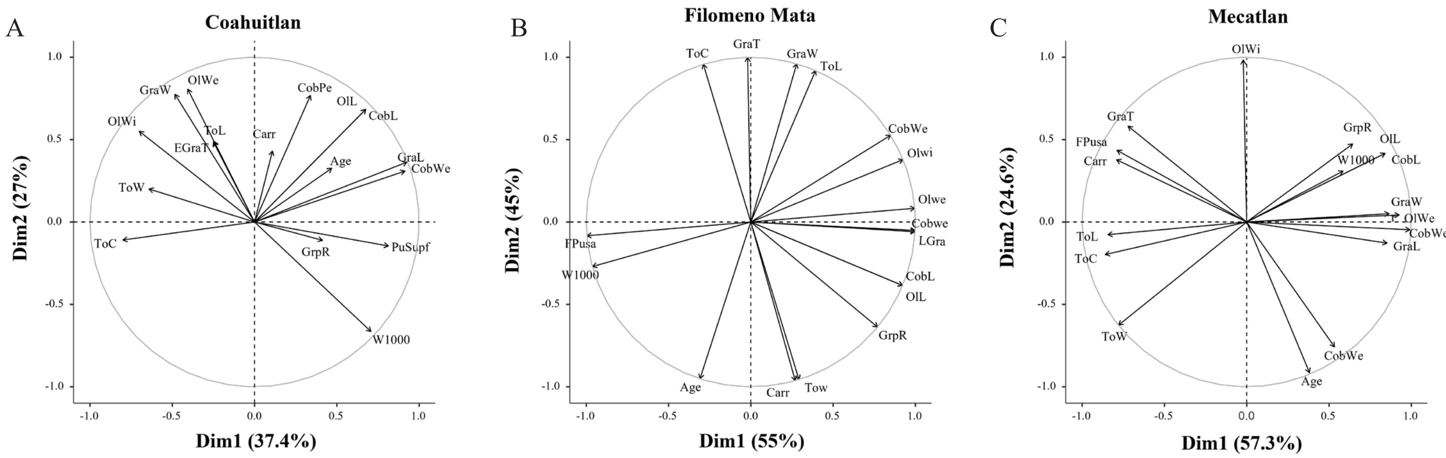

Figure 1. Contribution of the variables for the localities Coahuitlán (A), Filomeno Mata (B), Mecatlán (C). W1000: Weight of 1000 seeds; ToC: Totomoxtle coverage; ToW: Totomoxtle width; ToL: Totomoxtle length; OlWi: Olote width; OlWe: Olote weight; OlL: Olote length; Carr: Number of rows per cob; CobPe: Cob perimeter; CobL: Cob length; Age; GraT: Grain thickness; GraW: Grain width; GraL: Grain length; CobWe: Cob weight; FPusa: Family plantation unit surface area (usa)-(ha); GrpR: Grains per row.

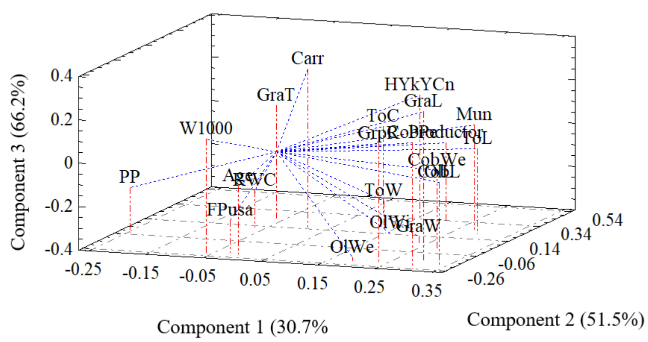

Figure 2. Graph of weights of the components of morphological variables of maize (*Zea mays*), in different localities of the Veracruz municipalities of Coahuitlán, Filomeno Mata and Mecatlán. LTo: Totomoxtle length; CTo: Totomoxtle coverage; Ato: Totomoxtle width; PMa: ear perimeter; PsMA: ear weight; LMa: ear length; Carr: rows; LOI: ear length; AOI: ear width; PsgrOI: ear weight; LOc: localities; Grcarr: grains.row^{-1}; Agra: grain width; EGra: grain thickness; P1000: Weight of 1000 grains; RWC: rent at what cost; HykYC: how do you keep your corn? Mun: municipality; PP: slope of the plot.

shown in figure 2, similar results to those obtained shared by Santillán-Fernández *et al*. (2021) in the study of the spatial delimitation of the genetic diversity of native maize within Mexican ethnic groups, finding a high relationship between the genetic diversity promoted by the different uses of maize within and between ethnic groups.

When developing a correspondence analysis between morphological variables of native maize with producers within each locality (figure 3), it was found that the producers of the Filomeno Mata locality produced native maize that stood out for being ‘big’ ears with thick cobs and long totomoxtle, according to the variables that were related to the morphology of the ear (width, weight and length), of the ear (perimeter) and totomoxtle (width and length) (figure 3A).

The producers of Coahuitlán and Mecatlán were characterised by having the largest surface areas for production, with their maize consisting of long and abundant grains per race, as well as heavy cobs and grains, morphological criteria that are desired by the producers, since they contribute, from their experience, incentives for greater productivity. These relationships made it possible to know the morphological characteristics of the maize produced in the localities under study, and the findings in commentary complement and enrich the representativeness of forms and possible races of native maize that are geographically restricted to these localities, which are vulnerable to biocultural erosion due to the introduction of improved varieties, a phenomenon that is becoming increasingly common (Deb, 2022).

Likewise, the characteristics of variables such as thickness (grain), coverage (totomoxtle) and races (per cob), which were grouped around producers in the different localities under study, suggest in the criteria of Caballero Salinas *et al*. (2023) the relationship with underlying factors that contribute to the process of genetic selection by the farmer (Lazos-Chavero, 2014), as well as the selection and segregation of seed to store (Villalobos-González *et al*., 2019), determining the variability of the use of an open production system that feeds back on seed exchange, empirical selection, uses, culinary customs, and ecological niches (Cabrera-Toledo *et al*., 2019; Coral Valenzuela *et al*., 2019), factors coinciding with the reported by Lazos-Chavero (2014) in the study of designations of origin of indigenous products.

Production practices and other activities related to native maize cultivation among different producers within and between localities (figure 3B), suggested that producers from Mecatlán and some from Filomeno Mata develop distinctive cultivation practices that were related to characteristics of the municipality of residence, while at least one producer from Filomeno Mata and two from Coahuitlán were organised and could predispose some ease to the type of land tenure and the way in which their maize was conserved.

In this sense, authors such as Navarro-Garza *et al*, (2012) pointed out that the production systems of creole maize within the parcel systems constitute a collective memory for the producers, being the

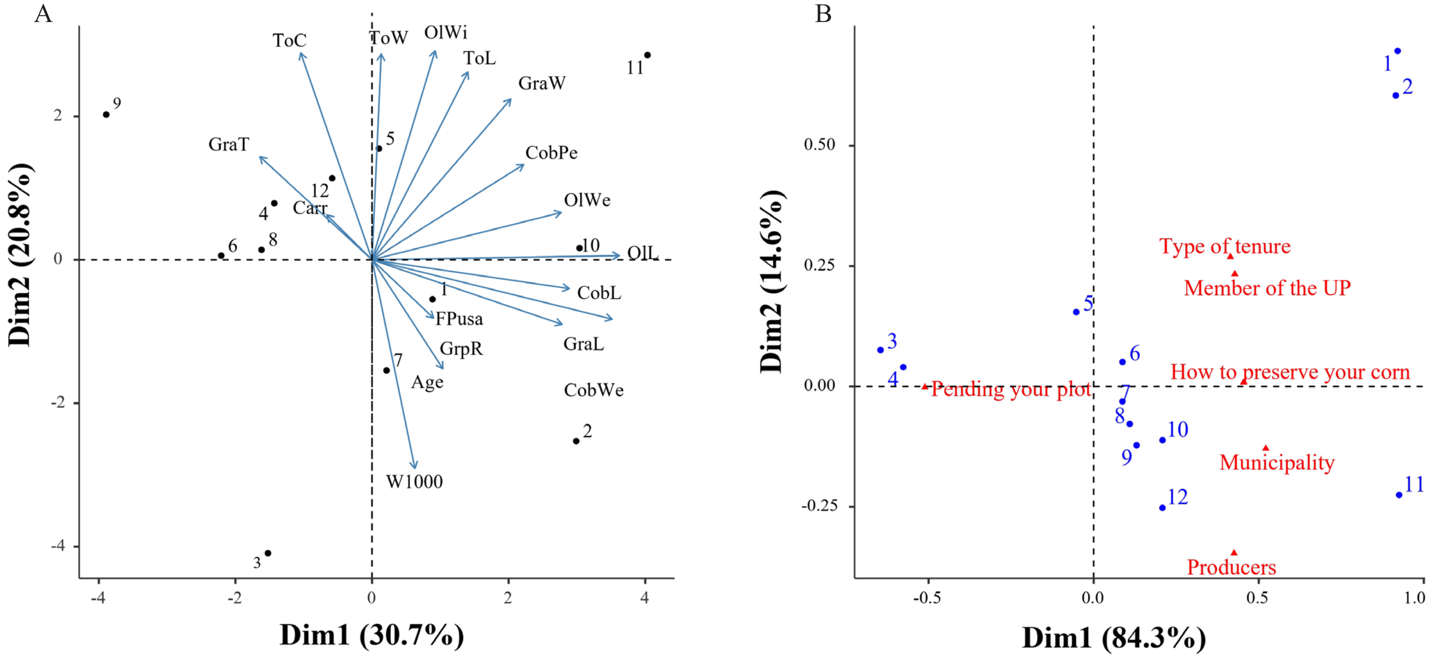

Figure 3. Correspondence analysis between morphological variables of cob, totomoxtle, and kernels with producers (A), between qualitative variables of some productive characteristics related to producers (B). W1000: Weight of 1000 seeds; ToC: Totomoxtle coverage; ToW: Totomoxtle width; ToL: Totomoxtle length; OlWi: Olote width; OlWe: Olote weight; OlL: Olote length; Carr: Number of rows per cob; CobPe: Cob perimeter; CobL: Cob length; Age; GraT: Grain thickness; GraW: Grain width; GraL: Grain length; CobWe: Cob weight; FPusa: Family plantation unit surface area (usa)-(ha); GrpR: Grains per row.

sowing practice a cultural heritage that has been transferred over the years, and under spatial and cultural circumstances contributed to explain the variability within a local race, overlaps between breeds and varieties that are managed individually and territorially by native maize producers, constituting a gene flow that promotes a complex genetic composite, implying that maize breeds are considered as an open genetic system that continues to evolve (Arteaga *et al.* , 2016).

When establishing the differences between municipalities, localities and producers in the morphological variables under study (figure 4), it was found that in the locality of Filomeno Mata some producers have totomoxtle of greater length (32.27 cm) (figure 4A), surpassing by 19.54 % to the value of other producers in the same locality (27 cm) ($P\leq0.001$); while in Coahuitlán, averages of 25.16 and 25.61 cm were recorded, representing an increase of 28.29 % and 26.03 % for the length of this bract, respectively ($P\leq0.001$) within the locality. In Mecatlán, the values were similar with no differences ($P\geq0.05$) (figure 4A), which is important considering the cultural use of this leaf for making tamales.

Totomoxtle width also differed among producers ($P\leq0.004$), across localities (figure 4B). Differences within each municipality were 30.4 %, 46.6 % and 43.1 % for Filomeno Mata, Coahuitlán and Mecatlán, respectively. And for coverage, differences were more evident between producers in each locality ($P\leq0.004$), and therefore between localities (figure 4C). In Filomeno Mata, the lowest values averaged between 7.03 and 7.08 cm, showing differences of 66.01 % and 64.84 %, respectively. These values were significantly lower compared to producers in other locations, with a constant difference of about 47.16 %.

The averages for ear length (figure 4D-H) were significantly higher (21-22 cm) ($P\leq0.001$) in Coahuitlán and Filomeno Mata, exceeding by 25.65 % and 24.15 %, respectively. The lowest values (17.54 and 17.75 cm) were recorded in Coahuitlán ($P\leq0.001$). Ear circumference showed some stability among producers within and between municipalities (figure 4E).

The highest value ($P\leq0.02$) was recorded in Filomeno Mata, with 15.46 cm, 13.17 % higher than the lowest value (13.66 mm) recorded in Coahuitlán, establishing differences between these municipalities.

A producer from Mecatlán obtained ears with a higher number of races (14.85 U), surpassing producers from Filomeno Mata and Coahuitlán by 38.25 %, who registered 10.75 U (figure 4F).

However, the number of grains per race.cob^{-1} (figure 4G) varied among producers of the same locality, in this way, a producer from Filomeno Mata reached 45.50 U of grains per race, surpassing in 46.7 % to a producer from Coahuitlán, who obtained 31 U, which generated significant differences between them and their respective municipalities ($P\leq0.02$).

The highest value ($P\leq0.001$) for ear weight (figure 4H) was recorded in Coahuitlán (194.75 g), exceeding by 80.32 % the lowest value recorded in the same locality (108 g) ($P\leq0.001$), promoting significant differences ($P\leq0.001$) between the producers of the different municipalities. The differences and similarities between municipalities in the morphology of the cob, denotes a dynamic in the flow of seeds between producers in each locality, expanding the probabilities that can lead to the variability of a considerable number of combinations, an aspect that allows the creation of new varieties

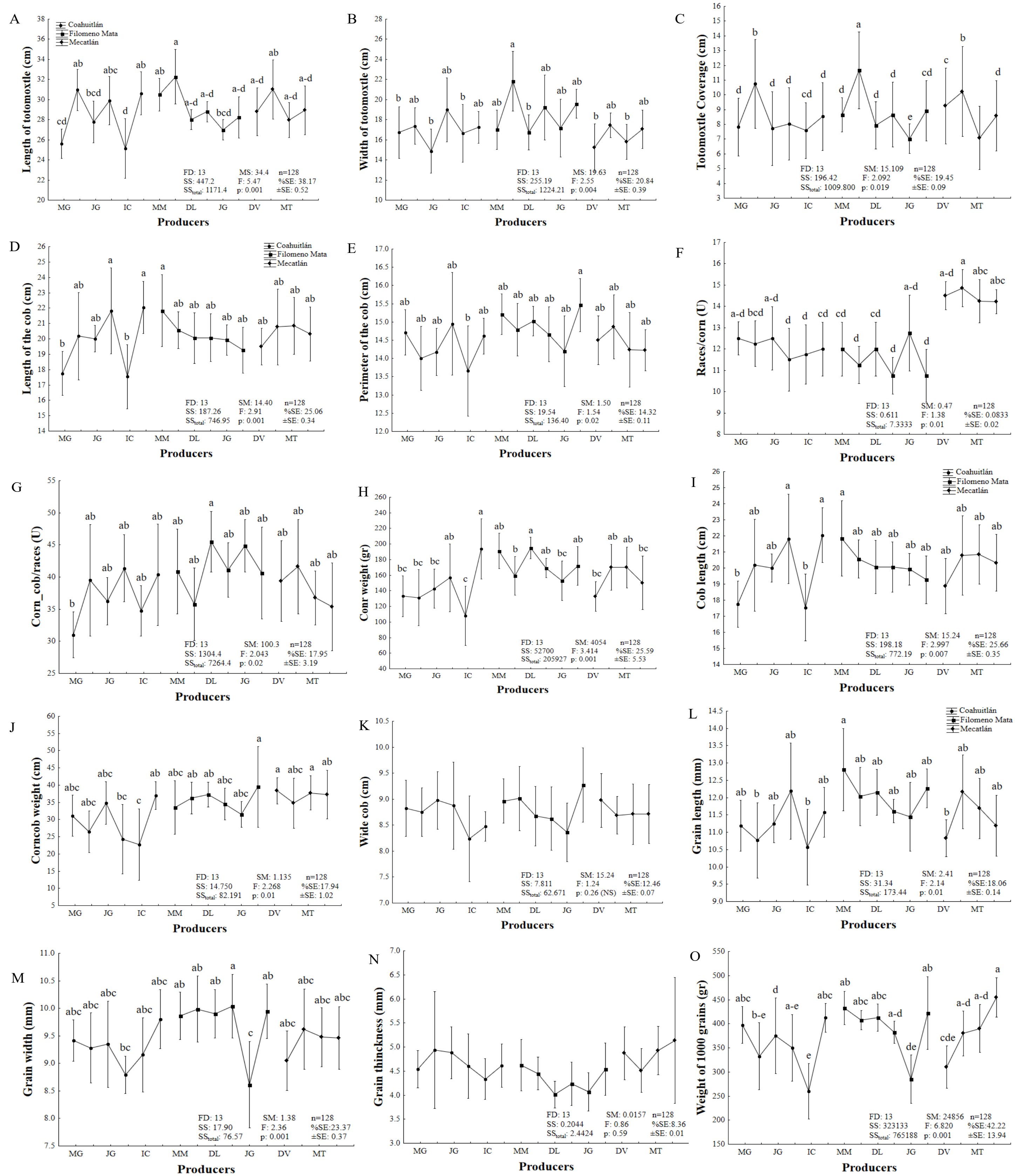

Figure 4. a, b, c, d Different superscripts suggest significant differences according to Tukey at 95% confidence. Vertical lines represent standard deviation (±SD); FD: Freedom degree; SS: Sum of squares; SCtotal: Total sum of squares; MS: Mean square; F: Fisher's f; p: P-value; n: number of data; %SE $\frac{SC_{Pr\,(Mn)}}{SC_{total}} \times 100$ ±SE (standard error) $= \sqrt{\frac{CM_{Pr(Mn)}}{n}}$ ear runs were transformed by √x+2; ear weight by √x+3.2; kernel thickness by √ x+2.5.

with desirable agronomic characteristics and attributes (Cabrera-Toledo *et al*., 2019).

Other morphological traits that contribute to ear diversity are ear and kernel morphology, which showed significant differences due to the effect of localities. In Coahuitlán, ear length (figure 4I) (P≤0.007), reached 22.04 cm, and exceeded by 25.66 % the averages of 17.5 and 17.7 cm in Filomeno Mata (P≤0.007), which represents an important variability in size.

For weight (figure 4J), the highest value (39.50 g) corresponded to a producer from Filomeno Mata, showing significant differences (P≤0.01) with some producers from Coahuitlán, where there was a 73.62 % decrease in the weight of the ear, represented by the lowest value (22.75 g). No significant differences (P≥0.05) were found in the width of the ear between producers or between localities.

In the analysis of grain morphology, it was observed that the significantly higher value for length (12.81 mm) (figure 4L) and width (10.04 mm) (figure 4M) was recorded in Filomeno Mata, and smaller by 21.25 % in producers from Coahuitlán and Mecatlán, while the thickness of the decreased in producers from Filomeno Mata (16.54 %) and Coahuitlán (14.19 %) (figure 4N), without being significant (P≥0.59). The unexplained variance was 18.16 %, 23.37 %, 8.36 % and 42.22 % for length, width, thickness and 1000-seed weight, respectively, with 1000-seed weight being one of the most variable aspects in maize (Contreras Molina *et al*., 2016), as obtained in this study.

Conclusions

The morphological diversity of native maize is dispersed among the localities under study, mainly due to cultivation practices, in which the type of tenure, maize preservation technique and whether or not they belong to a productive organisation stand out. The maize produced in Filomeno Mata was found to have large ears, coarse cobs and long totomoxtle, while the maize produced in Coahuitlán and Mecatlán was identified as having a larger number of kernels per run, and heavy cobs and kernels.

Acknowledgements

Thanks are due to the Universidad Veracruzana, the Asociación de Silvicultores de Totonacapan and native maize producers for their collaboration.

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