Colegio de Postgraduados

Identification of Native Maize (*Zea mays* L.) within the Area of Influence of Pico de Orizaba National Park

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Citation: Andrés-Meza, P., Sierra-Macías, M., Rodríguez-Escobar, J. G., Leyva-Ovalle, O. R., Díaz-José, J., Itehua-Panzo, E., Jiménez-Méndez, A. Y., Del Rosario-Arellano, J. L., Tadeo-Robledo, M., Espinosa-Calderón, A., Hernández-Salinas, G., & Serna-Lagunes, R. (2025). Identification of Native Maize (*Zea mays* L.) within the Area of Influence of Pico de Orizaba National Park. *Agro Productividad*. https://doi.org/10.32854/agrop.v18i2.3260

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: November 18, 2024.
Accepted: January 30, 2025.
Published on-line: March XX, 2025.

Agro Productividad, 18(2). February. 2025. pp: 241-248.

ABSTRACT

Objective: This study aimed to investigate the morphological diversity of native maize varieties from the area of influence of Pico de Orizaba National Park.

Design/Methodology/Approach: An exploration was conducted from December 2023 to May 2024 in the municipalities of Zongolica, Los Reyes, Astacinga, Atlahuilco, Tlaquilpa, Ixtaczoquitlán, Acultzingo, Amatlán de los Reyes, Chocamán, Huatusco, Calcahualco, Alpatlahuac, Mariano Escobedo, Rafael Delgado, Veracruz, Mexico. Quantitative characteristics of the ear were recorded, including ear length (EL), ear diameter (ED), number of rows (NR), number of grains per row (GPR), ear weight (EW), and cob diameter (CD).

Results: Ten original racial types were identified: Arrocillo, Cacahuacintle, Celaya, Cónico, Coscomatepec, Elotes Cónicos, Olotillo, Ratón, Tuxpeño, and Pepitilla. Among the interracial mixtures found: arrocillo-Cónico-Pepitilla-Tuxpeño, Celaya-Coscomatepec, Celaya-Coscomatepec-Ratón, Celaya-Elotes Cónicos, Celaya-Ratón, Cónico-Arrocillo, Cónico-Celaya, Cónico-Elotes Cónicos, Cónico-Pepitilla, Coscomatepec-Celaya-Pepitilla, Coscomatepec-Celaya, Olotillo-Tepecintle, Pepitilla-Cónico-Arrocillo, Ratón-Celaya, and Ratón-Tepecintle. The most frequent races were Cónico and Ratón. The most frequent native maize colors were white, cream, and yellow.

Limitations of the study/Implications: It is recommended to work with producers using participatory breeding tools for specific ecological niches.

Findings/Conclusions: The observed morphological diversity indicates a constant dynamism of seed exchange among maize producers who conserve this valuable resource.

Keywords: *Zea mays* L., biological diversity, conservation, traditional system, original races.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereals worldwide. The primary destination of the grain is for direct human consumption, in addition to many derivatives used in industrial products (Najar *et al.*, 2018). Globally, the annual production volume of 1.163 billion tons produced on approximately 206 million hectares, with an average yield of 5,878.6 kg ha^{-1} (FAOSTAT, 2023). Of the total grain produced, Mexico contributes about 2.3% (26.6 million tons), ranking it among the top ten countries with the highest production volume (SIAP, 2023).

On the other hand, there are more than 300 maize races in the world, most of which are cultivated on the American continent (Wellhausen *et al.*, 1951). Consecuently, Mexico is considered a center of origin, diversification, and domestication of maize, resulting in approximately 59 native races (Ortega *et al.*, 2013). Specifically for the state of Veracruz, Sierra *et al.* (2014b) reported around 17 original races and 640 interracial mixtures, making it one of the states with the greatest biodiversity (CONABIO, 2011). The regions with the greatest presence of native maize include Los Tuxtlas, the high and low Sierra of Zongolica, Huatusco, Ixtaczoquitlán, Coscomatepec, Mariano Escobedo, Acultzingo, Tuxpan, Papantla, among other municipalities (Sierra *et al.*, 2014b).

The majority of studies focused on the diversity of native maize in Mexico have concentrated primarily in the central-southern region of the country (Aragón-Cuevas *et al.*, 2005; Herrera-Cabrera *et al.*, 2004; Hortelano *et al.*, 2011; Sierra-Macías *et al.*, 2014a; Flores-Pérez *et al.*, 2015; Guillén-de la Cruz *et al.*, 2014). There is still a need for more detailed exploration of the genetic-morphological variation within maize races, particularly in regions near Pico de Orizaba, highlighting the necessity for updated information on the diversity of these native maize varieties. Therefore, the objective was to study the morphological diversity and racial identification of native maize populations from the area surrounding Pico de Orizaba National Park.

MATERIALS AND METHODS

Location of the study area and germplasm used

Fifty native maize populations were used, preliminarily classified visually by researcher Mauro Sierra Macías. These were collected from December 2023 to May 2024 in the municipalities of Zongolica, Los Reyes, Astacinga, Atlahuilco, Tlaquilpa, Ixtaczoquitlán, Acultzingo, Amatlán de los Reyes, Chocamán, Huatusco, Calcahualco, Alpatlahuac, Mariano Escobedo, and Rafael Delgado. These municipalities are located within two important polygons: Pico de Orizaba National Park and the Metlác-Río Blanco Protected Natural Area (Figure 1), covering an area of 6,350.85 km^2 in the central-southern part of the State (19° 22' 41.29" N, 97° 19' 59.42" W and 18° 21' 53.57" N, 96° 28' 47.10" W; and an altitude ranging from 70 to 5,560 meters above sea level).

Evaluated traits

The sample consisted of 20 to 30 ears of maize, ensuring that no duplicates were obtained. A passport sheet was used as a basis to collect all the information of the cultivar, including the producer's name and the collection site. At each location, geographic

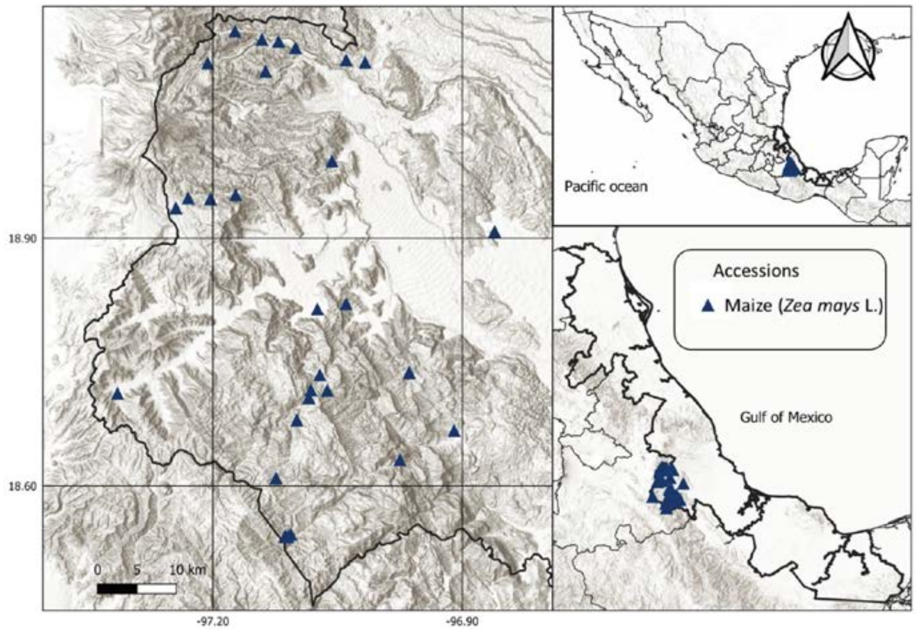

Figure 1. Origin of the 53 maize collections gathered in the area of influence of Pico de Orizaba National Park.

coordinates (latitude, longitude, and altitude), the common or local name of the cultivar, and the farmer's name were recorded. Information was collected on the quantitative and qualitative traits of the ear and grain. The following were quantified: ear length (EL), ear diameter (ED), number of rows (NR), number of grains per row (GPR), ear weight (EW), and cob diameter (CD).

Statistical Analysis

The generated data were integrated and systematized in a Microsoft Excel® spreadsheet. A principal component analysis (PCA) was performed using the evaluated variables. A graphical representation of the collections with the principal component one (PC1) and two (PC2) was created to visualize the differences and similarities among the 53 collections. All analyses were performed using the INFOSTAT statistical software, version 2008 (Di Rienzo *et al*., 2008).

RESULTS AND DISCUSSION

Racial identification

The classification of the maize populations at the race level identified the following racial groups: Cónico Group (Figure 2), Early Maturing Tropical Maize Races (Figure 3), Tropical Dent Maize Group (Figure 4), and Late-maturing Maize Group (Figure 5). According to Sánchez *et al.* (2000), races are grouped into racial complexes, which in turn are associated with specific geographic and climatic distribution.

Within the racial groups, 10 original race types were identified: Arrocillo (Figure 2a), Cacahuacintle (Figure 2b), Cónico (Figure 2c), Elotes Cónicos (Figure 2d), Ratón (Figure 3), Celaya (Figure 4a), Tuxpeño (Figure 4b), Pepitilla (Figure 4c), Olotillo (Figure 5a),

Figure 2. Cónico Group. a) Arrocillo, b) Cacahuacintle, c) Cónico, d) Elotes Cónicos.

Figure 3. Early Maturing Tropical Group. Ratón Race.

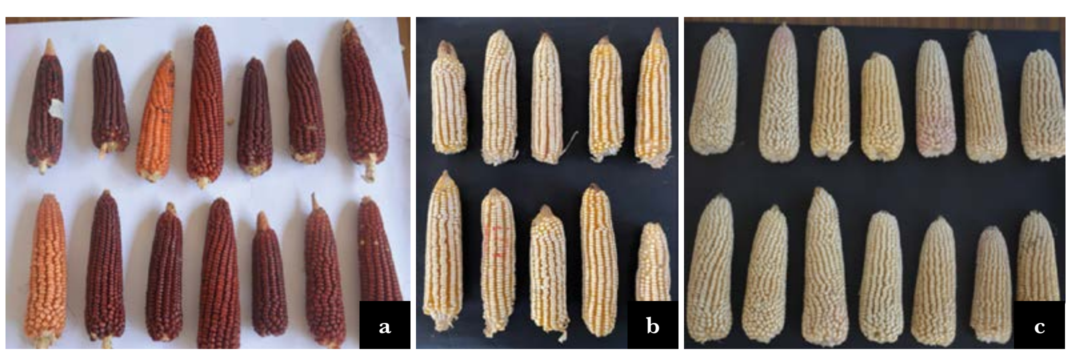

Figure 4. Tropical dented group. a) Celaya, b) Tuxpeño, c) Pepitilla.

Figure 5. Late maturing maize group. a) Olotillo, b) Coscomatepec.

and Coscomatepec (Figure 5b). These races are consistent with those reported by Sierra-Macías *et al.* (2014) for the state of Veracruz. Similar studies by Temoxtle-Mellado *et al.* (2023) identified 10 native maize races for the Altas Montañas region of Veracruz.

Among the interracial mixtures found were: Arrocillo-Cónico-Pepitilla-Tuxpeño, Celaya-Coscomatepec, Celaya-Coscomatepec-Ratón, Celaya-Elotes Cónicos, Celaya-Ratón, Cónico-Arrocillo, Cónico-Celaya, Cónico-Elotes Cónicos, Cónico-Pepitilla, Coscomatepec-Celaya-Pepitilla, Coscomatepec-Celaya, Olotillo-Tepecintle, Pepitilla-Cónico-Arrocillo, Ratón-Celaya, and Ratón-Tepecintle. Some crosses involve more than three races; however, the Celaya and Cónico races are involved in most of them. Valadez *et al.* (2008) identified eight interracial crosses for the state of Tamaulipas, indicating that the distribution of the crosses follows a pattern similar to that of the races involved in them.

The most frequent races were Cónico (Figure 2c) and Ratón (Figure 3). The races with the least distribution were Arrocillo, Olotillo, and Tuxpeño. The predominant native maize colors were white, cream, and yellow. Homogeneous collections of blue, purple, black, and red grains were also observed (Figures 2a, 2d, 4a, and 5b).

In most cases, the collected races and their distribution correspond to those reported by Sierra *et al.* (2014b); however, it is important to note the presence of the Cacahuacintle race in the border region of Veracruz and Puebla (Figure 2b), given that this race is distributed in specific ecological niches in areas of the central Mexican highlands, Puebla, Tlaxcala, and Hidalgo, at altitudes higher than 2,000 meters above sea level (Flores-Hernández *et al.*, 2022). This suggests a strong exchange of seeds between producers from Veracruz and Puebla, as well as an interest in increasing their income through the revaluation of different forms of consumption such as pozole, cookies, pinole, atole, among others (Fernández-Aulis *et al.*, 2019).

Principal Component Analysis

The eigenvalues and eigenvectors of the principal component analysis showed that the first three principal components (PCs) explained 90% of the total variation, 42% for PC1, 29% for PC2, and 18% for PC3, respectively. The characters that most defined PC1 were LMZ (0.82), NGRAN (0.66), and PMZ (0.95). Previous studies report similar results (Contreras-Molina *et al.*, 2016; Martínez-Sánchez *et al.*, 2017; González-Martínez *et al.*, 2020). Regarding PC2, the characters that contributed most to this component were DMZ (0.73) and NHIL (0.56), consistent with the findings reported by Martínez-Sánchez *et al.* (2017).

The scatter biplot (Figure 6), based on the first two principal components, allowed for the explanation of 72% of the total variance. This graph helps us understand the relationship between traits and their negative or positive association with the collections. In this sense, four population groups were identified.

Group 1 consisted of collections 34 (Pepitilla), 37 (Coscomatepec), 38 (Coscomatepec), 39 (Coscomatepec), and 50 (Tuxpeño). It was found that these collections were positively correlated to traits such as PMZ, LMZ, and NGRAN. Groups 2 and 3 consisted of collections 28 and 11. Although these two collections formed independent groups, both belong to the Cacahuacintle race. They were associated with traits such as NHIL, DOLO, DMZ, and PMZ. It is also important to highlight that collection 11 was collected on the northeastern side of Pico de Orizaba in the locality of San Miguel Tlacotiopa, municipality of Calcahualco. Collection 28 was collected on the south side of Pico de Orizaba in Texmola, municipality of Mariano Escobedo, suggesting different forms of adaptation such as precipitation, soil type, agronomic management, and seed selection, among others. Finally, Group 4 consisted of 43 collections, mostly of the Ratón and Cónico types, and the rest of the races found. These collections were negatively associated with the evaluated characters.

The genetic diversity constituted by groups of races with multiple local variants is the product of years of conservation and domestication by producers. The flow of germplasm, as the main route in seed exchange plays an important role in intra- and inter-population genetic diversity. It is important to make efforts to collect, study, and conserve the diversity present in ecological niches, given their broad cultural, environmental, and socioeconomic heterogeneity (Flores-Hernández *et al.*, 2022).

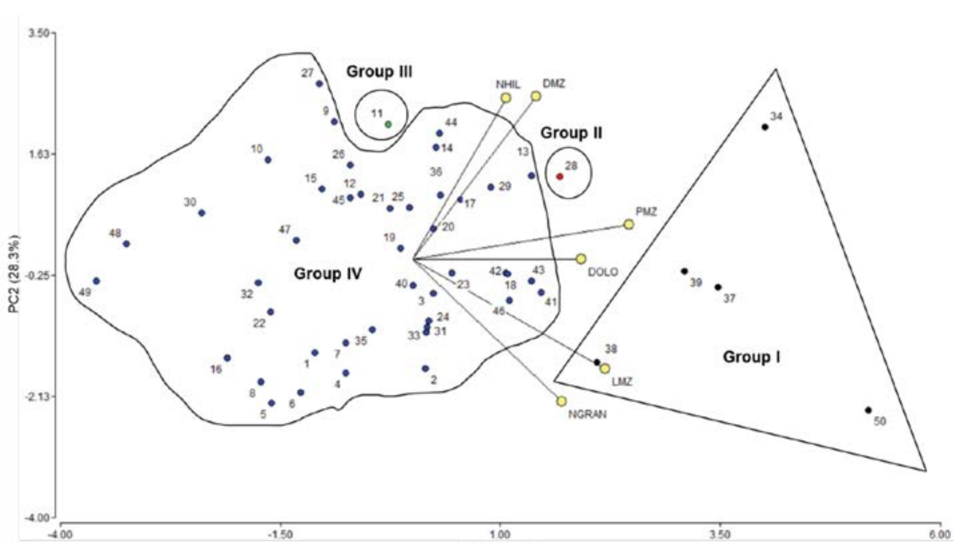

Figure 6. Dispersion of the collections on the first two principal components.

CONCLUSIONS

There is broad morphological diversity, expressed in the different races reported here, which are conserved by producers in various traditional systems near Pico de Orizaba. Races with specific characteristics were found, such as Tuxpeño and Coscomatepec, which express a large ear size and are an important part of maize breeding programs at the national and global levels. Likewise, Cacahuacintle is adapted to more humid ecological niches than its place of origin. Finally, this diversity of races is attributed to different geographic, environmental, social, economic, and cultural factors in the agriculture practiced in the Las Montañas region of the state of Veracruz.

ACKNOWLEDGMENTS

To the Consejo Veracruzano de Investigación Científica y Desarrollo Tecnológico (COVEICYDET) – Government of the State of Veracruz for the funding granted to the project "Biological Nitrogen Fixation in Native Maize Races for its Integration in Agricultural Systems with Producers in the Las Montañas Region of Veracruz, Mexico" with code CP 1111 1616/2023 to carry out this research.

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