Colegio de Postgraduados

Morphological and agronomic evaluation of short-cycle native maize varieties (*Zea mays* L.)

Caballero-Salinas, Juan C.[1]; **Guevara-Hernández, Francisco**[2*]; **Pizaña-Vidal, Hugo A.**[3]; **Cadena-Iñiguez, Pedro**[4]; **Ovando-Salinas, Jhony E.**[1]; **Gómez-Padilla, Ernesto J.**[5]

[1] Universidad Autónoma Agraria Antonio Narro, Centro Académico Regional Chiapas, prolongación avenida Benito Juárez, Rancho La Concordia, Cintalapa, Chiapas, México. C.P. 30400.
[2] Universidad Autónoma de Chiapas, Facultad de Ciencias Agronómicas Campus V, carretera Ocozocoautla–Villaflores km 84.5, Apartado Postal 78, Villaflores, Chiapas, México, C.P. 30470.
[3] Universidad Autónoma de Chiapas, Facultad de Contaduría y Administración, Boulevard Belisario Domínguez Kilómetro 1081, Terán, Tuxtla Gutiérrez, Chiapas, México. C.P. 29050.
[4] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Carretera internacional Ocozocoautla-Cintalapa Km.3, Ocozocoautla de Espinosa, Chiapas, México. C.P. 29140.
[5] Universidad Autónoma de Chiapas, Unidad de estudios de Posgrado, Doctorado en Ciencias Agropecuarias y Sustentabilidad (DOCAS), Boulevard Laguitos No. 424 Col. Los Laguitos, Tuxtla Gutiérrez, Chiapas, México. C.P. 29020.
* Correspondence: francisco.guevara@unach.mx

ABSTRACT

Objective: The objective of this study was to analyze the morphological composition and agronomic behavior of five varieties of *Zea mays* L. two Zapalote Chico, two Zapalote Grande and an improved variety (V-424) which are characterized by having a short vegetative cycle.

Desing/methodology/approach: The maize varieties evaluated were sourced from various locations within the municipality, with explicit consent from the producers, who provided the seeds for the study. Four native cultivars (treatments) were selected from the Zapalote Chico and Zapalote Grande races and one improved and open-pollinated maize variety (V-424 or Tuxpeño Precoz) as a control, released by INIFAP. The local farmers assigned the common names to the evaluated maize varieties, except for V-424. The varieties were distributed in a randomized block design with four replications, resulting in a total of 20 experimental units. Each unit consisted of four furrows, each measuring 4 meters in length.

Results: The findings of this study on native short-cycle maize varieties in Chiapas have significant implications at the genetic, social, cultural, economic, and environmental levels. Each of these aspects provides crucial guidance for decision-making related to the utilization, management, and conservation of local maize varieties. A key outcome of this study is the recognition of native maize as a repository of essential genes for food security in rural areas. Short-cycle landraces exhibit unique genetic adaptations that enable them to thrive under the specific agroclimatic conditions of the Central Valleys of Chiapas.

Limitations on study/implications: none

Findings/conclusions: The native maize varieties exhibited significant genetic variability across the variables under consideration. The Zapalote Chico race is characterized by its favourable characteristics, as recognized by farmers, including early maturity, drought resistance, lodging resistance, and resistance to the fall armyworm. These qualities make it a promising candidate for future research and for inclusion in genetic improvement programs, whether conventional or participatory. It is crucial to continue promoting agroecological inputs with the goal of fostering the development of resilient agroecosystems and, consequently, enhancing the well-being of farmers and the conservation of native maize reservoirs.

Keywords: *Zea mays* L., Native varieties, Endogenous biodiversity, Traditional agriculture, Mexico.

Citation: Caballero-Salinas, J. C., Guevara-Hernández, F., Pizaña-Vidal, H. A., Cadena-Iñiguez, P., Ovando-Salinas, J. E., & Gómez-Padilla, E. J. (2024). Morphological and agronomic evaluation of short-cycle native maize varieties (*Zea mays* L.). *Agro Productividad*. https://doi.org/10.32854/agrop.v17i10.3102

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

Received: August 21, 2024.
Accepted: October 13, 2024.
Published on-line: November 12, 2024.

Agro Productividad, 17(10). October. 2024. pp: 211-220.

INTRODUCTION

In Mexico, maize (*Zea mays* L.) holds significant cultural, economic, and political importance. It is estimated that 70-80% of the cultivated area is planted with native varieties, which play a critical role in the social reproduction of many peasant communities. Native maize also serves as a vital biotic resource, preserving the identity and history of rural families (Pérez-García, 2023).

In 2022, Chiapas, a state in southern Mexico, led the country in cultivated area with 686,943 hectares, ranking eighth in production, yielding 1,379,252.44 tons (SIAP, 2023). The region is home to nearly 34% (20 races) of Mexico's native maize races, including: Tehua, Comiteco, Cubano Amarillo, Nal-Tel, Olotillo, Olotón, Tepecintle, Tuxpeño, Vandeño, Zapalote Chico and Zapalote Grande (Caballero-Salinas *et al.*, 2023; Guevara-Hernández *et al.*, 2020). As a result, Chiapas is recognized as a region of significant genetic diversity (Hernández-Ramos *et al.*, 2020; Guevara-Hernández *et al.*, 2022).

In maize research, the term "race" is used to categorize individuals or populations that share common morphological, ecological, genetic, and historical characteristics, facilitating their identification as distinct groups. These races are structured into racial complexes, which are associated with their geographical and climatic distribution as well as their shared evolutionary history. In Mexico, maize races are grouped into seven categories: Chapalote, Conical (Cónico), Late Maturing (Maduración tardía), Eight-Row (Ocho hileras), Sierra Chihuahua, Early Tropical (Tropicales precoces), and Tropical Dentate (Dentados tropicales) (Estrada-Contreras *et al.*, 2022). The latter two categories include the distinctive races Zapalote Chico (Xhuba Huiini) and Zapalote Grande (Barrera-Guzmán *et al.*, 2020).

These races are distinguished by their short physiological cycles and high photosynthetic efficiency, requiring less water for vegetative development. These traits make them particularly well-suited for drought conditions (Barrera-Guzmán *et al.*, 2020). The primary use of this crop is in the production of traditional Mexican dishes and by-products such as tostadas, tamales, atole, and tortillas, contributing to the concept of food sovereignty (García-Franco and Gómez-Galindo, 2023). Given their origins, historical development, and unique characteristics, these varieties have been integrated into maize breeding programs (Guevara-Hernández and Mariaca-Méndez, 2023).

In Chiapas, the morphological and agronomic diversity of native maize populations has been studied to develop utilization and conservation strategies (Caballero-Salinas *et al.*, 2023). However, some maize races commonly cultivated by farmers in the municipality of Cintalapa, such as Zapalote Chico and Zapalote Grande, remain under-researched. Therefore, this study aims to characterize the morphological diversity and agronomic behavior of these races in the Central Valleys of Chiapas.

MATERIALS AND METHODS

The research was conducted in the experimental area at the Chiapas Regional Academic Centre, part of the Antonio Narro Agrarian Autonomous University, located in the municipality of Cintalapa, Chiapas, Mexico. The Centre is situated at 16° 39' North latitude and 93° 44' West longitude, at an altitude of 540 m. The mean annual

temperature ranges between 24 °C and 26 °C, with annual precipitation levels between 800 and 1,200 mm.

The maize varieties evaluated were sourced from various locations within the municipality (Table 1), with explicit consent from the producers, who provided the seeds for the study. Four native cultivars (treatments) were selected from the Zapalote Chico and Zapalote Grande races and one improved and open-pollinated maize variety (V-424 or Tuxpeño Precoz) as a control, released by INIFAP (Coutiño-Estrada, 2014). The local farmers assigned the common names to the evaluated maize varieties, except for V-424. The varieties were distributed in a randomized block design with four replications, resulting in a total of 20 experimental units. Each unit consisted of four furrows, each measuring 4 meters in length.

The sowing process was conducted manually during the spring-summer 2022 agricultural cycle. Plants were arranged in rows with 60 cm spacing between rows and 30 cm between plants, resulting in a population density of 110,556 plants per hectare. At each sowing point, three seeds were planted, followed by manual thinning to leave two plants per clump.

Table 1. Treatments with the maize varieties evaluated and their communities of origin in the municipality of Cintalapa, Chiapas.

Treatment	Local name /(Race)	Origin	Ear characteristic	Altitude (masl*)
T1	V-424 (Tuxpeño)	Villamorelos		704
T2	Cuarentano blanco (white) (Zapalote Chico)	Cintalapa		540
T3	Cuarentano amarillo (yellow) (Zapalote Chico)	Tuxtlita		540
T4	Opamil (Zopilote Grande)	Villamorelos		704
T5	Tapanero (Zapalote Grande)	Villamorelos		704

* masl: meters above sea level.

Vegetative variables were measured at various stages of the crop's growth and development. To ensure representativeness, 20 plants were randomly selected from each experimental unit. The evaluated characteristics included vegetative type, ear length (measured during the milky stage of the grain), and ear size, following the descriptors for maize established by the International Board for Plant Genetic Resources (IBPGR) in 1991 (CTA, 1992).

At 85 days after sowing (DDS), vegetative development variables were measured, including plant height (AP), stalk diameter (DT), number of leaves below the ear (NHDM) and above the ear (NHAM), total number of leaves (TH), and leaf width (AH) and length (LH) associated to the main ear.

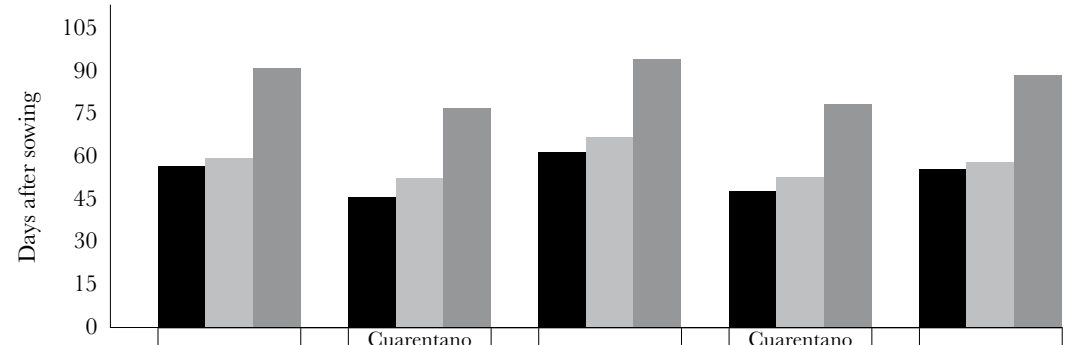
Phenological variables, such as days to male flowering (DFM) and days to female flowering (DFF), were recorded when 50% of the plants had released pollen and exhibited receptive stigmas. After the flowering period, additional characteristics were evaluated: spike length (LE), number of branches per spike (RE), stalk length (LP), branch length (LTR), and panicle length (LPA). Physiological maturity was determined when the ears reached senescence (SEN), indicated by the presence of dry bracts in 50% of the plants. Ear-related variables measured included diameter (MD), length (LM), number of rows (NH), number of grains per row (NGH), and corncob diameter (DO). Ear harvesting was carried out manually during the first two weeks of September, coinciding with the physiological maturity of the genotypes under evaluation.

For Statistical Analysis, SAS Studio® was used. Data were initially analyzed using the Shapiro-Wilk test and Bartlett's test to ensure they met the criteria for normality and homogeneity of variance. A two-way analysis of variance and Tukey's multiple comparison test were then conducted to analyse the results.

RESULTS AND DISCUSSION

Days to male and female flowering and Senescence

The observed data for DFM ranged from 45 to 62 DDS, while for DFF, it ranged from 49 to 66 days (Figure 1). The maize varieties exhibiting above-average values for



	Opamil	Cuarentano blanco	V-424	Cuarentano amarillo	Tapanero
DFM	56	45	62	47	53
DFF	60	49	66	50	57
SEN	91	76	94	77	88

Figure 1. Days to male flowering (DFM), female flowering (DFF), and senescence (SEN) of the maize varieties studied in Cintalapa, Chiapas.

DFM were Tapanero, Opamil, and V-424. The two Cuarentano maize varieties (white and yellow) showed the lowest DFM and DFF values, indicating early crop maturation. The female flowering values for Cuarentano maize varieties were like those reported by López-Romero *et al.* (2005), who characterized 14 populations of Zapalote Chico. Many studies found that the evaluation of 18 Zapalote Chico populations yielded results ranging from 45 to 51 days for DFM and 48 to 53 days for DFF.

The results regarding days to flowering indicate that the four native maize varieties (T2-T4) evaluated are considered short-cycle. However, the V-424 (T1) variety exhibited the highest values for both variables and is classified as an early to intermediate cycle cultivar among improved open-pollinated maize varieties. Regarding flower synchronization, the yellow Cuarentano maize showed the shortest period.

The early maturation of the Zapalote Chico and Zapalote Grande cultivars suggests that short-cycle maize may serve as a viable alternative in regions with limited precipitation or prolonged drought periods, as they can complete their developmental cycle with reduced water requirements. Additionally, these varieties are well-adapted to the spring-summer rainy season.

In this context, strategic actions can be developed to address the challenges posed by drought, water scarcity, and irregular rainfall patterns due to climate change. In their study, like the days to flowering, the two Cuarentano maize evaluated exhibited the shortest ear senescence periods. The highest values were observed in the Opamil and V-424 varieties, with durations of 91 and 94 days, respectively, after sowing. This highlights one of the most notable attributes of the Zapalote Chico maize variety: its early maturation. This characteristic allows for the possibility of two production cycles per year on the same plot, provided that the planting schedule is aligned with the onset of the regional rainy season.

Vegetative variables

Although no significant differences in plant height (AP) were observed, as expected, the V-424 variety showed a tendency for increased plant height, followed by the varieties of Zapalote Grande and Zapalote Chico, respectively (Table 2). On average, the ears were

Table 2. Response of vegetative variables in the maize varieties studied in Cintalapa, Chiapas.

Variety	AP (cm)	AM (cm)	DT (cm)	NHDM	NHAM	TH	AH (cm)	LH (cm)
Opamil	124.00	74.25^{a}	1.51^{a}	5.80^{b}	5.62^{b}	11.41^{b}	6.00^{ab}	67.49^{a}
White Cuarentano	122.40	66.70^{ab}	1.33^{b}	4.89^{cd}	4.65^{c}	9.57^{d}	4.83^{c}	52.14^{c}
V-424	131.80	68.67^{ab}	1.52^{a}	6.34^{a}	6.19^{a}	12.52^{a}	6.36^{a}	67.96^{a}
Yellow Cuarentano	121.70	58.00^{c}	1.29^{b}	4.59^{d}	4.66^{c}	9.25^{d}	4.48^{c}	54.72^{c}
Tapanero	123.30	63.20^{bc}	1.46^{b}	5.17^{c}	5.46^{b}	10.65^{c}	5.57^{b}	60.17^{b}
CV (%)	26.30^{NS}	27.40	21.40	20.70	17.60	14.60	21.30	19.90

Note: Different letters within the same column indicate a statistically significant difference between treatments. NS: Not significant. **Highly significant difference ($p<0.01$). The following variables were measured: AP (plant height), AM (ear height), DT (stem diameter), NHDM (number of leaves below the ear), NHAM (number of leaves above the ear), TH (total number of leaves), AH (leaf width), LH (leaf length), and CV (coefficient of variation).

observed at a mean height of 66.09 cm. However, Opamil maize exhibited a significantly greater ear height (74 cm) compared to yellow Cuarentano and Tapanero varieties (Table 2), although it was statistically like V-424 and white Cuarentano maize. The greatest stem diameter (DT) was observed in the V-424 and Opamil maize varieties. While the remaining cultivars exhibited lower values for this variable, they did not experience lodging due to their shorter height. Additionally, the V-424 variety outperformed others in several traits, including the total number of leaves (TH), number of leaves below the ear (NHDM), number of leaves above the ear (NHAM), leaf height (AH), and leaf length (LH) (Table 2). In contrast, the two Cuarentano varieties exhibited the lowest values for these variables, leading to reduced leaf development.

The variability in the number of leaves above and below the ear represents a crucial variable for study, as it contributes to understanding genetic and phenotypic diversity among maize populations. Numerous studies have shown that these traits influence not only maize yield and adaptation to diverse environmental conditions but also crop efficiency and disease resistance (Hernández and Avellaneda, 2021).

In this context, the specific number of leaves significantly influences sunlight capture, nutrient distribution, and pollination-factors that are fundamental for optimal plant development and grain production (Bisetti-Rivera, 2023).

Ear variables

Significant differences were observed across all ear-related variables (see Table 3). The largest ear diameter (DM) was observed in the V-424 maize variety, followed by Opamil and Tapanero. Maize with shorter plant height (AP) exhibited reduced ear length (LM) and ear diameter (DM), as seen in the white and yellow Cuarentano varieties (Table 3). This result may be associated with a shorter vegetative phase, which could lead to smaller ears (Sánchez-Hernández *et al.*, 2013). In their agronomic evaluation of two Zapalote Chico populations, others researchers reported mean ear lengths of 8.4 and 8.8 cm, and mean ear diameters of 3.6 and 3.5 cm, respectively.

In this study, Tapanero maize exhibited the highest length-to-maturity (LM) value (10.75 cm) and the highest number of grains per row (NGH) (24.02). Furthermore, the

Table 3. Ear variables of the maize varieties studied in Cintalapa, Chiapas.

Variety	DM (cm)	LM (cm)	NH	NGH	DO (cm)
Opamil	4.33^{b}	10.18^{a}	11.25^{b}	20.43^{b}	2.56^{b}
White Cuarentano	3.97^{b}	8.25^{b}	9.62^{d}	19.07^{b}	2.09^{d}
V-424	4.58^{a}	10.57^{a}	13.38^{a}	18.72^{b}	2.88^{a}
Yellow Cuarentano	3.86^{c}	6.89^{c}	9.92^{cd}	13.53^{c}	2.41^{bc}
Tapanero	4.19^{b}	10.75^{a}	10.57^{bc}	24.02^{a}	2.41^{c}
CV (%)	8.80	20.00	12.60	25.10	10.70

Note: Different letters within the same column indicate a statistically significant difference between treatments. A highly significant difference was observed ($p<0.01$). The variables measured include DM (ear diameter), LM (ear length), NH (number of rows), NGH (number of grains per row), DO (corncob diameter), and CV (coefficient of variation).

maize varieties with the highest LM values (Tapanero, V-424, and Opamil) also exhibited the highest values for days to male flowering (DFM), days to female flowering (DFF), and plant height (AP). Regarding the number of rows (NH), V-424 maize had the highest value, a characteristic feature of Tuxpeño ears (Caballero-Salinas *et al.*, 2023). Conversely, the lowest NH was observed in both Cuarentano maize varieties. Wellhausen *et al.* (1951) described the Zapalote Chico race as typically having ears with 10 to 12 rows. Ultimately, the largest corncob diameter (DO) was observed in V-424 maize, with significant differences compared to the other varieties. The smallest DO was found in the white Cuarentano maize.

Spike Variables

Notably, stalk length (LP) and branch length (LTR) exhibited the highest coefficients of variation, at 36.1% and 29.5% respectively (Table 4), indicating a high degree of relative variability in these traits within the studied population. The variables branches per spike (RE) and branch length (LTR) are particularly noteworthy in the Zapalote Grande maize, specifically in both Opamil and Tapanero varieties (Table 4). The plants with the longest peduncles (LP) were observed in the Zapalote Chico maize, including both yellow and white Cuarentano varieties. Similar findings were reported by Cabrera-Toledo *et al.* (2019). The LP in Zapalote Chico maize ranged from 9.45 to 9.96 cm, differing somewhat from the values reported by López-Romero *et al.* (2005). Ultimately, the highest values for panicle length (LPA) were observed in the Opamil and V-424 maize varieties, while the Cuarentano populations exhibited the lowest values (Table 4). These findings are consistent with those studies evaluated 18 native maize varieties of the Zapalote Chico race from Oaxaca, Mexico.

It is important to note that ear traits are phenotypic characteristics commonly used to describe and analyse genetic diversity in native maize varieties. These traits not only serve as visual indicators of variation between different races and varieties of maize but also reflect specific adaptations to local agroecological environments and traditional cultivation practices (Guevara-Hernández *et al.*, 2019). Numerous researchers have employed these traits to examine the genetic composition of maize and to facilitate the genetic improvement of existing varieties. Their importance in the selection and development of new varieties

Table 4. Spike variables of the maize varieties studied in Cintalapa, Chiapas.

Variety	LE (cm)	RE	LP (cm)	LTR (cm)	LPA (cm)
Opamil	35.70	11.19^{a}	7.00^{b}	9.28^{a}	29.61^{a}
White Cuarentano	33.30	9.11^{bc}	9.45^{a}	7.54^{b}	25.38^{bc}
V-424	35.30	10.14^{ab}	5.60^{c}	6.70^{b}	29.60^{a}
Yellow Cuarentano	33.50	8.56^{c}	9.96^{a}	7.08^{b}	23.29^{c}
Tapanero	33.30	10.44^{a}	6.44^{bc}	8.85^{a}	27.13^{ab}
CV (%)	22.20^{NS}	27.00	36.10	29.50	22.20

Note: Different letters within the same column indicate a statistically significant difference between the treatments in question. NS: Not significant. **Highly significant difference ($p<0.01$). LE: spike length; RE: number of branches per spike; LP: length of the peduncle; LTR: length of the branched section; LPA: length of the panicle; CV: coefficient of variation.

has been underscored by several studies (Wellhausen *et al.*, 1951; Estrada-Contreras *et al.*, 2022; Vizcarra Manríquez, 2023).

The results reported here confirm that native maize varieties represent a dynamic and resilient agricultural system. Open pollination facilitates genetic flow, which, together with the continuous exchange of seeds among farmers, generates a high diversity of genetic combinations (Hernández *et al.*, 2020). This process enables the preservation and adaptation of native varieties with valuable agronomic traits that are specifically sought after by farmers. These varieties are well-adapted to regional agroecological niches, ensuring their sustainability and relevance in diverse local environments (Fonseca-Flores *et al.*, 2023).

In the case of maize varieties belonging to the Zapalote Chico race, the phenotypic values observed are consistent with those reported in previous research conducted in the Isthmus of Tehuantepec, the region of origin for this race. This consistency demonstrates that, despite being cultivated outside of its original habitat, Zapalote Chico has shown a satisfactory adaptive response to the agroenvironmental conditions of the Central Valleys of Chiapas.

The attributes exhibited by the Zapalote Chico maize varieties —including early flowering, drought resistance, tolerance to armyworm, and wind resistance— highlight its valuable genetic characteristics for mass selection processes based on agromorphological criteria that are important to farmers, particularly in the context of climate change. Although it is often regarded as a low-yielding variety, with an average yield of approximately 1.25 t ha^{-1} under rainfed conditions and 2.0 to 3.0 t ha^{-1} under irrigation, its ability to produce two or even three harvests per year makes it a highly attractive option. In this context, it would be a mistake to focus exclusively on yield-based productivity criteria, overlooking other unique attributes of the race, such as its adaptation to local conditions, resistance to diseases, and cultural or nutritional value. These attributes are equally important for the long-term sustainability and utility of the race.

The findings of this study on native short-cycle maize varieties in Chiapas have significant genetic, social, cultural, economic, and environmental implications. These conclusions are crucial for decision-making regarding the utilization, management, and conservation of these local varieties.

A key outcome of this research is the recognition that native maize represents a vital repository of essential genes for food security in rural areas. Short-cycle landraces have developed unique genetic adaptations that allow them to thrive under the specific agroclimatic conditions of the Central Valleys of Chiapas. These adaptations, shaped over centuries by natural selection and traditional management practices, are critical for addressing contemporary challenges such as climate change, soil degradation, and emerging pests. The data generated from this study can strengthen germplasm banks and inform both *in situ* and *ex situ* conservation strategies, ensuring the preservation of seeds not only in laboratories but also in the fields of indigenous and peasant communities, thus safeguarding these varieties for future use and contributing to Mexico's agricultural and genetic heritage (Guevara *et al.*, 2019).

Maize holds deep cultural significance beyond being a staple food; it is a cornerstone of cultural identity for many rural communities in Chiapas and throughout Mexico. Preserving native varieties is crucial not only for food security but also for maintaining the diversity of traditional dishes, which are a vital part of these communities' cultural heritage. This study offers valuable insights that can help promote the cultivation of native maize, particularly varieties adapted to local conditions, enhancing the resilience of agricultural production in the face of current challenges (Guevara *et al.*, 2022).

Additionally, the cultivation of these varieties supports sustainable agricultural practices by leveraging the traditional knowledge of local farmers, who have managed these varieties without relying on external inputs like chemical fertilizers and pesticides. This approach strengthens food self-sufficiency in rural communities and reduces reliance on agricultural technologies that may not be sustainable in the long term (Guevara *et al.*, 2019; Pérez-García, 2023).

Finally, the study highlights the need for public policies that recognize the inherent value of native maize and promote its conservation and use. The increasing homogenization of agricultural biodiversity, driven by the commercial interests of large agribusinesses, poses a significant threat. However, preserving native varieties provides a crucial countermeasure, as these landraces retain invaluable genetic traits, such as resistance to diseases and extreme environmental conditions, which may prove indispensable for future breeding programs (Guevara-Hernández *et al.*, 2023).

CONCLUSIONS

The native maize varieties exhibited significant genetic variability across the variables under consideration. The Zapalote Chico race is characterized by its favourable characteristics, as recognized by farmers, including early maturity, drought resistance, lodging resistance, and resistance to the fall armyworm. These qualities make it a promising candidate for future research and for inclusion in genetic improvement programs, whether conventional or participatory. It is crucial to continue promoting agroecological inputs with the goal of fostering the development of resilient agroecosystems and, consequently, enhancing the well-being of farmers and the conservation of native maize reservoirs.

ACKNOWLEDGEMENTS

All authors express their gratitude to the Doctorado en Ciencias Agropecuarias y Sustentabilidad (DOCAS) at the Universidad Autónoma de Chiapas (UNACH) for covering the article processing charges (APCs).

REFERENCES

Barrera, G. L. A., Legaria, S. J. P., & Ortega, P. R. (2020). Diversidad genética en poblaciones de razas mexicanas de maíz. *Revista Fitotecnia Mexicana, 43*(1), 121-125. https://www.scielo.org.mx/scielo.php?pid=S0187-73802020000100121&script=sci_arttext

Bisetti-Rivera, S. N. (2023). Caracterización morfológica de siete razas de maíz (*Zea mays* L.) de Cusco y Apurimac bajo condiciones de Chiquian (Ancash). Tesis Profesional, Universidad Nacional Agraria La Molina, Lima, Perú. https://repositorio.lamolina.edu.pe/handle/20.500.12996/5865

Caballero-Salinas, J. C., Vidal, H. A., González-Cabañas, A. A., Núñez-Ramos, E., Aguilar-Cruz, F. y Ovando-Salinas, E. (2023). Composición morfológica y rendimientos de maíces nativos sin uso de agroquímicos en Chiapas, México. *Siembra, 10*(2), e3997. https://doi.org/10.29166/siembra.v10i2.3997

Cabrera-Toledo, J. M., Carballo-Carballo, A., Mejía-Contreras, J. A. y Vaquera-Huerta, H. (2019). Caracterización de poblaciones sobresalientes de maíz de la raza Zapalote Chico. *Revista fitotecnia mexicana, 42*(3), 269-279. https://doi.org/10.35196/rfm.2019.3.269

Coutiño-Estrada, B., Gómez-Montiel, N. O., Vázquez-Carrillo, G. y Vidal-Martínez, V.A. (2014). 'V-560', nueva variedad precoz de maíz para regiones tropicales. *Revista fitotecnia mexicana, 37*(2), 187-188. https://doi.org/10.35196/rfm.2014.2.187

CTA (1992). IBPGR: International Board for Plant Genetic Resources. Spore 38. CTA, Wageningen, The Netherlands. https://hdl.handle.net/10568/45742

Estrada-Contreras, I., Bourg, A. y Pavón-Hernández, N. P. (2022). Las razas de maíz ante el cambio climático en México. *Herreriana, 3*(2), 23-27. https://doi.org/10.29057/h.v3i2.8500

Fonseca-Flores, M.A., Guevara-Hernández, F., García-García, A., Márquez-Rosano, C. and Parra- Vázquez, M.R. (2023). Diversity of local maize in ejidos of the Frailesca region of Chiapas, Mexico. *Tropical and Subtropical Agroecosystems. 26*(1):1-18. http://doi.org/10.56369/tsaes.4397

García-Franco, A. y Gómez-Galindo, A. A. (2023). La milpa y la alimentación en México. *Educación Química, 34*(número especial). https://doi.org/10.22201/fq.18708404e.2023.4.86339e

Guevara, H. F., Pérez, R., Acosta, R. R., Ayan, L., La O, M., Ramos, M., Pinto, R. R., Martínez, F., & Reyes, M. (2022). Maíces locales de la Frailesca Chiapaneca: Diversidad, usos múltiples y distribución (1st ed.). Ediciones INCA y Unidad de divulgación científica-Unach-Unicach-Red de Estudios para el desarrollo Rural A.C. https://n9.cl/wf3lt

Guevara-Hernández, F. y Mariaca-Méndez, R. (2023). Importancia actual de los maíces locales (*Zea mays* L.): Aportes y reflexiones etnobotánicas desde Chiapas, México. *Universidad y Sociedad, 15*(6), 438-445. https://rus.ucf.edu.cu/index.php/rus/article/view/4162

Guevara-Hernández, F., Aguilar-Vázquez, E. H., Ruiz-Sánchez, E., Martínez-Aguilar, F., & Aguilar-Jiménez, C. E. (2023). Backyards: typology and contribution to food security in Mexico. *Ciência Rural*, 53.

Guevara-Hernández, F., Hernández-Ramos, M. A., Basterrechea-Bermejo, J. L., Pinto-Ruiz, R., Venegas-Venegas, J. A., Rodríguez-Larramendi, L. A. y Cadena-Iñiguez, P. (2019). Maíces locales; una contextualización de identidad tradicional. *Revista de La Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo, 51*(1), 369–381. https://revistas.uncu.edu.ar/ojs3/index.php/RFCA/article/view/2457

Guevara-Hernández, F., Hernández-Ramos, M. A., Basterrechea-Bermejo, J. L., Fonseca-Flores, M. A., Delgado-Ruiz, F., Ocaña Grajales, M. J. y Acosta-Roca, R. (2020). Riqueza de maíces locales (*Zea mays* L.) en la región Frailesca, Chiapas, México: Un estudio etnobotánico. *Revista de la Facultad de Agronomía (LUZ), 37*(3), 223-243. https://www.produccioncientificaluz.org/index.php/agronomia/article/view/32660

Hernández, C. E. P. y Avellaneda, C. (2021). Epidemiología de la mancha de asfalto en maíz bajo diferentes estrategias de manejo. CEIBA, Edición Zamorano Investiga, 65-82. https://revistas.zamorano.edu/index.php/CEIBA/article/view/1269

Hernández-Ramos, M. A., Guevara-Hernández, F., Basterrechea-Bermejo, J. L., Coutiño-Estrada, B., La O-Arias, M. A. y Pinto-Ruiz, R. (2020). Diversidad y conservación de maíces locales de la Frailesca, Chiapas, México. *Revista Fitotecnia Mexicana, 43*(4), 471-479. https://doi.org/10.35196/rfm.2020.4.471

López-Romero, G., Santacruz-Varela, A., Muñoz-Orozco, A., Castillo-González, F., Córdova-Téllez, L. y Vaquera-Huerta, H. (2005). Caracterización morfológica de poblaciones nativas de maíz del Istmo de Tehuantepec, México. *Interciencia, 30*(5), 284-290. http://ve.scielo.org/scielo.php?pid=S0378-18442005000500008&script=sci_arttext

Pérez-García, O. (2023). Diversidad biocultural ligada a maíces nativos del estado de Puebla, México. *Ecosistemas y Recursos Agropecuarios, 10*(2). https://doi.org/10.19136/era.a10n2.3430

Sánchez-Hernández, M. A., Aguilar-Martínez, C. U., Valenzuela-Jiménez, N., Joaquín-Torres, B. M., Sánchez-Hernández, C., Jiménez-Rojas, M. C. y Villanueva-Verduzco, C. (2013). Rendimiento en forraje de maíces del trópico húmedo de México en respuesta a densidades de siembra. *Revista mexicana de ciencias pecuarias, 4*(3), 271-288. https://cienciaspecuarias.inifap.gob.mx/index.php/Pecuarias/article/view/3188

SIAP. (2023). Información estadística de cierre del año agrícola 2022. Servicio de Información Agroalimentaria y Pesquera. http://infosiap.siap.gob.mx/gobmx/datosAbiertos.php

Vizcarra-Manríquez, D. L. (2023). Evaluación y selección de híbridos de maíz formados a partir de dos metodologías de predicción. Tesis de licenciatura, Universidad Autónoma Agraria Antonio Narro, Coahuila, México. https://repositorio.uaaan.mx/handle/123456789/49270

Wellhausen, E. J., Roberts, L. M. y Xolocotzi, E. H. (1951). Razas de maíz en México, su origen, características y distribución (Vol. 5). Secretaría de Agricultura y Ganadería México. https://library.wur.nl/WebQuery/titel/522520