

## AGRONOMIC PERFORMANCE OF NATIVE AND HYBRID MAIZE (*Zea mays* L.) IN THE MUNICIPALITY OF ATENCO, STATE OF MEXICO

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### ABSTRACT

In the municipal area of Atenco, State of Mexico, Mexico, 20 % of maize (*Zea mays* L.) seeds planted are from hybrids and improved varieties, and the rest are from native varieties. However, the diversity of native maize is being noticeably lost, as the recent land conflict has pushed agricultural activities to the background, where they must be reinigorated after the relocation of the Mexico City airport. To date, the investigations carried out in native maize races in the High Valleys are focused mainly in Puebla, Tlaxcala, and north of the State of Mexico, and little has been studied on the lake area of Texcoco. As a result, the aim was to determine the potential yield and agronomic characteristics of native varieties in relation to commercial varieties recommended for the area. Thirty-eight accessions from Atenco and surrounding municipal areas, along with 11 commercial hybrids recommended for the High Valleys, were evaluated. The evaluation was conducted in two locations: the ejido of San Salvador Atenco and the Valley of Mexico Experimental Field of the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP) in Santa Lucía de Prías, Coatlinchán, Texcoco, State of Mexico, using a 7 × 7 lattice design with three replications. Information was recorded regarding days to female flowering (DFF) and male flowering (DMF), plant height (PH) and ear height (EH), ear diameter (ED), ear length (EL), number of rows per ear (RPE), and grain yield (GY). There were differences ( $p \leq 0.01$ ) between genotypes for the variables; between locations, there were differences for the variables of flowering, plant morphology, and yield, and for the genotype × location interaction, there was no significance in two variables (EH and EL). The SAR-1 native genotype produced a similar grain yield to that of the best commercial hybrids, which can be used for further improvement.

**Keywords:** yield, agronomic performance.

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## INTRODUCTION

Maize (*Zea mays* L.) is the basis of the Mexican diet. Varieties and hybrids have been developed to cover the needs of the country's agroclimatic regions, with characteristics such as disease resistance, homogeneous phenotypes, and good yields (Espinosa *et al.*, 2009). Nonetheless, for Mexico's seasonal small-scale agriculture, 59 maize races have been reported, with plants and ears that exhibit distinctive variability in size, color, and shape, indicating a wide genetic diversity.

The races from the High Valleys of central Mexico, whose distinguishing feature is the pyramidal shape of their ears, are distributed predominantly in regions with altitudes greater than 2000 m (Sánchez *et al.*, 2000), and most of them are endemic to the High Valleys and mountain ranges of the center of the country (Wellhausen *et al.*, 1951). In these regions, mainly native races are identified, including Cónico, Elotes Cónicos, Chalqueño, Arrocillo Amarillo, Palomero Toluqueño, and Cacahuacintle (Sierra-Macías *et al.*, 2014). To date, the investigations carried out on maize native to the High Valleys have focused on Puebla, Tlaxcala, and the north of the State of Mexico, and little has been studied on the lake area of Texcoco.

The diversity of native maize in the area has been impacted, particularly in the municipal area of Atenco, where until 2019, 20 % of the maize seed planted was of commercial varieties and the rest of the native maize races (SIAP, 2019). A considerable loss is related to the long period of conflict lasting more than 15 years over land in the face of the construction of Mexico City's new airport, which led agriculture to a state of almost complete neglect. Due to this situation, there is a decline in the planting of native maize seeds, which lose their viability in a relatively short period, along with the lack of interest in youths to become farmers and the rapid demographic growth in recent years (Espinosa-Castillo, 2008).

The study of diversity in the highlands is essential. The diversity of native maize populations in the state of Puebla was investigated, with an evaluation of 41 native populations from the Serdán, Libres-Huamantla, and Puebla valleys, including 19 racial controls and two experimental varieties. The native populations were associated with the races Chalqueño, Cónico, Elotes Cónicos, and the sub-race Elotes Chalqueños, and variation was found in the resulting groups. Therefore, the environment and the dynamic process of selection of farmers favor a variation between and within groups (Flores-Pérez *et al.*, 2015).

Alvarado *et al.* (2019) analyzed the morphologic variability of the native maize of the western Puebla and eastern Tlaxcala mountain ranges in order to define and relate races, commercial varieties, and the altitude of the collection sites, resulting in the morphologic variability of the populations being unrelated to the altitude of the sites. These samples had more relation to the Chalqueño race, little relation with the Cónico race, none with the Cónico Norteño and Palomero Toluqueño races, and almost none with the commercial varieties.

Likewise, in the southern State of Mexico, maize diversity was evaluated in 103 native maize samples of the Chalqueño race and eight hybrids from the High Valleys as

controls in terms of morphology and grain yield. The creamy Chalqueño-type grain collections displayed similar yields to those of the best hybrids (Herrera-Cabrera *et al.*, 2013). In addition, producers use empirical selection of seeds and prefer local varieties, which allows for the conservation of diversity and the improvement of productivity *in situ*.

Based on the above, the goal of this study was to compare the agronomic performance of native maize varieties to commercial maize varieties recommended for the Atenco area in the State of Mexico, with the hypothesis that there are native maize varieties that yield as much as commercial hybrid varieties.

## MATERIALS AND METHODS

### Genetic material

A total of 38 native varieties were collected, 21 of which were native to the municipal area of Atenco, nine from Texcoco, one from Ixtapaluca, four from Tepetlaoxtoc, and one from Otumba, in the State of Mexico, and two genotypes from San Juan Ixtenco, in the state of Tlaxcala, which were evaluated along with 11 hybrid maize varieties recommended for the High Valleys, including four from the company ASPROS, one from ASGROW, one from CERES, two from the Postgraduate College (COLPOS), and three from the National Forestry, Agricultural, and Livestock Research Institute (INIFAP).

### Locations

The set of varieties was evaluated in the year 2022 in two locations: a) San Salvador Atenco, Atenco, State of Mexico (19° 33' N, 98° 55' W, at an altitude of 2250 m), with an annual average temperature of 15.1 °C and rainfall of 605 mm (García, 2004); and b) in the Valley of Mexico Experimental Field of the INIFAP in Santa Lucía de Prías, Coatlinchán, Texcoco, State of Mexico (19° 26' N, 98° 53' W, at an altitude of 2257 m), with an annual average temperature of 15.2 °C and rainfall of 637 mm (García, 2004), with hail 34 days after planting (the plant recovered because it was in a vegetative state).

### Experimental design

A 7 × 7 lattice experimental design with three replications was used; the experimental plot consisted of two rows, each 5 m long and spaced 0.8 m apart. Two seeds were placed every 25 cm along the bottom of the row.

### Agronomic management

In San Salvador Atenco, planting was carried out on May 28, and auxiliary irrigation was applied 16 days after planting (DAP), and in Santa Lucía, on June 13, with irrigations applied at 31 and 122 DAP. In each location, plants were fertilized 15 DAP with urea and triple superphosphate using an NPK formula of 140-40-00. For weed

control, Primagram® (atrazine and smetolachlor, 2 kg ha<sup>-1</sup>) was used 25 days after seedling emergence. In San Salvador Atenco, in order to control the fall armyworm (*Spodoptera frugiperda*), Karate Zeon® (lambda-cyhalothrin, dose 300 mL ha<sup>-1</sup>) was applied 126 DAP. Grain harvest in San Salvador took place 189 DAP, and in Santa Lucía, 164 DAP.

### Response variables

In each location, data were taken regarding days to male (DMF) and female flowering (DFF); the former, from planting until 50 % of the plants in the field released pollen; and the latter, until young ears were displayed, with exposed stigmata (SNICS, 2024). In order to record plant height (PH, cm) and ear height (EH, cm), five plants were chosen at random per plot and measured from the ground up to the knot of the flag leaf (cm) and up to the knot where the ear is inserted (cm), respectively (SNICS, 2024). In harvest, five representative ears were taken from each plot, whose lengths (EL, cm) were measured from the base to the tip, along with the diameter (ED, cm) in the middle section and the number of rows (RPE).

The ears dried outdoors, and the threshing factor (FCD, weight of grain without the cob divided by the weight of grain with the cob) was determined, along with the moisture content (%) and the weight of 100 g of seeds of each genotype. Later, using the Steinlite Electronic Tester, Model G (Chicago, IL, USA), the letter and number corresponding to the moisture content of the seed were determined. The temperature and grain yield (GY) were adjusted to 14 % moisture, extrapolating the weight of all the ears harvested from the experimental unit to kg per hectare using the formula:

$$Yield \left( \frac{kg}{ha} \right) = field\ weight \times shelling\ factor \left[ 1 - \frac{moisture\ percentage}{100} \right] + 0.14 \times 1250$$

### Statistical analysis

A combined analysis was performed using the SAS statistical package (version 9.4, SAS Institute Inc., Cary, NC, USA) to determine the average performance of the genotypes associated with the variables. The means were compared using Tukey's test ( $p \leq 0.05$ ).

## RESULTS AND DISCUSSION

The varieties displayed differences ( $p \leq 0.01$ ) for all variables, indicating the existence of genetic variability (Table 1). The diversity of native maize is not only found in the east of the State of Mexico but also in the Puebla Valley, where variations are found in ear shape and size. These traits are due to the selection practiced by farmers according to their needs, such as cob thickness and lodging of the plants (Hortelano-Santa Rosa *et al.*, 2008). Most variables (Table 1) showed significant differences ( $p \leq 0.01$ ), with the exception of diameter and number of rows per ear, which were similar. This suggests that the crop's performance is primarily influenced by its environment (planting date and soil type).

**Table 1.** Mean squares and statistical significance for eight variables evaluated in 38 native maize (*Zea mays* L.) varieties and 11 commercial hybrids grown in two environments in the eastern State of Mexico, Mexico, during the spring-fall season of 2022.

FV	Genotypes	Locations	Gen × Loc	Error	CV (%)
DF	48	1	48	156	
DMF	3286 **	22 112 **	559	12	3.9
DFF	2179 **	22 466 **	445	11	3.9
PH	57 013 **	56 709 **	38 465	631	9.7
EH	88 609 **	12 129 **	64 471 **	785	17.4
EL	176 **	4 *	99 **	1	6.9
ED	11 **	0.02	2	0.05	5.4
RPE	533 **	10	201	3.18	12.2
GY	569 817 659 **	57 927 439 **	63 930 014	1 476 090	31.5

\*, \*\*Significance of 0.05 and 0.01, respectively. FV: Sources of variation; Gen: genotype; Loc: location; CV: coefficient of variation; DF: degrees of freedom; DMF: days to male flowering; DFF: days to female flowering; PH: plant height; EH: ear height; EL: ear length; ED: ear diameter; RPE: rows per ear; GY: grain yield.

In a study conducted in the State of Mexico that evaluated 11 hybrids in five locations (Ixtlahuaca, Jilotepec, Temascalcingo, Jocotitlán, and Cuendó), contrasting responses were presented for the environmental effect (Martínez-Gutiérrez *et al.*, 2018). The performance of the germplasm evaluated was justified because the environments were contrasting, where the average temperature during the development of the cycle was the same, although rainfall displayed differences in both locations (Canales-Islas *et al.*, 2017).

Tadeo-Robledo *et al.* (2015) evaluated the productivity of two native maize varieties (Ixtlahuaca and Atlacomulco) and two hybrids (H-50 and H-52) at the Faculty of Higher Studies Cuautitlán of the National Autonomous University of Mexico in Cuautitlán Izcalli, State of Mexico, on two planting dates. They obtained yields of 7185 kg ha<sup>-1</sup> on the first planting date (May 17th) and 6082 kg ha<sup>-1</sup> on the second (June 1st), where the yield was lower because the best time for planting for these genotypes is in May, which coincides with the greatest number of days between planting and harvest to achieve the best expression of yield.

The Gen × Loc interaction showed no significance for 6 out of 8 variables (Table 1), indicating that the expression is not influenced by changes in genotype across environments. These results contrast with a study conducted in Molcaxac, Puebla (Ángeles-Gaspar *et al.*, 2010), where 52 native maize varieties from semi-warm and temperate environments and four hybrids recommended for the area under rainfed conditions were evaluated. In that study, a significant Gen × Loc interaction was found, indicating that the genotypes do not exhibit stable performance, and they respond differently in contrasting environments.

### Varieties

The comparison of means shows 11 varieties that presented the statistically greater grain yields from the average of both locations (Table 2). Ten of these were commercial hybrid maize varieties, and one was native to the municipal area of Texcoco, which borders the municipal area of Atenco. Finding one outstanding native variety represents an important discovery since it opens up the possibility of incorporating it into a recurring selection program. Improving it would provide benefits to farmers, such as lower seed costs and less dependence on multinational corporations, fewer chemical inputs, preservation of the culinary quality of dishes derived from this maize, favorable forage use, and potential tolerance to adverse environmental factors in the face of climate change.

**Table 2.** Maize (*Zea mays* L.) grain yield of the statistically superior group planted in San Salvador Atenco and Santa Lucía de Prías, State of Mexico, Mexico, during the spring-fall season of 2022.

Genotype	Origin	Yield (kg ha <sup>-1</sup> )
H-52	National Institute of Forestry, Agricultural, and Livestock Research (INIFAP)	7755
XV1613	ASPROS	7299
Cherokee F1	ASPROS	7282
Cenzontle	ASGROW	6824
Aníbal	ASPROS	6665
HS-2	Postgraduate College (COLPOS)	6013
Niebla	CERES	5985
Caribú	INIFAP	5862
SAR-1	Texcoco, State of Mexico	5488
Promesa	COLPOS	5207
Cherokee F2	ASPROS	5084
Maximum value		7755
Minimum value		1164
Average		3855
HSD ( $\alpha = 0.05$ )		2853

HSD: Honest significant difference.

The hybrid materials from commercial venues and institutions undergo a series of evaluations before being launched into the market, which provide information on the locations, potential yields, population density, and planting dates for the production of parents, lines, and simple crosses (Virgen-Vargas *et al.*, 2015). On the other hand, farmers select native materials after harvesting, observing the physical characteristics of the ear, considering grain size, thin cobs, ear health (Magdaleno-Hernández *et al.*, 2016), and ease of threshing. The performance shown by hybrids is due to

their selection for greater stability in grain yield and development under favorable environmental conditions (Echarte *et al.*, 2004); these characteristics are observed in the hybrids evaluated, which yielded over 5083 kg ha<sup>-1</sup>.

Ángeles-Gaspar *et al.* (2010), in a similar study, identified the genetic diversity among the local maize populations in the municipal area of Molcaxac, Puebla, and noticed that some local varieties surpassed or matched the grain yield of commercial hybrids (used as controls) recommended for the region. This performance can also be observed in the native maize varieties of the municipal area of Atenco.

The 15 genotypes that had the statistically lowest yield in the evaluation were native maize varieties (Table 3). Grain yield is the primary feature that farmers look for, but it is not the only one. Five low-yield varieties outperformed others in terms of ear morphology. These varieties were C-1, from the municipal area of Ixtapaluca, State of Mexico, with an average length of 15.45 cm; N-1 from Atenco and T-3 from Tepetlaoxtoc, State of Mexico, with an average of 16 and 17 rows, respectively; and variety TQ-1 from Texcoco, State of Mexico, with an average diameter of 4.58 cm. These particularities can be used to perform stratified visual mass selection as an alternative for producers to obtain plants and seeds with desirable and outstanding characteristics in each production cycle.

**Table 3.** Grain yield of the statistically inferior group of maize (*Zea mays* L.) planted in San Salvador Atenco and Santa Lucía de Prías, State of Mexico, Mexico, during the spring-fall season of 2022.

Genotype	Origin	Yield (kg ha <sup>-1</sup> )
N-8	Atenco, State of Mexico	2710
C-1	Ixtapaluca, State of Mexico	2706
A-1	Atenco, State of Mexico	2690
SD-1	Texcoco, State of Mexico	2632
N-1	Atenco, State of Mexico	2588
TQ-1	Texcoco, State of Mexico	2554
N-3	Atenco, State of Mexico	2546
F-1	Atenco, State of Mexico	2477
SJI-2	San Juan Ixtenco, Tlaxcala	2375
A-9	Atenco, State of Mexico	2305
A-3	Atenco, State of Mexico	2288
T-3	Tepetlaoxtoc, State of Mexico	1617
SJI-2	San Juan Ixtenco, Tlaxcala	1369
T-2	Tepetlaoxtoc, State of Mexico	1296
T-1	Tepetlaoxtoc, State of Mexico	1164
Maximum value		7755
Minimum value		1164
Average		3855
DSH $\alpha=_{0.05}$		2853

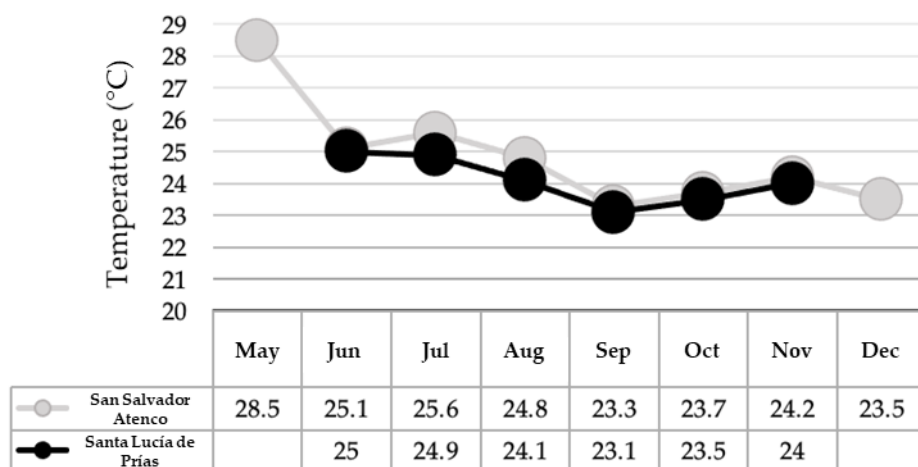
### Locations

In Santa Lucía, the time to male and female flowering observed was shorter than in San Salvador Atenco (Table 4). In both locations, the month of flowering was August (Figure 1). Planting dates are an important factor since the plant develops based on temperature; when it is hotter, the cycle shortens due to an acceleration in development. The cycle for Santa Lucía began in May and finished in November; therefore, the vegetative states were shorter, and germination and vegetative growth occurred in an average temperature of 25 °C. On the other hand, if it is cold during the reproductive

**Table 4.** Comparison of means of 49 varieties evaluated in two locations in the State of Mexico, Mexico, during the spring-fall season of 2022.

Locations	D (days)	DFE (days)	PH (cm)	EH (cm)	EL (cm)	ED (cm)	RPE	GY (kg ha <sup>-1</sup> )
San Salvador Atenco, Atenco	97 a	93 a	271 a	167 a	15 a	4 a	15 a	4297 a
Santa Lucía de Prías, Texcoco	80 b	76 b	243 b	154 b	14 b	4 a	14 a	3412 b

DMF: days to male flowering; DFE: days to female flowering; PH: plant height; EH: ear height; EL: ear length; ED: ear diameter; RPE: rows per ear; GY: grain yield. Different letters between columns indicate significant differences ( $p \leq 0.05$ ).



**Figure 1.** Average temperature during planting, germination, vegetative development, flowering, maturity, and harvest at the locations evaluated in the municipalities of Atenco and Texcoco, State of Mexico. Data were collected directly with maximum and minimum temperature thermometers in the center of the experiments, and the average was calculated as the median of the maximum and minimum temperatures.

stage, the crop cycle tends to elongate. In San Salvador Atenco, the temperature dropped during germination from 28.5 to 25.1 °C. During vegetative growth (June) and until flowering, the temperature dropped again (August) (Figure 1).

The ear morphology differed in both locations, with genotypes Niebla from CERES and Aníbal from ASPROS having the longest average of 16.6 and 16.2 cm, and yielding 6695.9 and 5984.5 kg ha<sup>-1</sup>, respectively (Table 4). This response can be due to the inherent characteristics of the Chalqueño, Cónico, and Elotes Cónicos races (Wellhausen *et al.*, 1951) as a result of the constant selection carried out by farmers who search for traits such as earliness, plant stature, and grain yield components (Muñoz-Orozco, 2003). Yields in both locations differed as genotypes responded to environmental variations in each location. This performance could be noticed in the evaluation of 29 hybrids in 15 environments of the tropical Americas carried out by Lozano-Ramírez *et al.* (2015), in which genotypes had to be obtained with greater yields and in stable environmental conditions.

#### Genotype × Location interaction

Both maize groups in both locations displayed similarities in DMF and DFF (Table 5). The earliest variety came from an unidentified farmer, with 80 DMF and 77 DFF, and the latest was also a native variety (from Cristian Zavala) with 96 DMF and 91 DFF, both from Tepetlaoxtoc. Quiroz-Mercado *et al.* (2017) mention that the average floral asynchrony interval for eight hybrid maize and two creole varieties of the region was four days. This evaluation was carried out in Cerrillo Piedras Blancas (Toluca), Mina México (Almoloya de Juárez), and Rancho Tiacaque (Jocotitlán), all of which are municipal areas in the State of Mexico.

Smith *et al.* (1969) mention that plant and ear height are characteristics that are affected to a certain degree by the environment. The Maximiliano Moran García variety from

**Table 5.** Comparison of means of the genotypes evaluated by group and by location in San Salvador Atenco and Santa Lucía de Prías, State of Mexico, Mexico, during the spring-fall season of 2022.

Varieties	DMF (days)	DFF (days)	PH (cm)	EH (cm)	EL (cm)	ED (cm)	RPE	GY (kg ha <sup>-1</sup> )
San Salvador Atenco								
Natives	98 a	94 a	278 a	176 a	15 a	4 a	14 b	3722 b
Hybrids	96 b	93 b	250 b	136 b	15 a	4 a	16 a	6284 a
Santa Lucía de Prías								
Natives	80 a	76 a	246 a	159 a	14 b	4 b	14 b	2636 b
Hybrids	78 b	75 b	233 b	135 b	16 a	5 a	16 a	6093 a

DMF: days to male flowering; DFF: days to female flowering; PH: plant height; EH: ear height; EL: ear length; ED: ear diameter; RPE: rows per ear; GY: grain yield. Different letters between columns indicate significant differences ( $p \leq 0.05$ ).

Acuexcomac presented a height of 284 cm, making it statistically the tallest, with an ear height of 189.9 cm, which can be used for forage. According to Franco-Martínez *et al.* (2015), they evaluated 29 outstanding forage cultivars for the Toluca-Atacomulco valley and identified landraces with contrasting plant heights in the range of 177 to 247 cm. Greater plant heights are considered a prerequisite to obtain a greater production of green and/or dry matter (Muñoz-Tlahuiz *et al.*, 2013).

Among the characteristics observed, the hybrid varieties presented lower plant height in comparison with the native varieties, an average ear length of 15.5 cm, 16 rows per ear, and a higher average yield in both locations (Table 5). This is attributable to the hybrids being the result of a genetic improvement process for the species, and they express their productive potential (heterosis), generally under optimal fertilization, moisture, agronomic management, and pest and disease control conditions, whereas native varieties have better traits for adaptation to the environment due to their broad genetic variation (Gil-Muñoz *et al.*, 2005).

## CONCLUSIONS

In the Atenco municipality, a native maize population was identified as having a yield equal to the group of superior hybrids, which, due to its long-term adaptation to the soil and environment of the research locations, competes successfully with modern hybrids. This is attributable to its good agronomic performance and grain yield, making it a candidate for inclusion in a genetic improvement program through recurrent selection to further increase its potential in the short and medium term.

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