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Article

Yield of varieties of pozolero corn of the 'elotes occidentales' race evaluated in High Valleys of Mexico

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Abstract

In the Valles Altos of Mexico, the use of corn (*Zea mays* L.) for pozole and the genetic improvement of pozolero corn have focused on using varieties of the races Ancho and Cacahuazintle, locally accepted and adapted to the region, and for this region, the productive response potential of other pozolero varieties originating from other regions of the country is unknown. The objective of this study was to evaluate grain yield and other agronomic variables of 12 varieties of pozolero corn of the Elotes Occidentales race, collected in Salvatierra, Guanajuato, Mexico, in 2018, along with a local variety of ancho corn and another of Cacahuazintle as controls, in order to identify the varieties with outstanding characteristics among the germplasms evaluated and with respect to the commercial controls. The 14 materials were evaluated in three sites of the municipality of Texcoco, State of México, under a randomized complete block design with three repetitions. Significant differences were found for yield between varieties and controls. The varieties yielded from 6.5 to 8.2 t ha^{-1} and the controls from 3.1 to 7.9 t ha^{-1}. The best varieties of 'Elotes Occidentales' exceeded the yield of the control Cacahuazintle by 4 t ha^{-1} and the control Ancho by 1.5 t ha^{-1} and the genotypes EOM-1 and EOM-6 were the ones that showed an average yield greater than 8 t ha^{-1}. It was also found that these varieties showed the best characteristics in terms of agronomic behavior and adaptation to the environment for yield (YIE), ear length (EL), number of grains per row (GR) and number of days to male (MF) and female flowering (FF) compared to the commercial pozolero controls Maíz Ancho and Cacahuazintle, with the EOM-1 population having the highest yield with 8.6 t ha^{-1}. The weight of 200 seeds (W200S), plant height (PH) and ear height (EH) were found in the ranges of commercial controls with averages of 2.5 m, 1.6 m and 130 g, respectively. Contrary to the number of rows, the evaluated populations presented a greater number compared to the controls, with the populations EOM-4, EOM-5 and EOM-8 being the most outstanding with 10 rows per ear.

Keywords:

Zea mays, elotes occidentales race, pozolero corn, varieties, yield.

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Introduction

Globally, corn (*Zea mays* L.) is the third most important agricultural product, as it contributes a third of global production (Oreamuno-Fonseca and Monge-Pérez, 2018). In Mexico, corn is the most important crop, and our country is considered the center of origin, domestication and diversification of corn, with extensive genetic, cultural and gastronomic diversity, product of millenary practices linked to the traditional knowledge of indigenous peoples (Turrent *et al*., 2010), who have cultivated it in ecological niches from sea level, in wet and dry areas, up to 3 400 m in High Valleys.

In 2020, the production of white corn in Mexico was 27 million tons, in an area of more than 7 million hectares (SIACON, 2023), which was insufficient to cover the demand of domestic consumption, and currently there is still dependence on voluminous imports to feed the population and meet the grain needs of industry and livestock farming. This is because in Mexico, corn of the different types is grown mainly in small areas with heterogeneous, marginal and transitional technological and economic characteristics (Polanco-Jaime and Flores-Méndez, 2008).

A special use of some types of corn is pozole, a typical dish of Mexican cuisine. Corn of the pozolero varieties Ancho and Cacahuazintle, an essential ingredient of pozole, is produced mainly in Mexico. In 2020, a pozolero corn production volume of 23 706 t was reached, presenting an increase of 11.4% compared to 2019 and with the state of Mexico being the largest producer of this grain with a production of 11 534 t, followed by Morelos with 11 088 and Puebla with 765 t (SIAP, 2022).

In rainfed farms, food self-sufficiency based on this grain is unfavorable, since the yield deficit is increasing every day among small and medium-sized producers of rainfed corn, who operate at 57% of their productive potential, and in some regions even less than 50% (Ramírez-Jaspeado *et al*., 2020). With respect to corns for special use, pozolero corn, Ancho and Cacahuazintle, in Mexico has been degenerating. This is due to genetic erosion it experiences and the fact that few or no agronomic and improvement studies focus on specific local germplasms, coupled with the lack of subsidies and incentives for farmers to continue growing these germplasms.

Due to this, pozolero corn has been partially displaced by other crops that are more consolidated in the market, such as sorghum, coupled with the multiple territorial phenomena attributable to both population growth and human settlements and latent socioeconomic changes (McLean-Rodríguez *et al*., 2019). The Elotes Occidentales race is native to the western region of Mexico in the states of Nayarit, Jalisco and Michoacán (CONABIO, 2011) and adapts to altitudes ranging from 100 to 1 500 m (Sánchez *et al*., 2000).

The size, color and texture of grain are the main attractive characteristics of this race, appreciated by farmers, producers and breeders, which lead to the conservation and improvement of this genetic resource (Gómez, 2006). In recent years, breeders face the challenge of climate change, which makes it necessary to generate new high-yielding germplasm and within the reach of producers (Jarvis *et al*., 2010). On the other hand, the revaluation in the forms of consumption and use of corn has increased, which makes it necessary to generate alternative genetic material that satisfies the needs of consumers.

Franco and Hidalgo (2003) mention that one way to exploit genetic diversity is the evaluation of germplasm of corn introduced to a particular environment. In this way, the genetic characteristics that are well preserved and expressed despite the change of environment and that allow determining the degree of genotypic and phenotypic similarity or difference between the introduced and local germplasms will be known and identified (Márquez-Sánchez, 2008).

Plants of native germplasm in their natural environment and those of introduced germplasm have an evolutionary dynamic that produces variability, which over time is used to identify, study and use the best populations. This is how phenotypic traits of anthropocentric interest, such as the

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grain for pozole, allow describing the plant in its morphology and architecture and its degree of interaction with the environment (Enríquez *et al*., 1991; Franco and Hidalgo, 2003).

Based on the above, the evaluation, characterization and classification of new germplasm in diverse environments is an important goal for corn improvement programs. This in order to conserve, improve, increase and exploit the genetic diversity of native corn species, as a survival strategy for families in rural communities, which, together with other products associated with the crop and alternative activities, contribute to food security (Damián *et al*., 2013).

The objective was to evaluate the yield and agronomic behavior of twelve populations of pozolero corn of the Elotes Occidentales race, in three environments of the Valles Altos of Mexico. The proposed hypothesis is that, of the populations evaluated, at least one will exceed in grain yield and of better or similar agronomic distinction with respect to control local materials.

Materials and methods

The genetic materials of this work consisted of 12 populations (EOM-1, EOM-2, EOM-3, EOM-4, EOM-5, EOM-6, EOM-7, EOM-8, EOM-9, EOM-10, EOM-11, EOM-12) of pozolero corn of the Elotes Occidentals race, which were collected in Salvatierra, Guanajuato and two commercial pozolero controls of the races Maíz Ancho and Cacahuazintle, adapted to High Valleys.

Evaluation sites and experiment design

The evaluations were established in three environments: two in the experimental field of the College of Postgraduates, Montecillo Campus and one more in the lands of the Campo Experimental Valle de Mexico (CEVAMEX) of the Instituto Nacional de Investigaciones Forestales Agricolas y Pecuarias (INIFAP), located in Santa Lucía de Prías, Coatlinchán, Texcoco, State of Mexico.

The materials were sown in March 2018 in the three environments under a randomized complete block experimental design with three repetitions. Sowing was manual, depositing two seeds per bush every 0.5 m in plots of two furrows with separations of 0.8 m wide and 6 m long. Each plot consisted of 52 plants, equivalent to a density of 60 000 plants ha^{-1}. In the two environments of the Montecillo *Campus*, it was fertilized with the dose 140-60-00 and in the environment of CEVAMEX with the dose 140-40-00.

In the three cases, half of the N and all of the P were applied at the time of sowing and the rest of the N was applied in the second weeding. In all cases, a germination irrigation and an emergence irrigation were applied. Subsequently, supplemental irrigations were applied when necessary, since the crop developed mainly with the moisture of summer rain.

In each plot, the days to male (MF) and female flowering (FF) were measured, the first when 50% of the tassels released pollen and the second when 50% of the baby ears exposed stigmas of at least 3 cm in length. Plant height (PH) and ear height (EH), two weeks before harvest, were recorded, measuring all the plants of each plot, from the base of the stem to the insertion node of the tassel and from the base of the stem to the insertion node of the upper ear, respectively.

Variables evaluated

In five randomly selected ears of each material, the length (LEN) and ear diameter (ED), number of rows (NR), and number of grains per row (GR) were recorded. The weight of 200 grains of each material was also determined. To calculate the yield of each plot (kg $plot^{-1}$), the harvested ears were weighed, and this weight was adjusted to 12% moisture.

The grain yield per hectare (YIE) was calculated based on the yield per plot, by multiplying the grain weight of the ears harvested in the useful plot by their respective factor of area and adjusting to 15% moisture (Mejía and Molina 1999). The variables were measured in triplicate in each genotype. All variables were subjected to a combined analysis of variance and the means

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were compared with the F test and a Tukey mean test ($p \leq 0.05$). The analyses were performed using the GLM procedure of the SAS® program (SAS Institute, 2019).

Results and discussion

The combined analysis of variance detected significant differences (p# 0.05) between genotypes (GEN), for all study variables (Table 1). Between environments (ENV), significant differences ($p \leq 0.01$) were detected in seven of the 10 variables evaluated. While for the interaction genotype × environment (GEN × ENV), there were significant differences ($p \leq 0.05$) only in two variables, which were male flowering (MF) and female flowering (FF). The analysis with Anova and the F test are global analyses, this is only an indicator of the effect between environments and genotypes.

Table 1. Mean squares of the combined analysis of variance of 14 genotypes of pozolero corn of the 'Elotes Occidentales' race evaluated in three environments of Valles Altos of Mexico.

SV	DF	MF	FF	PH	EH	NR	GR	LEN	ED	YIE	W200S
ENV	2	2253**	1201**	1.5**	0.6**	2	13*	5.83**	0.1	106.3**	29.6
REP(ENV)	6	25	64*	0.1**	0.01	1	7	2.56*	0.2	7**	198.2*
GEN	13	128**	185**	0.1**	0.1**	5**	61**	18.63**	0.2*	16.7**	1656.1**
GENxENV	26	37*	35*	0.02	0.02	0	6	1.48	0.1	1.3	89.6
Error	78	23	21	0.02	0.01	1	4	1.07	0.1	1.1	87.1
CV (%)		6	5	6	8	8	7	6	6	14	7.4

SV= sources of variation; DF= degrees of freedom; ENV= environments; REP(ENV)= repetition within environments; GEN= genotypes; GEN x ENV= interaction of genotype by environment; CV= coefficient of variation; *, **= significant at 0.05 and 0.01 probability; MF= male flowering; FF= female flowering; PH= plant height; EH= ear height; NR= number of ear rows; GR= grains per ear row; LEN= ear length; ED= ear diameter; YIE= yield; W200S = weight of 200 seeds.

The fact that statistical differences were observed between genotypes and between environments indicates, on the one hand, the existence of genetic diversity between the varieties evaluated and, on the other, that the environmental effects, measured by the behavior of the genotypes, were different between environments. On the other hand, the interaction between GEN × ENV indicates that the genotypic and phenotypic expression of the varieties for most agronomic characteristics was consistent across the environments, so that the yield and its components were stable despite the fact that the environments were contrasting (Becker and León, 1988). Likewise, the effect of a genotype not significant by the F test in environments can be significant in an average or contrast test. So, it is important to check for minimal and non-global specific differences between genotypes.

Behavior of varieties in environments

The mean test for environments of the combined analysis shows that the environment of the Montecillo Campus CP-C8 was the most favorable in terms of grain yield with 9.2 t ha^{-1} (Table 2). Likewise, in this environment it is observed that the populations had the highest values for plant height (PH) and ear height (EH), and on average they were later. On the contrary, the environments of CEVAMEX and the Montecillo Campus CP-C13 had the lowest yield (6 and 7.3 t ha^{-1}, respectively), lower values for PH and EH, and in flowering, they were earlier.

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Table 2. Means of three environments of evaluation of 12 genotypes of pozolero corn of the 'Elotes Occidentales' race and two corn controls, Ancho and Cacahuazintle, in Valles Altos of Mexico.

ENV	MF (days)	FF (days)	PH (m)	EH (m)	NR	GR	LEN (cm)	ED (cm)	YIE ($t\ ha^{-1}$)	W200S (g)
CP-C13	83 b	87 b	2.6 b	1.4 b	9 a	32 a	18.3 a	4.8 a	7.3 b	126.5 a
CP-C8	92 a	93 a	2.9 a	1.7 a	9 a	31 b	17.7 b	4.8 a	9.2 a	126 a
INIFAP	77 c	82 c	2.6 b	1.5 b	9 a	32 a	18.3 a	4.9 a	6 c	127.6 a
HSD	13.6	4.7	0.3	0.3	0	0.6	0.4	0	4.9	0

Means with equal letters within columns are statistically equal (Tukey, 0.05). MF= male flowering; FF= female flowering; PH= plant height; EH= ear height; NR= number of rows; GR= grains per row; LEN= ear length; ED= ear diameter; YIE= yield; W200S= weight of 200 seeds.

These results coincided with that reported by Pérez-de la Luz *et al*. (2011), who point out that native populations evaluated in different environments present different yields, mainly due to the effect of environmental factors on genotype expression. On the other hand, based on the yield, it was observed that the germplasms of Elotes Occidentales evaluated in the Valles Altos of Mexico adapt well to this region, since their average yield, for the three environments, was three times higher than the regional average yield, which is 2.8 $t\ ha^{-1}$ in Valles Altos (SIAP, 2018).

Behavior of genotypes

The genotypes evaluated equaled and, in some cases, exceeded the grain yield of the control varieties (Table 3), but the genotypes EOM-1 and EOM-6 presented average yields of 8.4 and 8.6 $t\ ha^{-1}$, respectively, significantly higher than that of the controls. The ancho control (TMA) had a yield of 7.9 $t\ ha^{-1}$ and the Cacahuazintle corn (TMC) yielded 3.1 $t\ ha^{-1}$. The rest of the genotypes yielded between 6.5 to 8.2 $t\ ha^{-1}$.

Table 3.Means of 14 populations of pozolero corn Elotes Occidentales evaluated in the Valles Altos of Mexico.

GEN	MF (days)	FF (days)	PH (m)	EH (m)	NR	GR	LEN (cm)	ED (cm)	YIE ($t\ ha^{-1}$)	W200S (g)
EOM-1	83 bc	83 bc	2.7 abc	1.5 abc	9 cd	33 a	18.4 abc	4.7 b	8.6 a	125.3 b
EOM-2	93 a	92 a	2.8 a	1.6 a	8 d	33 a	20 a	4.7 b	6.5 b	133.9 b
EOM-3	83 bc	88 ab	2.6 bc	1.4 abc	9 cd	32 ab	18.4 abc	4.9 ab	7.7 ab	125.3 b
EOM-4	81 c	80 c	2.6 abc	1. 4bc	10 abc	31 ab	16.3 de	4.7 b	8.2 ab	106.8 d
EOM-5	81 c	84 bc	2.5 c	1.3 c	10 ab	30 ab	17 de	4.8 ab	7.6 ab	108.3 cd
EOM-6	83 bc	86 abc	2.7 abc	1.5 abc	9 b	33 a	19.2 abc	4.9 ab	8.4 a	126.4 b
EOM-7	85 bc	92 a	2.6 abc	1.4 bc	9 bcd	33 a	18.5 abc	4.7 b	8.1 ab	122.6 bc
EOM-8	82 c	85 bc	2.5 c	1.4 c	10 a	32 ab	17.5 cd	4.8 ab	8.2 ab	108.9 cd
EOM-9	87 abc	93 a	2.8 ab	1.6 ab	8 d	32 ab	19.1 abc	4.8 b	7.6 ab	129.9 b
EOM-10	83 bc	87 ab	2.6 abc	1.5 abc	9 d	32 ab	19.3 ab	4.6 b	7.5 ab	136.4 b
EOM-11	80 c	88 ab	2.6 abc	1.5 abc	9 bcd	31 ab	18 bcd	4.7 b	8.2 ab	126.2 b
EOM-12	90 ab	93 a	2.8 ab	1.6 a	8 d	34 a	20 a	4.7 b	7.1 ab	132.3 b
TMA	83 bc	87 abc	2.7 abc	1.5 abc	9 d	30 b	16.6 de	5.2 a	7.9 ab	160 a
TMC	79 c	81 bc	2.6 bc	1.5 abc	9 bcd	24 c	15.4 e	5 ab	3.1 c	131.6 b
HSD	12.3	11.7	0.2	0.1	2	7.6	3.3	0.5	3.4	30.1

Means with equal letters within columns are statistically equal (Tukey, 0.05). MF= male flowering; FF= female flowering; PH= plant height; EH= ear height; NR= number of rows; GR= grains per row; LEN= ear length; ED= ear diameter; YIE= yield; W200S= weight of 200 seeds.

The competitive yields obtained by the Elotes Occidentales genotypes in Valles Altos are attributed to the good characteristics in terms of agronomic behavior and adaptation that the native genotypes have for diverse environments. These results show that the initial sowings of exotic corn in a new region where it generally presents maladaptation, susceptibility to diseases,

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modification of the vegetative cycle and low yield (Gordon-Navas and Cervantes, 1991; Mendoza *et al*., 2006) is not strictly acceptable for evaluations of agronomic behavior of exotic material in a new study region.

This is a product of its wide intrapopulation genetic variation and good yield, aspects achieved over many years of cultivation, as pointed out by Muñoz (2005); Pérez-de la Luz *et al*. (2011). These advantages of Elotes Occidentales corns can be used for genetic improvement purposes for rainfed or irrigation tip areas in Valles Altos.

In Table 3, morphological and physiological variables of the genotypes were analyzed, because it was considered that they have a direct or indirect contribution in the expression of yield, it is observed that the diameter of ear and number of rows of all genotypes were equal to the controls. Only in grains per row and ear length, the values of the genotypes EOM-1, EOM-2, EOM-6, EOM-7 and EOM-12 were higher. On the other hand, the average values of the days to female flowering (FF) showed that the populations were of early cycle for the three environments of evaluation, except for the populations EOM-2 and EOM-12 which presented 92 and 93 days to flowering on average, according to the classification of Ángeles-Gaspar (2010).

These results indicate that the genetic materials of Elotes Occidentales in the Valles Altos of Mexico present physiological characteristics of short cycle since they showed potential for development in cold environments, coupled with the presence of high grain yields (Table 2), which gives an advantage over the germplasms of the region since there are few materials with these characteristics in the market and less in the process of improvement programs.

The materials of pozolero corn Elotes Occidentales, according to the results obtained, had grain yields of up to 8.6 t ha^{-1}, presenting competitiveness compared to the two commercial local controls and in some cases higher than the local average yield of the commercial corns ancho and Cacahuacintle of Valles Altos, which presented average yields of 2.8 t ha^{-1}.

Likewise, it was identified that two of the germplasms, EOM-1 and EOM-6, of Elotes Occidentales presented the best characteristics in terms of agronomic behavior and adaptation to the environment (YIE, LEN, GR, FF and MF) compared to the commercial pozolero controls Maíz Ancho and Cacahuazintle.

Regarding plant height (PH) and ear height (EH), the genotypes evaluated showed homogeneous heights and lower than those of the commercial control, mainly for the populations EOM-5 and EOM-8 H-48 with 2.3 m in plant height and 1.4 m for ear height, which is desirable for corn improvement germplasms for the Valles Altos, which prefer low size materials since they are more tolerant to lodging, in addition to being able to be harvested mechanically.

The above is due to the fact that, because they are native populations, Elotes Occidentales corns can have wide intrapopulation genetic variation and good behavior *per se* (López *et al*., 2008), advantages that can be exploited for genetic improvement purposes for poor rainfed or irrigation areas in High Valleys (Gil *et al*., 2004).

With the results obtained, it can be established that the proposed hypothesis that, of the populations evaluated, at least one will exceed control local materials in grain yield is verified. This shows the importance of introducing and taking advantage of native germplasms from other regions in High Valleys and also indicates the importance of evaluating these materials under different environments, to generate strategies to improve the germplasm of pozolero corn in Valles Altos de México.

Conclusions

The corns of the Elotes Occidentales race, from Guanajuato, adapted well to the Valles Altos of Mexico, presented on average similar and superior yields with ranges of 6.5 to 8.5 t ha^{-1} with respect to local controls. With these results, it is established that all genotypes responded favorably to the edaphic and climatic conditions of the area of Valles Altos of Mexico since grain yields were not affected with significant differences.

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In this regard, the genotypes EOM-1 and EOM-6 were the most outstanding populations since they presented average yields of 8.4 and 8.6 t ha^{-1}, respectively, being significantly higher than the local commercial controls, achieving an average grain yield higher than 8 t ha^{-1}. This turns the evaluated collections into promising germplasm to begin a genetic improvement program for high yield pozolero corn in Valles Altos of México.

With the incorporation of different germplasm to the Valles Altos region, new heterotic patterns are being exploited and increased that help to exceed to the maximum the ceilings in yield and in phenological, morphological and physiological characteristics of the existing genotypes.

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