Colegio de Postgraduados

Yield of Popcorn varieties in different population densities in the Valles Altos region of Mexico

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ABSTRACT
Objective: the objective of this study was to determine the grain productivity of four Mexican varieties of popcorn maize (Palomero UNAM, Puma Palomero, Palomero Oro and Palomero Unamita) under three population densities.
Design/Methodology/Approach: during the Spring-Summer 2020 agricultural cycle, these four varieties were evaluated in two different environments and three population densities were used: 50, 65 and 80 thousand plants per hectare. The experimental design used was completely randomized blocks, with a factorial arrangement of treatments and four replications.
Results: the results showed that the population densities of 65 and 80 plants ha^{-1} were statistically equal with yields of 6340 and 6357 kg ha^{-1}, but significantly different to the density of 50 thousand plants per hectare. As for the varieties, Palomero Unamita and Palomero Oro showed yields of 6809 and 6625 kg ha^{-1}.
Study limitations/Implications: it is important to note that is necessary to continue the evaluation of these varieties in different years and environments to obtain more solid and generalizable results.
Findings/Conclusions: based on the results obtained in terms of yield, yield components and outstanding vegetative traits, it can be concluded that there are favorable perspectives for the commercial use of the popcorn varieties evaluated in this study.

Keywords: *Zea mays* L., productivity, improved varieties of popcorn, seeds, Valles Altos.

INTRODUCTION

The popping seed varieties of maize (*Zea mays* L.), or popcorn is one of the many types of corn grown in Mexico, under the management of native people. This maize has cultural, socioeconomic and gastronomic relevance, especially in gastronomy, due to multiple

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nutritional properties of popcorn which then has a high nutritional value. Popcorn contains high amounts of fiber, vitamins, minerals, proteins, and antioxidants. This type of corn in Mexico is in risk of extinction nowadays (De la O-Olán *et al.*, 2018).

Popcorn is one of the most appreciated snacks, mainly in the United States, where more than 60 000 hectares (ha) of improved varieties are planted annually. These varieties have exceptional burst quality in one of the largest areas planted with popcorn in the world, which provides an average yield of 7 Mg ha^{-1}. In Mexico, the consumption of popcorn is almost totally dependent on imports. About 400 tons (Mg) are produced in the country, but 80 000 Mg of popcorn kernels are imported.

Those improved varieties had their origin in Mexican germplasm of some of the seven breeds whose kernels can burst and form the popcorn, which are Palomero Toluqueño, Chapalote, Nal-Tel, Arrocillo Amarillo (Bautista *et al.*, 2020), Palomero de Jalisco, Palomero de Chihuahua and Reventador (Bautista *et al.*, 2018; Bautista *et al.*, 2020).

It is considered necessary to implement an ethnobotanical exploration of Palomero Toluqueño in the areas estimated as potential (Romero *et al.*, 2005). In order to generate conservation schemes and favor genetic improvement and use, within their distribution areas (CONABIO, 2012; Bautista *et al.*, 2018; Granados, 2019; Bautista *et al.*, 2020; CONABIO, 2020).

A relevant contribution in the country was the popcorn variety V 460 P, registered in the Mexico's National Catalog of Plant Varieties (CNVV) in 2012, with adaptation to southern Tamaulipas by Dr. Juan Valadez Gutiérrez of INIFAP (Valadez *et al.*, 2012). On the other hand, the Faculty of Higher Studies Cuautitlan under the National Autonomous University of Mexico (FESC UNAM), and Campo Experimental Valle de México (CEVAMEX INIFAP) have worked on genetic improvement to develop varieties of popcorn since 27 years ago. In 1986, the first evaluation of a group of popcorn maize varieties was done, as a product of the studies developed there in collaboration with INIFAP. Improved and native materials were evaluated, protein quality sources (QPM) were combined with native popcorn varieties and inbred lines to offer popcorn with higher amounts of lysine and tryptophan. Then varieties were selected, lines were derived, compounds were integrated in a broad genetic base, crosses were made among better lines, recombination cycles, backcrosses, new self-fertilizations, fraternal, and dialelic lines were integrated, until obtaining quality populations and varieties of popcorn.

As a result of those investigations, there are elite varieties in their last stage of evaluation, seed production, varietal characterization, prior to their registration in the National Catalog of Plant Varieties (CNVV) and their commercial release. The varieties Palomero Oro, Palomero Unamita, Palomero UNAM, Puma Palomero have been defined as outstanding. This study was established based on these varieties, with the aim of determining productivity under three population densities.

MATERIALS AND METHODS

Geographic location of study sites

During the Spring-Summer 2020 cycle, two uniform trials were established. The first locality at A) Huexotla, Texcoco, State of Mexico (19° 28' 54.5" N, 98° 52' 34.4" W) at

2240 m altitude. The area has a climate C(Wo)(w)b(i')g that corresponds to temperate climate with rains in summer, the driest of the subhumid climates, with cool and prolonged summers, with temperature annual averages between 12 and 18 °C; the annual oscillation of average monthly temperatures is 5 to 7 °C (García, 2004).

The second locality is B) the Rancho Almaraz of the Facultad de Estudios Superiores Cuautitlán (FESC UNAM), Campo 4 of the National Autonomous University of Mexico (UNAM), located at 19° 41' 35" N, 99° 11' 42" W at an altitude of 2274 m; the climate at Cuautitlan is classified as C $(_{W0})$ $(_{W})$ b (i"). The historical average of annual rainfall is 609.2 mm (García, 2004).

Genetic material

Four improved varieties of maize from FESC UNAM, Palomero UNAM, Puma Palomero, Palomero Oro, and Palomero Unamita were evaluated. These varieties were planted in 50, 65 and 80 plants ha^{-1}; an experimental design of complete randomized blocks was used under a factorial arrangement with four repetitions (Espinosa-Calderón *et al.*, 2018).

Statistical design and experimental units

The experimental plot consisted of a row 5 m long by 0.80 m wide. The experiments were established following the complete randomized blocks design, with four repetitions and under rainfed conditions. The plantings were made on foot in the month of June with three seeds deposited in each hole every 0.50 m. Then thinning was done to obtain the population densities of 50, 65 and 80 thousand plants ha^{-1}.

In the field, variables evaluated were days to male flowering, days to female flowering, plant height, and plant height to the ear expressed in cm. The harvest was carried out manually in December 2020. In each plot, all the ears were pinched and in a representative sample of five ears the percentage of moisture of the grain was determined, with a Dickey-John Gac 2100® moisture determiner, to obtain the percentage of dry matter (% DM); the percentage of grain/cob by means of ratio between the grain weight and the grain weight plus cob weight (Mexican name, olotes) (% G), volumetric weight, weight of 200 grains, ear length, number of rows in the ear, and grains per row. To obtain the grain yield this formula was applied:

$$Yield = (PC \times \%\ MS \times \%\ G \times FC) / 8600.$$

Statistical analyses

SAS/STAT® 9.4 was used for all statistical analyses of the data (SAS Institute Inc., 2018). Likewise, a comparison of means was performed (Tukey, $p \leq 0.05$).

RESULTS AND DISCUSSION

The combined analysis of variance showed significant differences ($p<0.05$) among genotypes for all variables except FF and LM. Significant differences ($p<0.05$) were also detected between environments in all variables except GH; whereas, for plant density as the source of variation, there were significant differences ($p<0.05$) only in the variables RG, PV and LM. In the interaction environments×genotypes, there were significant differences ($p<0.05$) in the variables RG, FM, PV, P200G and LM.

In contrast, in the interaction environment×plant density, significant differences ($p<0.05$) were detected in the variables grain yield, FM, P200G, LM and %GRAIN (Table 1). The coefficients of variation ranged from 0.5 to 13% considered as low, suggesting reliability in the results (Castillo, 2007). Finding statistical differences among genotypes and between localities, as well as high levels of variation in traits, indicates the existence of genetic diversity in the varieties evaluated, which respond differently across environments.

Regarding the productive and agronomic characteristics of the varieties evaluated, the overall average grain yield was 6017 kg ha^{-1}. The Palomero Unamita and Palomero Oro varieties yielded 6809 kg ha^{-1} and 6625 kg ha^{-1}, statistically different from the other two varieties (Table 2). When comparing these results with a recent study in native popcorn populations in southern Brazil, yields are considered appropriate (Zulkadir and Idikut, 2021).

When comparing the days to flowering among varieties, it was observed that the Palomero Oro variety was of late cycle with 78 and 80 days to male and female flowering. Whereas the Palomero Unamita variety presented an early cycle with 73 and 69 days to male and female flowering (Table 2, Figure 1). According to Gil *et al.* (2004) early varieties generally manage to evade the periods of water deficiencies that manifest when there is low rainfall.

Table 1. Mean squares and statistical significance in the combined analysis of four free-pollinated varieties of popcorn; under three population densities in Valles Altos (Mexico), Spring-Summer 2020 cycle.

Source of variation	Environment	Block	Population density	Varieties	Environment × varieties	Environment × population density	Coefficient of variation (%)
GY (kg ha^{-1})	79305462**	480871*	5265535**	10715819**	1515295**	316035**	4.9
MF (días)	204.2**	5.5	0.64	49.3**	9.6**	5.9**	1.8
FF (días)	617*	113.8	95	263.4	54.7	99.9	13.0
PH (m)	0.068*	0.108*	0.011	0.048**	0.01	0.014	4.4
PHE (m)	1.08**	0.048**	0.013	0.054**	0.01	0.013	7.6
VW (kg hL^{-1})	33.2**	0.43	6.13**	14**	4.2*	1.75	1.3
W200G (g)	335**	5.0	4.1	138.9**	12.9**	7.5*	4.2
EL (cm)	21.3**	1.33	2.02*	1.05	1.38*	1.56**	4.1
NRE	14**	0.08	0.58	6.14**	0.027	0.87	5.9
GPE	420	324	1748	5915**	248	1334	7.0
DM (%)	68.6**	0.08	0.09	0.77*	0.2	0.17	0.5
Grain (%)	31**	2.57	6.15	10.11**	3.4	5.6**	1.6

*: $p<0.05$, **: $p<0.01$; GY: grain yield, MF: male flowering, FF: female flowering, PH: plant height, PHE: plant height to the ear, VW: volumetric weight, W200G: weight 200 grains, EL: ear length, NRE: number of rows in the ear, GPE: grains per ear, %DM: percentage of dry matter.

Table 2. Comparison of means among varieties of popcorn maize, considering the mean of the evaluation environments.

Varieties	Palomero Unamita	Palomero Oro	Palomero UNAM	Puma Palomero	DHS
GY (kg ha^{-1})	6809 a	6625 a	5910 b	4728 c	334
MF (días)	73 c	78 a	76 b	76 b	1.6
FF (días)	69 a	80 a	78 a	78 a	11.3
PH (m)	2.2 ab	2.3 a	2.2 ab	2.1 b	0.11
PHE (m)	1.0 bc	1.1 a	1.07 ab	0.96 c	0.09
VW (kg hL^{-1})	78.4 b	79.1 b	80.5 a	78.1 b	1.13
W200G (g)	40.6 a	36.1 b	34.4 c	32.7 d	1.7
EL (cm)	16 a	16 a	15 b	16 a	0.74
NRE	16 b	17 a	16 b	17 a	1
GPE	460 b	480 ab	467 b	510 a	37.9
DM (%)	87 b	88 a	87 b	88 a	0.52
Grain (%)	83.2 a	81.9 ab	81.2 b	81.5 b	1.52

GY: grain yield, MF: male flowering, FF: female flowering, PH: plant height, PHE: plant height to the ear, VW: volumetric weight, W200G: weight 200 grains, EL: ear length, NRE: number of rows in the ear, GPE: grains per ear, %DM: dry matter.

Figure 1. Varieties of popcorn maize. A: palomero Puma; B: palomero oro; C: Palomero UNAM; D: palomero Unamita.

As for the variables AP and AM, the Palomero Oro variety presents high values with 2.3 and 1.1 m; on the contrary, Puma Palomero presented a low size with 2.1 and 0.96 m (Table 2). According to Bernal *et al.* (2021) they are related to the architecture of the plant and, mainly, to the stalk lodging. For the PV variable, the Palomero UNAM variety showed the highest mean (80.5 kg hL^{-1}). This indicates that it has a higher specific weight compared to the other varieties (Table 2). This result coincides with previous research conducted by Martínez (2022), who found that the PB6×PB1 crosses turned out to have higher PV than other crossed evaluated.

As for the P200g variable, the variety Palomero Unamita showed the highest mean (40.6 g), followed by the other varieties in descending order. This could indicate that the variety Palomero Unamita has heavier grains compared to the others. Likewise, it was observed that there was a relationship for the variable %GRAIN of 83.2%; on the contrary, Puma Palomero presented the best values for the variable GM. These findings are supported by similar and current research that has found differences in grain yield, volumetric weight, and other characteristics among popcorn varieties.

On the other hand, the best environment was CEVAMEX with 7303 kg ha^{-1}, slightly higher than the overall average (Table 3). The yields indicated are competitive with those reported by Miranda (1977) and Valadez *et al.* (2012), although studies were done in different regions, they could be used as references. These results are consistent with previous studies that have shown that popcorn productivity can vary according to differences in nutrient availability, soil management, and climatic conditions.

In regard to the yield components PV, P200G, LM, HM, GH, GM and %GRAIN in this same environment the best values for these variables were recorded (Table 3). According to Valadez *et al.* (2012) these differences may be related to genetic traits in grain size and grain development. Similarly, Reyes *et al.* (2009) have reported variations in the number of grains per ear in popcorn related to grain composition and its endosperm and pericarp ratio. In addition, this type of study requires defining the quality and volume of expansion of the popcorn produced with the varieties, in a given planting density and evaluation

Table 3. Comparison of means between evaluation environments, considering the mean of four varieties of popcorn and three population densities.

Main factor	GY	VW	W200G	EL	NRE	GPR	GPE	Grain
Environment	(kg ha^{-1})	(kg hL^{-1})	(g)	(cm)				(%)
FESC 2020	4732 b	78.2 b	33.3 b	15 b	17 a	30 a	482 a	82.8 a
CEVAMEX 2020	7303 a	79.9 a	38.6 a	16.3 a	16 b	28 b	476 a	81.1 b
average	6017.5	79.05	35.95	15.65	16.5	29	479	81.95
Density								
50 000	5355 b	78.5 b	35.5 a	16 a	16 a	29 a	469 a	81 a
65 000	6340 a	78.9 a	35.9 a	15 b	16 a	30 a	490 a	82 a
80 000	6357 a	79.7 a	36.5 a	16 a	16 a	29 a	479	82 a
average	6017.3	79.0	36.0	15.7	16.0	29.3	479.3	81.7

GY: grain yield, VW: volumetric weight, W200G: weight 200 grains, EL: ear length, NRE: number of rows in the ear, GPR: grains per row, GPE: grains per ear environment, which is part of other studies within the research group (Soylu and Tekkanat, 2007; Sweley *et al.*, 2012).

Similarly, planting density influenced yield and other characteristics evaluated between planting densities of 50 000, 65 000 and 80 000 ha^{-1} plants. Overall, it was found that the planting density of 65 000 and 80 000 ha^{-1} plants tended to outperform 6340 kg ha^{-1} and 6357 kg ha^{-1}, different from 50 thousand plants ha^{-1}. These results are consistent with previous studies that have shown that planting density can influence the yield and quality of popcorn (Canales *et al.*, 2017). These results support the importance of considering the growing environment when selecting popcorn varieties, and highlight the need for additional research to better understand the factors influencing the production and quality of popcorn in different environments.

Following the same premise, the yields of the Palomero Unamita and Palomero Oro varieties expressed to some extent the product of the studies in genetic improvement for popcorn varieties (Figure 1), implemented by FESC UNAM and CEVAMEX INIFAP since 1996 (Espinosa-Calderón *et al.*, 2018). These varieties have in their germplasm, source for varieties of popcorn; which is a good argument in favor of the preservation of this type of maize to maintain its permanence in the region where the Palomero Toluqueño breed thrives (Gámez *et al.*, 2014).

CONCLUSIONS

The Palomero Unamita and Palomero Oro varieties presented high grain yield and outstanding vegetative characteristics through the two evaluation environments. The yields in population densities of 65 and 80 thousand plants per ha-1 were good and indicate the convenience of continuing with this type of studies to confirm the commercial prospects to the use of popcorn maize varieties. Nonetheless, the four evaluated varieties could be options to support the production of popcorn in Mexico; thus, it is advisable to continue in parallel with the development of promotional schemes.

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