Article

Yield and expansion capacity of the corn grain in the Palomero Toluqueño race

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Abstract

It has been suggested that the Palomero Toluqueño corn race contributed to the origin of other races and despite having the capacity to burst, this quality has not been enhanced. The objective of the present study was to evaluate the yield and expansion capacity of accessions of this race kept in germplasm banks. 47 accessions of Palomero Toluqueño were evaluated, three materials in the process of genetic improvement for trapping and a commercial material as a reference. The experiments were established in a randomized complete block design with two repetitions in the spring-summer 2014 agricultural cycle in Montecillo, State of Mexico and Santa Maria Zacatepec, Puebla. The variables evaluated were grain yield, expansion volume, percentage of grains without popping, rosette shape, pericarp spray and volume of popcorn per hectare. The general average yield was 3.38 t ha^{-1} and the volume of popcorn per hectare was 8.86 m3 ha^{-1}, while the volume of expansion per sample, percentage of unpopped grains and the pulverized pericarp had averages of 2.73 cm^3 g^{-1}, 67.59% and 3.2 (visual scale 1-5), respectively; in contrast, the commercial control, for the same variables, showed values of 19.33 cm^3 g^{-1}, 27.49% and 1.6. Only the butterfly rosette shape was featured. The results indicate that the Palomero Toluqueño race has a low expansion capacity in relation to the commercial material; however, its grain yield exceeded the national average. The variables evaluated demonstrate the diversity that exists within the race.

Keyword: native corn, pericarp, popcorn, pop corn, rosette.

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Introduction

Mexico is considered a center of origin and one of the main centers of diversity for corn (Matsuoka *et al*., 2002; Kato *et al*., 2009). It has been suggested that the ancient indigenous races of Mexico are at the base of the evolutionary scale of cultivated maize; these races are Palomero Toluqueño, Chapalote, Nal-Tel and Arrocillo Amarillo, all of them with trapping capacity (Wellhausen *et al*., 1951).

With respect to popcorn maize, in addition to the ancient indigenous races, Mexico has other races such as Palomero de Jalisco, Palomero de Chihuahua and Reventador, with wide diversity within them (Ortega *et al*., 1991).

Palomero Toluqueño is considered a direct ancestor of other races such as Conico and Pepitilla, it is cultivated at altitudes above 2 000 m its biological cycle is short (Wellhausen *et al*., 1951), this being an escape mechanism from frost, its grains they burst when exposed to high temperatures (Mauricio *et al*., 2004).

However, currently its main consumption is in tortillas, so several producers sow it together with floury materials to improve the quality of the dough (Gámez *et al*., 2014), while the trapping character has been ignored and its capacity expansion is low compared to commercial materials from the United States. Santacruz-Varela (2001) recorded volumes of 1.62 cm^3 g^{-1} in samples of 30 g of grain, in native popcorn materials of Mexico against 38.86 cm^3 g^{-1} in the improved materials of the United States of America.

The main variables to evaluate the expansion capacity in popcorn are: volume of product obtained per unit of grain weight, rosette shape, persistence of the pericarp after explosion (Ziegler, 2001), as well as the proportion of grains without bursting (Soylu and Tekkanat, 2007), all of them influenced by physical factors of the seed, such as thickness and hardness of the pericarp (Hoseney *et al*., 1983) and grain moisture (Gökmen, 2004) and by chemical factors such as amylose content and amylopectin (Borras *et al*., 2006).

Despite its evolutionary importance and its production capacity in unfavorable environments, there are no studies aimed at promoting the popcorn races of Mexico. These races have been neglected as they have not carried out raceing for trapping the grain, making their expression low compared to that of their peers from other countries; therefore, the objective of this work was to evaluate the yield and expansion capacity in accessions of the Palomero Toluqueño maize race, protected in germplasm banks of Mexico and by custodial farmers of said race, as a starting point for the design of genetic improvement programs of the same, it is hypothesized that within the diversity protected in germplasm banks and materials owned by the custodial producers there are some appropriate populations of maize to start an improvement program, which would allow in the medium term obtain materials that compete with commercial popcorn in both yield and expandability.

Materials and methods

Genetic material

51 materials were evaluated, 42 corresponding to accessions of the Palomero Toluqueño race, of which 38 were provided by the germplasm banks and four were obtained from the custodians of the Palomero Toluqueño race originating from San Marcos Tlazalpan, State of Mexico, in addition to eight accessions miscellaneous items from the genetic improvement program of the Postgraduate College and a commercial witness of the 'Valle Verde' brand, as described in Table 1.

Table 1. Origin of the evaluated materials.

Accessions			Donator
Mex-5	Mex-994	Pue-956	INIFAP germplasm bank
Mex-6	Pue-235	Pue-957	
Tlax-311	Pue-947	Pue-958	
Hgo-609	Pue-948	Pue-959	
Mex-167	Pue-949	Ver-744	
Mex-169	Pue-950	Ver-746	
Mex-35	Pue-951	Ver-747	
Mex-79[$]	Pue-952	Ver-748	
Mex-79-Red[$]	Pue-953	Ver-749	
Mex-94	Pue-954	Ver-750	
Mex-993	Pue-955	Ver-751	
ARR-1,2PL (white)[&]	ARR-76	ARR-81	BANGEV- UAch
ARR-1,2PL [&]	ARR-80		
Encarnacion creole	Odilon creole		Custodial Farmers, SINAREFI
Fortino creole	Plaza creole		
Comp. Yellow	Palomero Cream	Palomero Late	Programa de Mejoramiento Genético CP
Comp. White	Palomero Slim	Palomero Pinto Yellow	
NayPP-II × Mex-5-77	Palomero Thick		
Valle Verde (Control)			Commercial

[$], [&]= materials with the same origin and separated by color for evaluation. INIFAP= National Institute of Agricultural and Livestock Forestry Research; BANGEV-UACH, Plant Germplasm Bank of the Autonomous University Chapingo; SINAREFI= National System of Plant Genetic Resources for Food and Agriculture.

Location of the experiments

The experiments were established in the field in the 2014 spring-summer agricultural cycle in Montecillo, Texcoco municipality, State of Mexico (19° 27’ 54.8” north latitude and 98° 54’ 20.5” west longitude, altitude of 2 250 m, mean annual temperature of 15.1 °C and annual precipitation of 656.9 mm) and in Santa Maria Zacatepec, municipality of Juan C. Bonilla, Puebla (19° 7’ 52” north latitude and 98° 21’ 23” west longitude, altitude of 2 260 m, mean annual temperature of 16 °C and annual precipitation 834.9 mm) (SMN, 2015).

Design and experimental unit

A randomized complete block design was used with two repetitions in each location, the experimental unit consisted of three rows of 5 m in length with furrows of 0.8 m wide, where three seeds were deposited every 0.5 m and two plants were cleared, which produced a final population of 66 plants per experimental unit, which corresponds to a density of 55 000 plants ha^{-1}.

Handling of experiments

Plantings were carried out on May 15 and 21, 2014 in Montecillo and Santa Maria Zacatepec, respectively. In both locations the cultivation was conducted under irrigation. The fertilization in Montecillo was carried out with the formula 140N-60P-00K, applying 60% of the N and all the P in the sowing and the rest of the N in the second weeding, while in Santa María Zacatepec the formula was 160N-60P- 00K, applying 30% of N and all the P in the first weeding and the rest of the N in the second weeding. The harvest took place in November 2014.

Response variables

Two of the three rows of each experimental unit were used for the evaluation of grain yield, in the remaining row, mesofraternal crosses were carried out (Márquez-Sánchez, 2001) to obtain pure seed and carry out the evaluation of the trapping variables. Grain yield (REND). It was determined in a sample of five cobs of each experimental unit, with the respective corrections for shelling coefficient and moisture content at 14%. The result was reported in tons per hectare (t ha^{-1}).

The trapping characteristics were recorded in grains with a moisture content of 13.5%, as it is considered optimal to obtain the maximum expansion volume (Gökmen, 2004). To achieve this humidity, grain samples from each experimental unit were placed in a controlled environment chamber at 21 °C with 70% relative humidity for seven days.

The trapping was carried out on 30 g of seed placed in plastic containers with a lid in Daewoo Model KOR-164H microwave ovens (127 V and 1600 W) set at 70% power for 2:45 min. The following variables were recorded: expansion volume (VE). It was determined in a circular graduated cylinder of 8.89 cm in diameter with a capacity of 2 000 mL (Santacruz-Varela, 2001). The result was reported in cm^3 g^{-1}. Percentage of unpopped grains (PGSR). The weight of the unpopped grains was divided by the weight of the sample (30 g) and the result was multiplied by 100.

Rosette shape (FR). A visual scale of 1 to 5 was used, where 1 corresponds to the ‘butterfly’ type (rosettes with highly accentuated bumps of irregular shape) and 5 to the ‘mushroom’ type (round rosettes). Spraying the pericarp (PP). A visual scale of 1 to 5 was used, where 1 corresponds to completely pulverized pericarp and 5 to pericarp only with slight ruptures after the explosion of the grain.

Expansion volume per hectare (VEH)

It was obtained by multiplying the yield per hectare by the expansion volume. The result was reported in m^3 ha^{-1}. The last four variables are proposed as alternatives to describe the expansion capacity of the accessions of the Palomero Toluqueño maize race.

Statistical analysis

Analysis of variance was performed using the linear model of the randomized complete block design combining the two locations using the Anova procedure of SAS Version 9.1 (SAS, Institute, 2004). The comparison of means was carried out with the Tukey test ($p \leq 0.05$) and the correlation coefficients between variables were calculated using the CORR procedure of SAS Version 9.1 (SAS, Institute, 2004).

Results and discussion

Variance analysis

The accessions showed highly significant differences for all variables, except for pericarp spraying; while the localities only showed significant differences for yield and pericarp pulverization (Table 2), this may be attributable to the fact that the yield is a polygenic character (Ma *et al*., 2007) and its behavior is highly influenced by the environment, while that trapping is controlled by a smaller number of genes (Lu *et al*., 2003), making this characteristic and its components have less environmental influence.

Table 2. Mean squares and significance in the analysis of variance.

Variables	Variation sources			CV	R^2	Error
	Localities (L)	Accessions (A)	A × L			
REND	6.48*	3.38**	0.76 ns	21.76	0.81	0.54
VEH	0.56 ns	102.11**	24.51**	34.84	3.09	9.54
VE	1.96 ns	31.41**	1.86**	24.68	0.97	0.57
FR	0.44 ns	0.16 ns	0.16 ns	39.52	0.49	0.17
PP	5.83**	3.22**	0.03*	16.95	0.86	0.3
PGSR	7 ns	359.19**	108.45 ns	13.75	0.73	88.42

**, * significant at the 0.05 and 0.01 probability levels respectively; ns = not significant.

Effect of environments

Montecillo, State of Mexico was the town with the conditions that allowed the spraying of the greatest amount of pericarp at the time of trapping, but in turn produced lower yields than those obtained in Santa María Zacatepec, Puebla (Table 3).

The conditions of the localities could have modified the concentrations of cellulose, arabinoxylans, structural proteins, phenolic polymers and lignin, which are related to the characteristics of the pericarp (Bidlack *et al*., 1992), these alterations could be the cause of the variation in spraying the pericarp from one locality to another. While the difference in grain yield is attributable to the climatic and agroecological conditions of the localities for the same year (Buenrostro-Robles *et al*., 2017).

Table 3. Comparison of means of two localities for the variables evaluated.

Location	REND ($t\ ha^{-1}$)	VEH ($m^3\ ha^{-1}$)	VE ($cm^3\ g^{-1}$)	FR (1-5)	PP (1-5)	PGSR (%)
Sta. Maria Zacatepec	3.56 a	8.916 a	3.16 a	1.1 a	3.41 a	68.57 a
Montecillo	3.25 b	8.8104 a	2.96 a	1	3.07 b	68.2 a
$DSH_{0.05}$	0.206	0.87	0.21	0.11	0.15	2.61

Means with equal letters in columns are not statistically different (Tukey≤ 0.05). DSH= honest significant difference (0.05).

Effect of genotypes

Grain yield

The grain yield ranged between 1.05 and 5.14 t ha^{-1}, with an average of 3.38 t ha^{-1}. This interval generated nine statistically different groups, the values being close to the average where the largest number of accessions was concentrated (Figure 1).

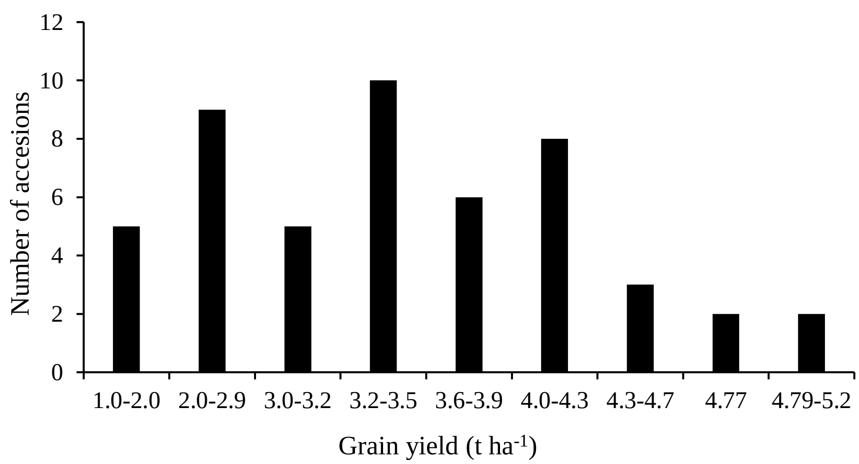

Figure 1. Absolute frequency distribution of the accessions evaluated for their grain yield.

These values exceed the expectation of the race, considering that Brazilian popcorn maize has yields below 2.5 t ha^{-1} (Vieira *et al*., 2016); however, they are not yet able to compete in the national market, since the commercial variety of popcorn maize V-460P, yields 5 t ha^{-1} in irrigation and more than 2.3 t ha^{-1} in rainfed in the Huastecas area (Valadez -Gutiérrez *et al*., 2014).

The average grain yield obtained in this research was slightly lower than the values presented by other native maize materials grown and evaluated under rainfed conditions in the Valley of Mexico (González *et al*., 2007), so it is possible that in temporary Palomero Toluqueño has lower yields than other materials and is one of the reasons why it is stopped cultivating.

Trapping characteristics

The volume of expansion of the grain ranged between 1 and 7.25 cm³ g^{-1} with an average of 2.73 cm³ g^{-1} (Table 4); however, none of the evaluated materials was close to the expansion volume of the control (Figure 2) and even less to the improved popcorn maize from the United States of America, with expansion volumes of 35 to 55 cm³ g^{-1} (Dofing *et al*., 1990; Sakin *et al*., 2005) or Brazilian materials with averages of 18.7 cm³ g^{-1} (Miranda *et al*., 2003); They were even below 11.4 cm³ g^{-1}, which is the average volume of trapping of the Chapalote race (Vázquez *et al*., 2011).

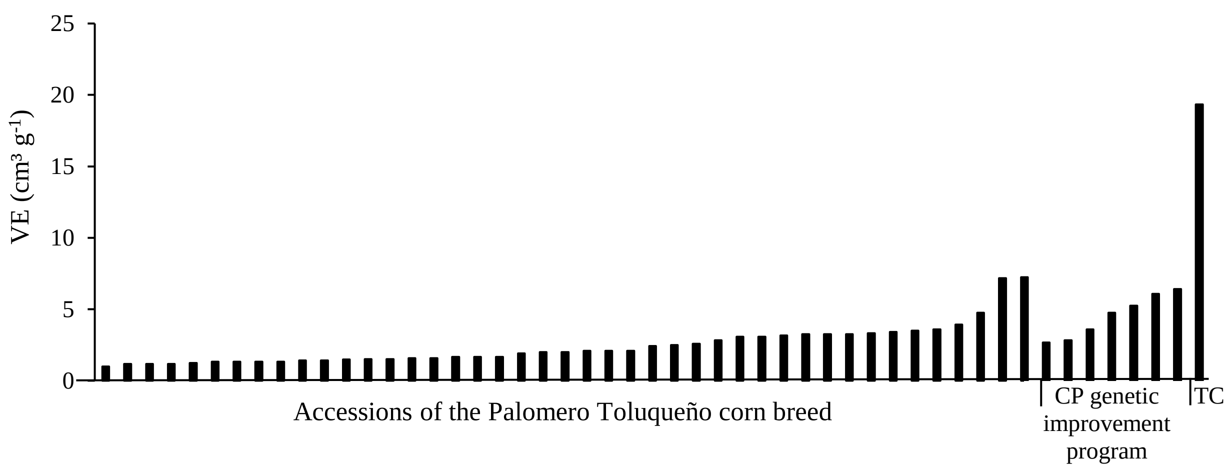

Figure 2. Absolute frequency distribution of the evaluated accessions and the commercial control (TC) by expansion volume.

The difference between the volume of expansion of the materials protected in the germplasm banks of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) and the maize of the custodians was not significant, despite not having the same origin; this may be indicative that the race's expandability has not changed significantly over time. This may be attributable to the selection made by the producers in their barn, where they look for cobs similar to Palomero Toluqueño, although at sowing it is necessary to associate them with floury grain maize that improve the quality of use for tortilla (Gámez *et al*., 2014).

The mean volume of expansion per hectare (8.86 m^3 ha^{-1}) is similar to that obtained in materials from other countries (Berilli *et al*., 2013; Vieira *et al*., 2016), although some of the materials evaluated were found Outstanding for this variable, such as: Yellow pinto, Plaza creole, Palomero slim among others (Table 4).

Table 4. Comparison of means of five variables of the best 10 and worst 5 accessions in their expansion volume per hectare and the commercial control.

Accession	REND (t ha^{-1})	VE (cm^3 g^{-1})	PP (1-5)	PGSR (%)	VEH (m^3 ha^{-1})
NayPP-II × Mex-5-77	4.15 a	6.08 b	1.88 j	58.64 a	24.35 a
Comp. Yellow	3.41 a	7.25 b	1.75 k	53.8 d	24.27 a
Pal. Pinto Yellow	3.82 a	4.75 c	1.38 m	59.29 a	18.43 a
Plaza Creole	3.85 a	4.75 c	2.63 f	58.53 a	17.92 a
Comp. White	3.23 a	5.25 b	1.75 k	59.79 a	16.67 a
Palomero Slim	2.55 d	6.42 b	1.63 l	55.72 c	14.94 b
Palomero Late	4.03 a	3.58 e	2.13 i	53.79 d	14.34 b
Hgo-609	4.08 a	3.33 e	2.63 f	70.55 a	13.51 b
Encarnacion Creole	3.79 a	3.25 e	2.88 d	57.07 b	12.87 b
Mex-5	3.12 a	3.58 e	2.75 e	59.76 a	11.94 b
Palomero Cream	1.55 j	2.67 f	2.5 f	62.39 a	4.18 h
Pue-955	2.05 f	1.33 i	3.25 a	79.69 a	2.73 i
ARR-1,2PL	2.63 c	1 l	4.63 a	84.33 a	2.57 i
ARR-81	2.02 f	1.17 l	4.88 a	81.81 a	2.35 i
Pue-954	1.87 i	1.17 l	4 a	84.67 a	2.15 i
Valle Verde	nd	19.33 a	1 n	57.5 a	nd
$DSH_{0.05}$	2.15	9.01	2.21	1.6	27.49

Means with equal column letters are not statistically different (Tukey, 0.05). DSH= honest significant difference. nd= not determined

These accessions are not suitable in their current state for commercialization, since it was the grain yield and not the expansion volume that caused the apparent superiority, since the commercialization of popcorn is done by volume of already popped corn (Soylu and Tekkanat, 2007).

Unpopped grain values were greater than 50% and less than 85%, even in the commercial popcorn. The Pue-235 accession presented a lower percentage of unpopped grain and ARR-1,2PL-White was extremely low in the percentage of unpopped grains, even though its expansion volume was the lowest (Table 4).

The observed values for this variable are at least five times higher than those reported by Sweley *et al*. (2012) in commercial hybrids of popcorn, making the Palomero Toluqueño race in its current state, unable to compete with existing materials on the market, so it is necessary to establish a genetic improvement program for trapping characteristics.

The fact that popcorn grains pop does not necessarily imply good quality, as the rosettes are expected to be large in size and the pericarp to be almost completely pulverized (Ziegler, 2001). In this regard, the pericarp pulverization in the control had a value of 1, while in the native materials it was from 1.3 to 4.8.

Two accessions of the Palomero Toluqueño race presented values lower than 1.8 indicative of small pericarp remains in the rosettes. In the nine accessions with values of 4 for spraying the pericarp, the expansion was manifested in the upper part of the grain, leaving more than 80% of the pericarp intact. The custodians' materials presented values between 2.3 and 3.1 (Table 4), indicating that the seeds form rosettes without eliminating more than 40% of the pericarp.

The genotype × environment interaction is linked to the stability of the genotypes through the environments (Cortes *et al*., 2000) in this sense, the Palomero Toluqueño accessions changed their response in expansion volume per hectare, expansion volume per sample 30 g and spraying the pericarp according to the environment.

In these variables, the genotypes interacted varying in magnitude and direction in the localities (Table 2). Whereas grain yield, rosette shape and percentage of grains without bursting did not significantly interact with the localities; therefore, they have greater stability across environments.

Correlation between the variables evaluated

The pulverized pericarp was the variable with the highest number of significant correlations; it maintained negative correlations with the expansion volume per hectare and per gram of grain. It was also observed that the expansion volume had a negative correlation with the percentage of grains without popping (Table 5), which agrees with the assumption that the greater the number of popped grains and the amount of pericarp removed, the greater the expansion volume (Hoseney *et al*., 1983); therefore, the increase in the expansion volume is associated with a better palatability of the rosette by eliminating pericarp debris.

Table 5. Correlation coefficients between trapping and yield characteristics.

	PGSR	VEH	PP	FR	REND
VE	-0.585**	0.7993**	-0.734**	-0.109	-0.241
PGSR		-0.685**	0.808**	0.177	0.193
VEH			-0.769**	-0.122	0.281
PP				0.083	0.124
FR					-0.01

** = $p \leq 0.01$.

In the commercial exploitation of popcorn, a negative correlation of yield with trapping has been observed (Dofing *et al*., 1991; Vieira *et al*., 2016), both characteristics are of great interest in popcorn maize (Ceylan and Karababa, 2001; Soylu and Tekkanat, 2007). In the Palomero Toluqueño materials evaluated, the yield did not have a significant correlation with any variable related to trapping, which makes simultaneous selection difficult for both aspects, therefore it would be desirable to involve selection indices to improve characteristics of different nature in a parallel way, such as This has been shown by Berilli *et al*. (2013); Freitas *et al*. (2014); Vieira *et al*. (2016), the last two specifically in popcorn.

Conclusions

In their current state, the materials of the Palomero Toluqueño maize race protected in the germplasm banks and by custodial farmers, do not have sufficient trapping attributes to compete with commercial popcorn producers in the production of popcorn. However, there are outstanding accessions in grain yield and expandability that will allow starting genetic improvement programs for the race.

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