Genetic potential of S_1 lines derived from native maize populations of Tamaulipas, Mexico

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Abstract

This study is designed to evaluate and select the best S_1 maize top cross lines to continue their process of inbreeding. Nineteen top crosses samples were examined from three contrasting environments (two places from Tamaulipas and one place from the Central High Valleys of Mexico) during 2008. These S_1 lines were derived from native populations of four ecological zones of Tamaulipas; one tester from the High Valleys was used. Some top crosses had high yield as well as favorable agronomic traits, though these varied between environments. Some had better performance in Northern Tamaulipas, mainly the tropical groups 1 and 2 that are from hot and dry climates. In the High Valleys these groups had lower yields compared with the top crosses groups 3 and 4. Group 1, the top cross of I-C3001-2915-2 with high yield in the Central and Northern Tamaulipas environments (2.4 and 5.8 t ha^{-1}, respectively) was outstanding. In the High Valleys, the top crosses from group 3 (from the Tamaulipas Huasteca, a hot, and humid climate zone) had yields of 7.4 to 8.5 t ha^{-1} and from group 4, the top cross of IV-C4031-2939-5(C) yielded 8.8 t ha^{-1}. The S_1 lines being evaluated show potential for those top crosses with better grain yield and earliness, indicating good combining ability. It has been suggested that the S_1 lines are better to continue the inbreeding process, planning test crosses and field assessments in the environments where they had better performance.

Keywords: native maize, top crosses, plant breeding, combining ability

Introduction

The practical aspect of genetic maize (*Zea mays* L) improvement by hybridizing is based on the development and selection of inbred lines that exhibit the best general combining ability (GCA) and specific combining ability (SCA) to integrate hybrids with higher grain and forage yield, besides desirable expression of other agronomic attributes. Initially, maize breeders self-pollinate of an open pollinated population and visually select lines by plant type, resistance to pests and diseases, ear weight, resistance to lodging, and earliness. However, the performance per se of these inbred lines does not provide on appropriate assessment of their value in hybrid combinations (Hallauer, 1990), other simple and low time consuming methods are used to evaluate lines in order to guarantee generation of hybrids with high productive potential (Bernardo, 2001).

After forming lines with a high level of inbreeding, all possible crosses are sometimes produced and tested to evaluate their combining ability based on their yield. This diallel process can be applied with only a few lines (10 to 15), but if the number is higher, it is difficult to test. From 1920 to 1930, the classic procedure for evaluating GCA of selfed maize included the test n (n–1)/2 possible crosses of a group of n lines; this procedure is impractical if n is large. This led to the introduction and generalized adoption of the top cross test proposed by Davis (1927), who pointed out that the combining ability of selfed maize lines, could be estimated by testing the performance of their crosses using a common tester. Top crosses were generally evaluated using lines with a high level of homozygosity Jenkins (1935) proposed early testing of lines, arguing that the inbred lines acquire their individuality from the first generations of inbreeding and remain relatively stable through successive selfings. Thus, it is convenient to evaluate performance of the test crosses as early as possible (S_2 or S_3) to discard a large number of lines that may not have important attributes that can be used in forming commercial hybrids (Hallauer, 1990).

The utilization of maize genetic diversity on genetic improvement in Mexico has been limited to a few races and population variants (Carrera and Cervantes, 2006). In Tamaulipas and other northern re-

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gions of the country, several populations have been used in breeding programs; however, the origin of this genetic base is restricted to the central area of the state. Recently, native maize populations have been collected in several regions of central and southern Tamaulipas to evaluate their potential (Pecina-Martínez et al, 2011) and to analyze the possibility of better utilization of maize diversity. Inbred lines have been derived from outstanding populations to pursue this purpose.

The objectives of this study were to identify S1 maize lines with greater genetic potential using top crosses, and to determine the effect of geographic origin of the inbred lines on performance of the top crosses in contrasting altitude and environmental temperature in order to direct appropriately the formation of hybrids or synthetic varieties.

Materials and Methods

In 2006, the experimental station in the Colegio de Postgraduados at Montecillo, Texcoco, Mexico, a group of approximately 200 S_1 lines derived from native populations of Tamaulipas, 35 were selected for their per se grain yield (≥ 150 g plant^{-1}), and other agronomic traits. In 2007, top crosses were obtained with these lines by VS-16 as tester (improved composite from the High Valleys, with a broad genetic base, high yield potential, and with no kinship to the inbreds; it was developed in the maize breeding program at the Universidad Autonoma Chapingo by Dr. Moises Mendoza Rodríguez), and detasseling the S_1 lines. In 2008, during the fall-winter growing season (Tamaulipas) and the spring-summer (the High Valleys), 19 of the top crosses were selected based on the amount and physical quality of the seed to be evaluated in three environments. These top crosses represented the four ecological zones of Tamaulipas described by Pecina-Martínez et al (2009) on the bases of the geographic origin of populations, sources of the S_1 lines. An additional test cross comes from a S_1 lines derived from UAT-Comp II, which is a balanced composite of outstanding native maize populations detected in previous tests (Pecina and López, 2004). Two commercial hybrids were included as checks, each environment included well adapted hybrids.The original populations are preserved in the gene bank of the Universidad Autonoma de Tamaulipas (Table 1), for identification letter "C" is followed by accession number.

During 2008, field experiments were carried out under irrigation conditions in each of three locations contrasting in altitude and climate: I) Central Tamaulipas (CT): planting date was on February 25 at Güemez, Tamaulipas (23°56'N and 99°06'W, 200 masl altitude, mean annual temperature of 23.8°C, and mean annual rainfall of 800 mm); II) Northern Tamaulipas (NT): planting date was on February 14

Table 1 - Top crosses of S_1 lines derived from maize native populations of Tamaulipas, and field evaluated in three environments contrasting in altitude and temperature, in 2008.

Group	Top cross	Collection	Municipality of origin
1: Central	I-C3001-2915-2 x VS-16	C-3001	Padilla
	I-C3024-1213-2 x VS-16	C-3024	Hidalgo
	I-UAT Comp II-1239-1 x VS-16	UAT-Comp II	Güemez
2: Ex IV District	II-C3006-1214-3 x VS-16	C-3006	Tula
	II-C3006-1214-2 x VS-16	”	”
	II-C3006-2919-4 x VS-16	”	”
	II-C3006-2919-1 x VS-16	”	”
	II-C3007-1215-1 x VS-16	C-3007	”
	II-C3023-1220-3 x VS-16	C-3023	”
	II-C3023-1220-2 x VS-16	”	Llera
3: Huasteca	III-C3038-1222-1 x VS-16	C-3038	”
	III-C3038-2927-1 x VS-16	”	”
	III-C3039-1223-1 x VS-16	C-3039	”
	III-C3039-1223-4 x VS-16	”	”
	III-C3039-1223-3 x VS-16	”	”
4: Mountain	IV-C4028-2937-1 x VS-16	C-4028	Miquihuana
	IV-C4031-2939-5 (A) x VS-16	C-4031	”
	IV-C4031-2939-5 (B) x VS-16	”	”
	IV-C4031-2939-5 (C) x VS-16	”	”
5: Commercial check	CT y NT: H-437 and H-Santa Bárbara		
	HV: H-San José and Asgrow-Pantera		

group 1: central zone, hot subhumid climate; group 2: former IV District zone, dry warm climate; group 3: Tamaulipas Huasteca zone, humid hot climate: group 4: Southwestern Tamaulipas mountain zone, dry temperate climate; group 5: commercial checks, specific for each environment. In group 4, the letters in parentheses indicate the grain color: white, pink and orange, respectively. The commercial checks used was H-437, a hybrid form INIFAP (Reyes y Cantú, 2004), from Asgrow company we used hybrid "Pantera", and hybrids named "H-San Jose" and "H-Santa Barbara" are from group ZEATL SPR.

Table 2 - Mean squares of the analysis of variance combined for morphological and phenological variables for groups of top crosses of maize across three locations, 2008.

SV	df	DA	DS	ASI	PH
Env	2	7611.6**	8055.7**	7.9 *	13012.5 **
Rep(Env)	4	1.9	1.9	1.0	501.2
Gps	4	305.6**	419.8**	27.0**	982.8 **
TC(Gps)	17	219.1**	236.4**	6.8**	1056.2 **
Env x Gps	8	41.9**	54.2**	4.8**	722.5 **
Env x TC (Gps)	31	0.0ns	5.4ns	4.6**	158.5 ns
Error	79	3.7	4.3	1.4	120.3
CV (%)		2.3	2.4	-33.2	5.2

** $p \leq 0.01$; * $p \leq 0.05$; ns = not significant. Env = environments; Rep(Env) = replications within environments; Gps = groups of top crosses by region from origin of the parental populations; TC (Gps) = top crosses nested in groups; Env x Gps = environment x groups interactions; Env x TC (Gps) = environment x top crosses nested in groups interactions; CV = coefficient of variation. SV = source of variation; df = degrees of freedom; DA = days to anthesis; DS = days to silking; ASI = anthesis-silking interval; PH = plant height (cm).

at the Experimental Station Río Bravo of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) (25°59'N and 98°06'W, 30 masl altitude, mean annual temperature of 22°C); and III) High Valleys (HV): planting date was on May 10 at Texcoco, State of Mexico (19°29´N and 98°53´W, 2250 masl altitude, mean annual temperature of 15°C and mean annual rainfall of 645 mm) (García, 1987). Three yield trials were carried out under a randomized complete blocks design with three replications in location VA, and two replications in CT and NT locations. Each experimental plot was two rows 5 m long and 0.80 m wide.

Planting was done by hand at a density of 100 000 seeds ha^{-1} and plot were later thinned to a density of 50 000 plants ha^{-1}. In the CT and NT locations, planting was done in moist soil, with pre-sowing irrigation. In HV, the soil was dry and irrigated immediately after sowing. Chemical fertilizers were applied at a dosage of 120N-60P-00K; half of the nitrogen and all of the phosphorus were applied just before planting and the other half of the N during the second plugging. For weed and pest control, technical recommendations for maize were followed in each region (Reyes et al, 1990). Variables recorded were: days to anthesis (DA) and days to silking (DS), a plot was considered as having reached anthesis or silking when 50% of plants showed functional anthers or silks; the anthesis-silking interval (ASI) was calculated as DS - DA; plant height (PH) in cm, in as the average of five plants from the base of the stem to the ligule of the flag leaf.

In a sample of five ears per plot the following variables were recorded: ear length (EL) in cm, ear diameter (ED) and cob diameter (CD), number of rows per ear (RE), kernels per row (KR), kernels per ear (KE) as the product of RE x KR, individual kernel weight (IKW) as the average weight of 100 kernel sampled at random. Grain yield per hectare (GY) was estimated with the weight of ears harvested per experimental plot multiplied by the proportion of grain in the ear and transformed into grain yield per hectare, adjusted to 12% moisture.

A combined analysis of variance (SAS, 1996) across environments (locations) was computed. The statistical model was:

$$Y_{ijkl} = \mu + A_k + R_{l(k)} + G_i + M_{j(i)} + AG_{ik} + AM_{kj(i)} + \pounds_{ijkl}$$

where Y_{ijkl} = performance of the jth maize top cross nested the ith group evaluated in the kth environment and in the lth replication; μ = the general mean; A_k = the effect of the kth environment; $R_{l(k)}$ = the effect of lth replication nested in the kth environment; G_i = the effect of the ith group of maize top crosses by ecological origin; $M_{j(i)}$ = effect of the jth top cross nested in the ith group; AG_{ik} = effect of interaction ith group of top crosses x kth environment; $AM_{kj(i)}$ = interaction effect of kth environment by jth top cross nested in the ith group; $\pounds_{ijkl}$ = random effect attributed to experimental error.

In the significance test for environments, the replications nested in environments was considered the term of error. The other sources of variation were tested against the experimental error. Comparison of means was performed among environments, groups, and top cross within groups. For the Tukey test ($p \leq 0.05$) among groups, the harmonic mean was calculated with of the number of observations within each group.

Results and Discussion

Phenology and morphology

There were highly significant differences ($p \leq 0.01$) among environments, between top cross groups for days to anthesis and silking, and plant height. Differences for anthesis-silking interval among environments was only significant ($p \leq 0.05$). The interaction environments x top cross groups was highly significant ($p \leq 0.01$) for all variables, and the interaction of environments x top crosses nested in groups was significant only for anthesis-silking interval (Table 2).

Because of the highly significant environments x top cross groups interaction (Table 2), comparisons among top crosses were done within each environment (Table 3).

There were differential environmental effects among top crosses groups for days to anthesis and

Table 3 - Mean values of morphological and phenological traits for groups of top crosses, by environments. 2008.

Environment	Group	DA	DS	ASI	PH
CT	1	73.0 b	76.5 b	-3.5 b	188.6 b
	2	76.6 a	81.4 a	-4.8 b	206.6 a
	3	73.7 b	77.5 b	-3.8 b	191.8 b
	4	69.8 c	71.6 c	-1.9 a	188.9 b
	5	75.8 a	76.8 b	-1.0 a	178.7 c
	MSD	1.1	1.5	1.4	6.2
	Mean	74.0 B	77.5 B	-3.5 AB	194.5 B
NT	1	73.8 bc	77.8 a	-4.0 b	210.3 ab
	2	77.6 a	80.8 a	-3.2 b	223.0 a
	3	74.7 ab	77.9 a	-3.2 b	198.0 bc
	4	70.6 c	74.1 b	-3.5 b	199.8 bc
	5	72.8 bc	72.8 b	0.0 a	191.3 c
	MSD	3.4	3.3	2.7	16.4
	Mean	74.6 B	77.6 B	-3.1 B	207.8 B
HV	1	93.6 b	97.2 b	-3.7 bc	222.8 a
	2	99.7 a	104.3 a	-4.6 c	225.6 a
	3	94.8 b	99.1 b	-4.2 bc	225.1 a
	4	87.9 c	91.1 c	-3.2 ab	229.4 a
	5	96.2 b	98.5 b	-2.3 a	228.0 a
	MSD	2.7	3.04	1.2	16.7
	Mean	94.9 A	98.7 A	-3.9 A	226.0 A

CT: Central Tamaulipas, NT: Northern Tamaulipas, HV: High Valleys. Group 1 = central zone, hot subhumid climate; group 2 = former IV District zone, Dry warm climate; group 3 = Tamaulipas Huasteca zone, humid hot climate: group 4 = Southwestern Tamaulipas mountain zone, dry temperate climate; group 5= checks, specific for each environment. In the same column, upper case letters indicate statistical differences between environments and lower case letters indicate differences among groups within the environment ($p \leq 0.05$). DA = days to anthesis; DS = days to silking; ASI = anthesis-silking interval; PH = plant height (cm).

silking: although higher altitude and lower temperature (HV) time from planting to flowering was long, in the Tamaulipas sites (CT and NT), all groups had similar performance. Even when the S_1 lines were derived and selected under highland conditions, which contrasts with the ecologic tropical origin of populations, the resulting top crosses maintained the tropical performance. This would indicate that it would be necessary to continue selecting better adapted, early lines. The top crosses of the group from the mountains of Tamaulipas (group 4) were earlier at the HV, than other Tamaulipas germplasm which explains the interaction. The original populations showed similar performance in a previous study (Pecina-Martínez et al, 2009).

Plant height mean for HV was greater ($p \leq 0.05$) than in the Tamaulipas environments. Considering the average of groups within each environment, group 2 was statistically superior ($p \leq 0.05$) at the CT and NT environments, and the group of checks showed the lowest plant height, while in HV all of the groups were statistically equivalent (Table 3). Plant height of top crosses in HV was agronomically acceptable and values were similar to those found by Pecina-Martínez et al (2009).

It has been mentioned that when introducing tropical material to highlands, with lower temperature, as in this study, wether populations per se or in crosses with local materials, it tends to show greater plant height and longer ears (Carrera and Cervantes, 2002; Pérez-Colmenares et al, 2000); however, it is not desireable since there is correlation between plant height and lodging (Antonio et al, 2004), a problem that is generalized among highlands native populations. The top crosses here evaluated did not lodge in any of the environments (data not presented). Since the maize improvement programs in México prioritize resistance to lodging and grain yield, these attributes in the top crosses are desireable, even in the tester since, according to Hallauer and Miranda (1981) the best tester shown have low allele frequencies for the trait of interest.

Grain yield and its components

There were statistical differences ($p \leq 0.01$) among environments, among groups of top crosses and among top crosses within the group for grain yield and for yield components, with the exception of EL among top cross within groups, and KE into groups of top crosses, whose significance was of 0.05. The environment x groups of top crosses interaction was significant ($p \leq 0.01$) for all variables, except CD. The environment x top crosses within the group interaction was significant ($p \leq 0.01$) for GY, EL, ED, RE and IKW, and at $p \leq 0.05$ for CD, KR and KE. This suggests that there is variability and specific performance of some top crosses in the environments in this study (Table 4). Because grain yield and several yield components showed highly significant differences for environments x groups of top crosses interaction (Table 4), on Table 5 means of top crosses within each

Table 4 - Mean squares of the analysis of variance for grain yield and yield components for the evaluation of maize top crosses in three environments, 2008.

SV	df	GY	EL	ED	CD	RE	KR	KE	IKW
Env	2	278.3 **	20.1 **	14.0 **	2.8 **	23.2 **	411.4 **	173375 **	174119 **
Rep(Env)	4	1.08	1.2	0.17	0.03	0.69	7.5	1107	1502
Gps	4	10.9 **	9.8 **	0.36 **	0.22 **	3.3 **	40.7 **	10305 *	3992 **
TC(Gps)	17	6.3 **	2.4 *	0.14 **	0.08 **	7.0 **	25.5 **	9490 **	3650 **
Env x Gps	8	5.0 **	5.8 **	0.19 **	0.05 ns	3.2 **	36.6 **	14449 **	3416 **
Env x TC(Gps)	31	5.2 **	2.8 **	0.20 **	0.06 *	1.9 **	21.4 *	7302 *	3412 **
Error	79	1.4	1.3	0.06	0.03	0.96	10.9	3369	1053
CV (%)		28.1	7.1	5.5	6.5	7.0	11.3	14.2	11.9

** and * = significant at $p \leq 0.01$ and 0.05, respectively, ns = not significant; SV = source of variation; df = degrees of freedom; Env = environments; Rep(Env) = replications within environments; Gps = groups; TC(Gps) top crosses nested in groups; Env x Gps = environment x groups interaction; Env x TC(Gps) = environments x top crosses nested in groups interaction; CV = Coefficient of variation; GY = grain yield (t ha^{-1}); EL = ear length (cm); ED = ear diameter (cm); CD = cob diameter (cm); RE = rows per ear; KR = kernels per row; KE = kernels per ear; IKW = individual kernel weight (mg).

environment are shown. In this study, similarly as in Pecina-Martínez et al (2009) and Pecina-Martínez et al (2011) on the performance of parental populations of these S_1 lines, the lowest grain yield and yield components were found in the Central Tamaulipas environment (CT) relative to the other environments of this yield trial (Table 5). In this area, a considerable rise in temperature has occurred during the last decade, mainly at flowering and grainfilling period; major losses of grain yield and lower expression of its components have been reported (Castro-Nava et al, 2011). The Mexican Northeastern region has suffered two extensive problems for maize production: scarce moisture and high temperatures. Over the years, this has meant broad variability of maize grain yield from total loss of the crop to production of more than 7.0 t ha^{-1} (Reyes and Cantú, 2005).

Grain yield was higher at HV ($p \leq 0.05$) than in NT, and it was higher than CT. The yield components were statistically different between environments, while only the number of rows was non significant between CT and NT. For IKW, at CT showed lower values (Table 5).

For the three environments, groups of top crosses were different according to the origin of the parental populations of S_1 lines. Group 5, commercial checks, on the average in each environment, had higher grain yield than the top crosses, followed by group 1 (germplasm from central Tamaulipas) in CT and NT, and group 2 (from the former District IV zone); while at HV, top crosses of group 4 (from the mountainous zone of Tamaulipas) followed the checks (Table 5).

Kernel per row was significantly different among environments, the highest values at the HV and the lowest at CT. For HV all the groups were statistically equivalent, unlike the CT and NT environments in

Table 5 - Grain yield and yield components of outstanding top crosses formed from native populations of Tamaulipas and a tester from the High Valleys, 2008.

Env	Gp	GY	EL	ED	CD	RE	KR	KE	IKW
CT	1	1.26 ab	14.6 bc	3.7 b	2.43 b	13.4 ab	27.3 ab	366 ab	172 ab
	2	1.28 ab	15.4 ab	3.8 ab	2.52 ab	13.8 ab	27.7 ab	383 ab	199 ab
	3	1.22 ab	15.4 ab	4.0 ab	2.48 b	13.2 b	25.6 ab	342 ab	217 a
	4	0.81 b	13.3 c	3.6 b	2.30 b	12.6 b	21.8 b	273 b	158 b
	5	1.80 a	16.6 a	4.3 a	2.82 a	14.6 a	31.9 a	468 a	219 a
	MSD	0.97	1.8	0.49	0.30	1.3	7.7	128	53
	Mean	1.22 C	15.0 B	3.8 C	2.5 C	13.4 B	26.4 C	357 C	191 B
NT	1	4.49 ab	14.9 ab	4.4 b	2.8 ab	13.1 ab	27.7 ab	360 ab	295 ab
	2	4.46 ab	16.9 a	4.6 ab	2.7 ab	13.4 ab	30.0 a	405 a	318 a
	3	3.97 b	15.2 ab	4.6 ab	2.7 ab	14.0 a	28.3 ab	397 ab	294 ab
	4	3.77 b	14.5 b	4.5 ab	2.6 b	13.7 ab	25.5 b	347 b	265 b
	5	5.33 a	16.4 ab	4.7 a	2.9 a	12.9 b	28.7 ab	369 ab	318 a
	MSD	1.16	2.0	0.28	0.25	1.1	4.3	57	53
	Mean	4.30 B	15.7 AB	4.5 B	2.7 B	13.5 B	28.3 B	382 B	299 A
HV	1	6.11 bc	16.2 a	4.8 ab	2.9 a	14.0 a	32.0 a	448 a	305 a
	2	4.67 c	16.1 a	4.7 b	2.9 a	14.0 a	32.2 a	451 a	308 a
	3	5.82 bc	15.9 a	4.9 ab	2.9 a	15.1 a	31.0 a	468 a	291 a
	4	6.71 ab	16.6 a	5.1 a	3.0 a	14.9 a	32.8 a	490 a	313 a
	5	8.39 a	17.1 a	5.1 a	3.1 a	15.4 a	31.7 a	488 a	313 a
	MSD	1.86	1.3	0.3	0.23	1.4	3.3	68	51
	Mean	5.95 A	16.3 A	4.9 A	2.9 A	14.6 A	31.9 A	466 A	304 A

Env = environments; CT: Central Tamaulipas, NT: Northern Tamaulipas, HV: High Valleys. group 1: central zone, hot sub-humid climate; group 2: former IV District zone, dry warm climate; group 3: Huasteca zone, humid hot climate: group 4: Southwestern Tamaulipas mountain zone, dry temperate climate; group 5: commercial checks. GY = grain yield (t ha^{-1}); EL = ear length (cm); ED = ear diameter (cm); CD = cob diameter (cm); RE = rows per ear; KR = kernels per row; KE = kernels per ear; IKW = individual kernel weight (mg). In the same column, upper case letter indicate statistical differences between environment, and lower case letters indicate differences between top cross groups within the environment ($p \leq 0.05$).

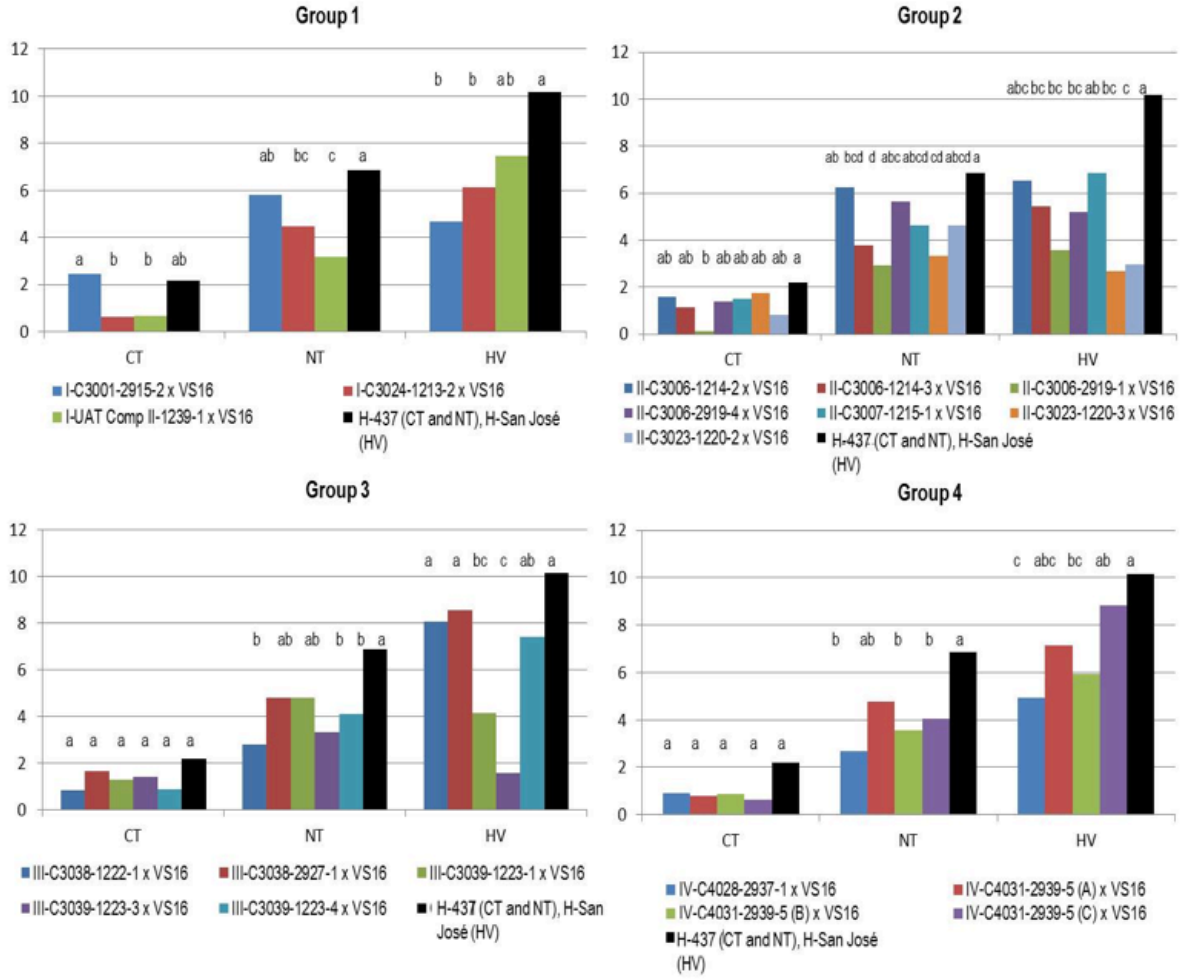

Figure 1 - Grain yield (t ha^{-1}) of top crosses from each group, evaluated in contrasting environments in 2008 and compared with the best commercial check for each environment. Lower case letters indicate statistical differences between top crosses within the corresponding group (Tukey, 0.05).

which groups 1, 2 and 3 were similar to the checks. In these lowland environments, group 4 (germplasm from the mountains of Tamaulipas) had the lowest values (Table 5). All of the top cross groups showed the highest kernel number per ear (KE) in the HV, followed by those in NT and CT. Group 4 presentedhigher interactions with the environment, presenting lower values at CT and NT and the highest at HV (Table 5). For individual kernel weight (IKW), at NT and HV environments were statistically equivalent, while a lower value occurred at CT. In the three environments, the commercial checks (group 5) had higher values; at CT group 3 equivalent values to those of commercial checks, and at NT group 2 showed the highest IKW of the top cross groups. In the case of the HV, all the top cross groups were statistically equivalent to the commercial checks (Table 5). The number of kernels per ear and individual kernel weight are the main yield components (Andrade et al, 1996); in this study, group 4 at CT and NT had the lowest values of these variables, and so grain yield was low for these environments. The opposite occurred at HV where this group had higher values for these variables and equaled the check´s yield. Lower values in the Tamaulipas environments were due mainly to the inability of group 4 to adapt to high temperatures during pollination and grain filling period, causing reduction of the number of kernels per ear, as well as lower IKW (Boyer and Westgate, 2004).

Figure 1 presents individual grain yield of each top cross, within each regional group and each environment. In group 1 there were two top crosses with S_1 lines derived from different populations and one top cross, whose S_1 line was derived from on improved material of the same zone. The top cross I-C3001-2915-2 x VS-16 performed well in the Tamaulipas environments: in both sites it had high yield, statistically equivalent to the best commercial check within each environment. The top cross whose S_1 was derived from the improved material (V-UAT Comp II-1239-1 x VS-16) had low grain yield at the Tamaulipas environments, but at HV was statistically equivalent the best check.

About the seven top crosses of group 2, S_1 lines were derived from three native populations, and thus, more variation among top crosses can be seen; there were lines with good combining ability, but others were not so good, such as the ones from population II-C3023 whose top crosses had low grain yield at the NT and HV environments. Among top crosses of group 2, II-C3006-1214-2 x VS-16 was outstanding, with good grain yield in the three environments. Top crosses II-C3007-1215-1 x VS-16 and II-C3006-2919-4 x VS-16 also showed acceptable grain yields. The contrasting case was the top cross II-C3006-2919-1 x VS-16 with the lowest yields in the three environments (Figure 1). The good expression of the top crosses of groups 1 and 2 in the Tamaulipas environments may be due to the origin of the parental populations, which are from the municipalities of Padilla and Tula, Tamaulipas, zones of high temperatures and low relative humidity. Because they have been cultivated for a long time, adapted and conserved by the region's farmers, they may have accumulated favorable genes that allow them to adapt to these environmental conditions. These results are similar to the ones reported by Castro-Nava et al (2011) while initiating maize breeding with these native populations (deriving inbred lines and forming top crosses), they observed good genetic potential in yield trials under the environments at conditions of Central Tamaulipas.

In group 3 (parental populations from the Huasteca zone, hot humid climate), there were five top crosses with S_1 lines from two different populations. Of these, III-C3038-2927-1 x VS-16 was outstanding, with higher yields at the three environments, particularly in HV where it yielded 8.5 t ha^{-1}, statistically equivalent to the San José hybrid, the best check of the environment. The S_1 line of this top cross comes from tropical material that combined well for HV, having higher values relative to the best top crosses from groups 1 and 2, whose parental populations are also of tropical origin and yielded 6 to 6.5 t ha^{-1} at HV. In this sense, top crosses III-C3038-1222-1 x VS-16 and III-C3039-1223-4 x VS-16 had low yields at the Tamaulipas environments, but their yield was high at HV, indicating that their GCA is better for HV, but not for the CT and NT environments. In this same group 3, the top crosses III-C3039-1223-3 x VS-16 had intermediate grain yield at the Tamaulipas environments, but it had the lowest yield of all the top crosses at HV. Because of this poor performance, the S_1 line should be eliminated from the breeding program (Figure 1).

The variation in grain yield of top crosses with S_1 lines from tropical origin at the HV environment can be explained by their limitations to adapt since at contrasting conditions as CT, they were able to express phenological and morphological changes (Pecina–Martínez et al, 2009).

Evaluating lines with low inbreeding may contribute to orient genetic improvement programs. With few more cycles of selfing on the outstanding lines, it would be possible to obtain new versions with probed combining ability and desireable traits that could overcome problems of adaptation of maize introduced to the High Valleys (Perez-Colmenares et al, 2000), some of which may even be used for production in the tropics. In studies such as Carrera and Cervantes (2002), it has been shown that when selection is done in the High Valleys, adaptation of tropical maize populations can be achieved; adaptation manifested as earliness, plant health and grain yield similar to the commercial hybrids of intermediate cycle that are available in the region.

The top crosses of S_1 lines from mountainous zone of the state of Tamaulipas germplasm are included in group 4. Pecina-Martínez et al (2011) found that parental populations of these top crosses have good yield potential in the High Valleys. Four top crosses at this group with S_1 derived from two parental populations native to that region. Of these, IV-C4028-2937-1 x VS-16 had low grain yield in the three environments; however, top crosses of S_1 lines derived from population IV-C-4031 were better (Pecina-Martínez et al, 2011, reported it as the best yielding), but showed different grain color (white, pink and orange). At CT, the four top crosses of group 4 had low yield, with respect to top crosses of the tropical groups and to H-437, the best check of the environment. At NT, the white grain top cross IV-4031-2939-5(A) x VS-16 was outstanding, followed by that of orange grain IV-4031-2939-5(C) x VS-16. These top crosses, at the HV environment, performed well and the one with orange grain had the highest yield (8.8 t ha^{-1}) of all of the top crosses evaluated in this study (Figure 1); which indicates good combining ability and may be recommended additional work in the future. The white-grain top cross can be used for human and animal consumption, while the orange top cross could be studied with a nutraceutical approach, suggested by its pigments (possibly carotenes), as well as for forage purposes.

Results of this study, together with the history of germplasm collected from central Tamaulipas, we can conclude the following. Germplasm from central Tamaulipas has high yield potential. Improved varieties have been generated from germplasm of similar geographical origin since the middle of last century and such native populations have been used in breeding programs in other states such as Coahuila, Jalisco and Sonora because of their high yield potential and other agronomic attributes; among the outstanding varieties can be mentioned Carmen, San Juan and Llera II (Gamez et al, 1996), which, although they are no longer planted in the region, new versions, such as Llera III, have appeared. Genetic erosion of these materials is mainly due to the farmers' lack of attention when selecting their seed, since many of them emigrate to the United States, as well as to changes in environmental conditions (higher temperatures and lower precipitation). Moreover, in the last 25 years native maize germplasm has not been considered in plant breeding programs of traditional research institutions in the state of Tamaulipas, public or private. For this reason it is important to follow up on the new lines detected in this study and on the native populations that have tolerated high temperatures, as reported by Castro-Nava et al (2011).

Conclusions

Some of the evaluated S_1 lines have good genetic potential. Top crosses were found with good agronomic performance, some showed high-yielding potential and earliness, some others were good for specific environmental conditions.

There was variation among S_1 lines (top crosses) derived from the same population with respect to their performance between and within the contrasting environments, indicating that among sister lines, individuality is expressed from the early stages of inbreeding.

The best lines which are good candidates for continue improvement are I-C3001-2915-2, II-C3006-1214-2 and II-C3006-2919-4 for central and northern Tamaulipas; for the High Valleys III-C3038-1222-1, III-C3038-2927-1, III-C3039-1223-4, IV-C4031-2939-5(A) and IV-C4031-2939-5(C).

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