Article

General and specific combinatorial aptitude of low-inbreeding yellow maize varietal hybrids

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Abstract

The production of yellow maize (*Zea mays* L.) in Mexico is in deficit and its demand increases every year. In this paper, the effects of general and specific combinatorial aptitude, maternal and reciprocal effects for yield variables and their components of five varieties of yellow maize with low level of inbreeding and their diallel crosses were estimated. All genotypes were evaluated in a randomized complete block experimental design with three repetitions per environment, during the spring-summer cycle from 2017 to 2019. Genetic analysis was performed using Griffing's method I. The results indicated that the variety IA324 due to its high yield would have a high contribution in the expression of the yield of its progeny and could be included in a maize genetic improvement program. The direct and reciprocal crosses with higher specific combinatorial aptitude (ACE) for yield were HVAA-10 x IA324 and IA324 x HVAA-9, respectively. It was found that the use of progenitors of contrasting general combinatorial aptitude (ACG) allowed the favorable expression of their progeny. The yellow grain varieties of this work with high ACG effects can be used to develop synthetic varieties or continue advancing more selection cycles, considering that the lines with high ACG detected in early tests retain their additive values in advanced generations, while crosses with high ACE can be used for hybridization.

Keywords: *Zea mays* L., general combinatorial aptitude, specific combinatorial aptitude, varietal hybrids.

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Introduction

In the region comprised by the High Valleys of central Mexico, constituted by Mexico City, Hidalgo, Puebla, Tlaxcala and the State of Mexico, 1.4 million hectares were planted with maize (*Zea mays* L.) during the spring summer cycles of the years 2017 to 2019. Of those states, only Hidalgo, the State of Mexico and Puebla sow yellow grain maize under rainfed conditions, on an approximate area of 2 786 hectares, with an average yield of 2.9 t ha^{-1} (SIAP, 2020).

The average national yield of yellow maize under rainfed condition in 2019 was 3.9 t ha^{-1} and under irrigation was 9.9 t ha^{-1} (SIAP, 2020). In contrast, the yield of yellow grain maize under rainfed conditions, in the north of the country, was 5.6 t ha^{-1}, while in the south it was 2.1 t ha^{-1} (SIAP, 2020). The above data imply taking into consideration the type of production that occurs in these contrasting maize-producing regions. Additionally, it can be mentioned that the type of seeds used during sowing is one of the core axes of this yield (Olguín-López *et al*., 2017).

In this context, it should be considered that the production of this crop is a matter of great complexity, in addition to the impact it has on the public policies and food sovereignty of the country (Echánove-Huacuja, 2009; Valencia-Romero *et al*., 2019).

Given the current changes in climatic conditions, it is important to make use of the wide diversity of the crop, in order to take advantage of genotypes that are tolerant of water deficit and allow to continue having favorable or even better yields, such as those obtained so far with the use of improved varieties (Espinosa *et al*., 2009; Virgen *et al*., 2016; Martínez-Gutiérrez *et al*., 2018). The widespread use of improved materials has been a viable alternative to increase the profitability of the crop, so it is necessary to form new genotypes superior to the current ones (Ávila-Perches *et al*., 2009).

To increase the yields of this crop, a widely used improvement system is hybridization, with which hybrids have contributed to the significant increase in production. The genetic structure that prevails in these is the use of three lines to form the so-called trilinear hybrids, double and single-cross hybrids have also been used (Márquez-Sánchez, 2009).

However, there are unconventional crossings that by their composition allow the favorable expression of hybrid vigor. For its part, a genetic design is a mating system between individuals from one or more populations that provides information on the type of gene action that controls the character in question and generates an improved population that can be used as a basis for the selection and development of potential varieties (Acquaah, 2012).

The estimation of the genetic parameters of a variety can be made by using one of the Griffing (1956) methods, which are useful for plant breeders when using inbred progenitors or free pollinated varieties that show wide genetic diversity. Particularly, method I analyzes the progenitors using direct crosses and reciprocal crosses.

It allows to estimate the general combinatorial aptitude (ACG), the specific combinatorial aptitude (ACE), as well as the maternal and reciprocal effects, which provide elements to establish the genetic relationships between the progenitors and their progeny, being useful in the identification of hybrids and promising crossings (González *et al*., 2007).

Sprague and Tatum (1942) defined the terms general (ACG) and specific combinatorial aptitude (ACE). The first represents the average behavior of a line based on its hybrid combinations (crosses), while the second term is used to designate those cases in which certain crosses are relatively better or worse, based on the average behavior of the progenitors involved. Griffing (1956) established that the concept of combinatorial aptitude is important in the development of experiments in which the behaviors of lines in hybrid combinations are studied and compared, in relation to the type of gene action that determines the combinatorial aptitude of the lines.

It is considered that ACG is associated with effects of additivity (average effects of genes), while ACE is associated with the effects of dominance and epistasis (average deviations) (Ceballos, 1995; Poehlman and Allen, 2003; Hallauer *et al*., 2010). The objective of this research was to determine the type of gene action involved and the influence of maternal and reciprocal effects on the yield and agronomic characteristics of direct and reciprocal diallel crosses, of five varieties of yellow maize and their respective crosses evaluated in three localities in the High Valleys of central Mexico.

Materials and methods

Geographical location

The experiments were established in the spring-summer cycle from 2017 to 2019 in three localities. The first, located in the municipality of Cuautitlán Izcalli, State of Mexico, the second in Santa Lucía de Prías, Coatlinchán, Municipality of Texcoco, State of Mexico, where the Experimental Field Valle de Mexico of the National Institute of Forestry, Agricultural and Livestock Research (CEVAMEX-INIFAP) is located, and the third in the locality of Huexotla, Texcoco, State of Mexico (Table 1).

Table 1. Evaluation of five varieties of yellow maize and their diallel crosses. Spring summer from 2017 to 2019.

Localities	Geographical location	Altitude (m)	Soil (texture)
FESC-UNAM	19° 41’ NL, 99° 11’ WL	2 274	Clay loam
Santa Lucía de Prías	19° 27’ NL, 98° 51’ WL	2 326	Sandy loam
Huexotla	19° 29’ NL, 98° 52’ WL	2 300	Silt loam

In Figure 1, the behavior of precipitation can be observed, while in Figure 2, the behavior of average temperatures in the three assessment localities in the period from May to December from 2017 to 2019 can be seen.

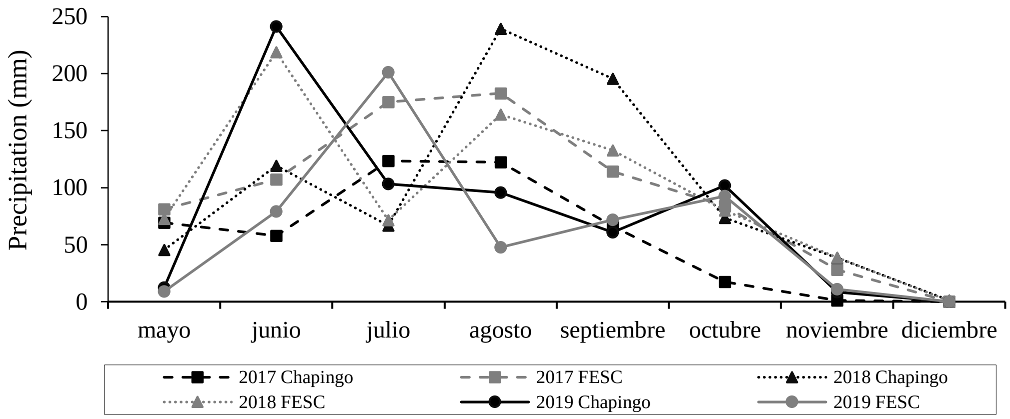

Figure 1. Precipitation (mm) of the evaluation environments. Elaboration with data from the meteorological station of the Chapingo Autonomous University, and from the Almaraz meteorological station located in the Cuautitlán Faculty of Higher Studies, Field 4.

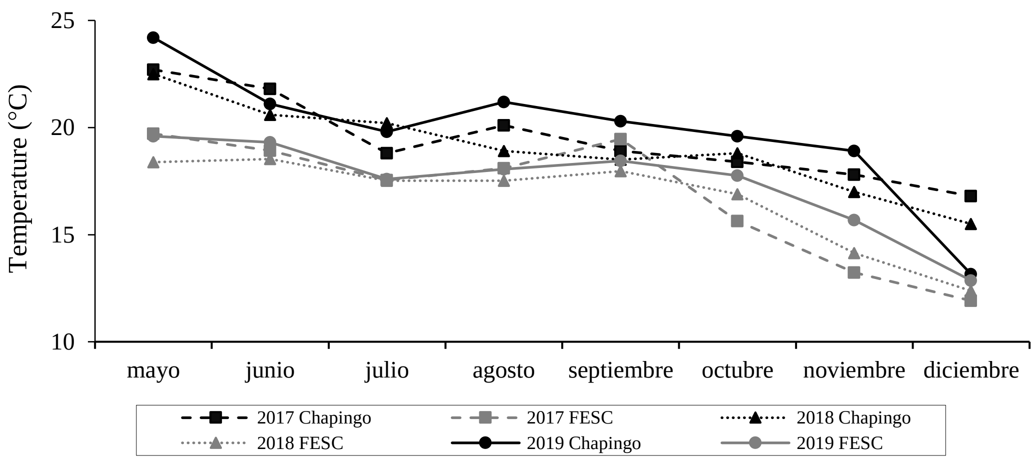

Figure 2. Average temperature (ºC) of the evaluation environments. Elaboration with data from the meteorological station of the Chapingo Autonomous University, and from the Almaraz meteorological station located in the Cuautitlán Faculty of Higher Studies, Field 4.

In the evaluations carried out in FESC-UNAM, in June the land at the time of sowing presented residual humidity in the years of evaluation. Only a germination irrigation was applied after sowing, and the subsequent water requirement of the crop was covered by the rainfall that occurred during the crop cycle. In the case of Santa Lucía, in 2017 there was an irrigation after sowing and two auxiliary irrigations prior to flowering.

In 2018, in Huexotla there was moisture in the soil at the time of sowing and three auxiliary irrigations were applied, one before flowering and two after it. For 2019, in Santa Lucía also the soil had moisture at the time of sowing, and one irrigation was applied during flowering and two more after this stage; in this year there was hail after the physiological maturity of the crop. It should be clarified that the inconsistency in the irrigation in the environments of Texcoco was due to the low availability of water and failures in the pumps of the Experimental Field. In all environments, the harvest was manual and this was carried out in December in the respective years of evaluation.

Genetic material

During the spring summer cycle of 2016, the direct, reciprocal and diallel crosses of the five varieties of yellow grain maize (Table 2) were made, four of these are of germplasm from High Valleys (HVAA-10, HVAA-9, E5-6F2 and IA351), obtained with the application of three cycles of stratified mass selection.

Table 2. Genealogy of varietal crosses.

Variety	Female progenitor	Male progenitor	Varietal cross
1	HVAA-10	HVAA-10	1 x 1
		HVAA-9	1 x 7
		E5-6F2	1 x 17
		IA324	1 x 18
		IA351	1 x 19
7	HVAA-9	HVAA-10	7 x 1
		HVAA-9	7 x 7
		E5-6F2	7 x 17
		IA324	7 x 18
		IA351	7 x 19
17	E5-6F2	HVAA-10	17 x 1
		HVAA-9	17 x 7
		E5-6F2	17 x 17
		IA324	17 x 18
		IA351	17 x 19
18	IA324	HVAA-10	18 x 1
		HVAA-9	18 x 7
		E5-6F2	18 x 17
		IA324	18 x 18
		IA351	18 x 19
19	IA351	HVAA-10	19 x 1
		HVAA-9	19 x 7
		E5-6F2	19 x 17
		IA324	19 x 18
		IA351	19 x 19

The variety IA324 comes from germplasm from High Valleys-Transition to which three cycles of stratified mass selection were applied. With these genotypes, 20 F_1 crosses were generated; in addition, seed was obtained from the progenitors by means of fraternal crosses. The 25 genotypes were evaluated in six experiments sown in June in the years from 2017 to 2019.

Each sowing date was considered as a different evaluation environment. In the six environments, genotypes were distributed in a randomized complete block experimental design with three repetitions. A population density of 65 000 plants ha^{-1} was used, where the experimental plot consisted of furrows 5 m long by 0.8 m wide.

During the growth cycle and at the date of harvest, information on 20 quantitative characters associated with morphological characteristics and yield components was obtained, estimated with the average value of five representative cobs of each experimental unit. With the data obtained, a statistical analysis was performed to identify the variables with the highest positive correlation with grain yield and perform the discrimination of variables, being defined that the components that most correlated with yield were male flowering (FM; days), plant height (AP; cm), cob length (Lmz).

With these variables, the genetic analysis was carried out, which was performed with model I (fixed effects), method I (complete diallel) of Griffing (1956), which examines parental lines, direct and reciprocal F_1 crosses, for which the DIALLEL-SAS program proposed by Zhang and Kang (2003) was used, which allows the division of reciprocal effects (ER), maternal and non-maternal.

The relative importance of ACG and ACE was evaluated with the formula [2 x CM_{ACG}]/ [2 x CM_{ACG} + CM_{ACE}] (Baker, 1978), where CM_{ACG} is the mean square of ACG and CM_{ACE} is the mean square of ACE.

Results and discussion

Analysis of variance

In the mean squares of the combined analysis of variance (Table 3), highly significant differences ($p\leq$ 0.01) between environments, crosses, general combinatorial aptitude (ACG), specific combinatorial aptitude (ACE), as well as in the environment interaction by crosses were detected. The statistical differences between crosses are attributed to the different expression of the genetic variation between them, associated with the types of gene action that was expressed in each one, such as additivity and dominance, as well as the result of the additivity and interaction of the progenitor varieties.

The differences in the expression between environments indicate a changing environmental situation between years and localities and indicates adaptability of the crosses to the differences between climatic, soil and cultivation conditions. These contrasts were manifested in the significant environmental interaction by crosses, which Hallauer *et al*. (2010) attribute it to the narrow variation of simple crosses compared to those of more than two progenitors or varietal progenitors.

Given the significant differences between the crosses, the sum of squares was partitioned in ACG and the maternal effects of the progenitors, and in ACE and the reciprocal effects of crosses. ACG and ACE showed highly significant differences ($p\leq$ 0.01) for the variables evaluated, indicating genetic contrasts due to additive and non-additive effects, respectively.

Baker (1978) suggested a relationship between ACG and ACE (ACG:ACE) to infer the importance of these on the behavior of the progeny. Values close to the unit indicate a higher probability of behavior based solely on ACG.

For this research, the contribution of the mean squares of ACG to the variation was higher than that presented by ACE for all variables, except for plant height and cob length. For the rest of the variables, the contribution of ACG was 80% (yield), 79% (male flowering) and 91% (volumetric weight) (Table 3).

Table 3. Mean squares of the combined analysis of variance for yield and other agronomic variables in a complete diallel cross system.

Factor of variation	GL	Yield	FM	AP	PV	LMz
Environment	5	599 365 446**	361.9**	40962.4**	315**	79**
Crosses	24	17 561 889**	22.2**	572.7**	62**	6.2**
ACG	4	38599842**	30.2**	648**	212**	5**
ACE	10	19 789 076**	15.6**	696**	44**	9**
Emat	4	13 881 918**	58.7**	607**	30**	6.9**
Erec	10	6 919 520**	25.7**	419**	19.4**	4**
Amb x cruzas	120	3 717 342**	4**	337.9**	15.5**	2.1**
Amb x ACG	4	3 603 456**	5.8*	1813**	34.7**	0.97
Amb x ACE	10	3 516 460**	5.5**	535**	19.8**	0.32
Error	288	269 472	1.3	78.2	1.58	1.04
CV (%)		8.3	1.5	4.09	1.67	6.9
Mean		6219	76	215.7	75.5	15
ACG:ACE		0.8	0.79	0.65	0.91	0.53

**, *= $p\leq$ 0.01 and $p\leq$ 0.05, respectively; GL= degrees of freedom; peso vol= volumetric weight; ACG= general combinatorial aptitude; ACE= specific combinatorial aptitude; EMat= maternal effects; ERec= reciprocal effects; Amb= environment; FM= male flowering; AP= plant height; PV= volumetric weight; LMz= cob length; CV= coefficient of variation.

The relative proportion of the effects of ACG and ACE determined by the respective mean squares indicates the type of gene action (Antuna *et al*., 2003), where ACG is mainly associated with additive effects and ACE with non-additive effects, therefore, with the results it can be inferred that the additive genetic variance was superior to the non-additive. Overall, the analysis of mean squares shows that additive genetic effects (ACG) were of greater expression for grain yield, male flowering, volumetric weight and number of rows per cob.

Maternal effects (EMat) were highly significant ($p\leq$ 0.01); that is, the characteristics assessed (yield, male flowering, plant height, volumetric weight and cob length) were statistically determined by nuclear and cytoplasmic effects, meaning that crosses can be made and used in both directions (direct and reciprocal). Reciprocal effects (ERec) showed highly significant differences ($p\leq$ 0.01), which is attributed to the interaction affects between nuclear and cytoplasmic DNA (Sánchez-Hernández *et al*., 2011), which were referred to by Cockerham (1963) as non-maternal effects.

The significant interaction Amb x crosses conditioned the division of the interaction effects of Amb x ACG and Amb x ACE, which were also statistically significant ($p \leq 0.01$), except for male flowering and cob length.

Phenotypic expression and effect of ACG of varieties

Highly significant differences ($p \leq 0.01$) were found for each variable (Table 4), but not in all the progenitors evaluated. For yield, the variety four (IA324; 7 163 kg ha^{-1}) was the one that expressed the highest value for this variable, followed by the varieties HVAA-10 (6 533.9 kg ha^{-1}), E5-6F2 (5 673 kg ha^{-1}), IA351 (5 735 kg ha^{-1}) and HVAA-9 (3 761 kg ha^{-1}).

These results indicate that the variety four (IA324) will have a high contribution in the expression of the yield of its progeny and that the additive effects are the most important, therefore, it could be included in a maize genetic improvement program by selection, to contribute with favorable alleles for this variable (Guillén-de la Cruz *et al*., 2009).

All progenitors presented desirable values for the various variables evaluated, with special emphasis on male flowering (-0.614) for IA351 (74 days to FM), plant height (1.74) for IA324 (216 cm), volumetric weight for the progenitor HVAA-9 (70 kg hl^{-1}), cob length (-2.26) for E5-6F2 (15 cm) (Table 4).

Table 4 Effect of general combinatorial aptitude (ACG) for grain yield and other agronomic variables of five yellow grain varieties evaluated in six environments. Spring-summer 2017-2019.

Variety	Yield	FM	AP	PV	LMz
HVAA-10	-42.5	-0.131	1.66*	-0.75**	0.056
HVAA-9	-383.6**	0.474**	-0.99	-1.39**	0.1
E5-6F2	-119.2*	0.219*	0.31	0.063	-2.26**
IA324	795.11**	0.052	1.74*	1.21**	0.15*
IA351	-249.8**	-0.614	-2.73**	0.86**	-0.049

**, *= $p \leq 0.01$ and $p \leq 0.05$, respectively; FM= male flowering; AP= plant height; PV= volumetric weight; LMz= cob length.

For the maternal effects of the progenitors, it is observed that the higher (positive) values for yield and its components indicate that the progenitors can express their potential in the variables evaluated in the case of their direct crosses (Table 5); that is, when they are used exclusively as a female progenitor.

In the cases of the progenitors HVAA-10 and IA351 presented negative values for yield, so it is expected that their direct crosses behave unfavorably. These progenitors when used as a female, their progeny will show detriment in this characteristic, but with high values in the other variables as mentioned by Núñez-Terrones *et al*. (2019).

Table 5. Maternal effects of five yellow grain maize varieties evaluated in six environments. Spring-summer 2017-2019.

Variety	Yield	FM	AP	PV	LMz
HVAA-10	-222.2**	0.23*	2.89**	-0.04	0.32**
HVAA-9	-150*	0.59**	-3.4	0.19	-0.13
E5-6F2	601.6**	0.22*	-0.2	-0.68**	0.19*
IA324	-10	0.18*	1	-0.17	-0.26**
IA351	-219.4**	-1.24**	-0.28	0.7**	-0.13

**, *= $p \leq 0.01$ and $p \leq 0.05$, respectively; FM= male flowering; AP= plant height; PV= volumetric weight; LMz= cob length; HMz= rows per cob.

Phenotypic expression and effect of ACE of varietal hybrids

The effect of the ACE for the yield components was variable for most of the crosses (Table 6), nine of the direct crosses were highly significant ($p \leq 0.01$), their yield was from 4 759 to 7 490 kg ha^{-1}. The direct crosses with the highest ACE for the yield variable were 1 x 18 (7 490 kg ha^{-1}) and 7 x 18 (7 272 kg ha^{-1}) (HVAA-10 x IA324 and HVAA-9 x IA324).

Table 6. Specific Combinatorial Aptitude (ACE) effect of 10 direct crosses and 10 reciprocal crosses, in the crossing of five varieties of yellow grain maize, for grain yield and yield components, evaluated in six environments. Spring-summer 2017-2019.

Type of cross	HVE	Yield		Male flowering		Plant height	
		ACE	kg ha^{-1}	ACE	days	ACE	Cm
CD	1 x 7	-774.9**	4 759	-0.47	76	-1.73	216
CR	7 x 1	-259.6*	5 278	0.19	76	1.61	213
CD	1 x 17	-288.5**	5 061	-0.047	76	-0.68	221
CR	17 x 1	-708.1**	6 477	-0.3	77	4.25*	213
CD	1 x 18	378.82**	7 490	0.34*	76	-0.73	224
CR	18 x 1	138.8	7 212	-0.028	77	5.3**	213
CD	7 x 17	725.08**	6 112	-1.09	76	3.5*	215
CR	17 x 7	-330.1*	6 772	0.639*	75	-3.38*	222
CD	7 x 18	1075.29**	7 272	-0.09	77	5.26**	216
CR	18 x 7	-434.2**	8 140	0.36	76	-6.08**	228
CD	17 x 18	150	7 430	-0.28	76	-1.98	216
CR	18 x 17	519.88**	6 390	-0.08	76	0.3	215
CD	1 x 19	285.22**	6 152	0.29	77	3.2	218
CR	19 x 1	-60	6 272	1.028**	75	0.41	217
CD	7 x 19	665.44**	6 156	-0.013	78	5.3**	215
CR	19 x 7	-95.2	6 347	1.61**	74	-2.52	220
CD	17 x 19	-143.5*	6 555	0.19	77	-2.69*	210
CR	19 x 17	848.3**	4 859	1.33**	75	-0.27	211
CD	18 x 19	-822.7**	6 126	0.29	77	0.17	218
CR	19 x 18	184.5*	5 758	1**	75	3.52*	211

**, *: $p \leq 0.01$ and $p \leq 0.05$, respectively; HVE= experimental varietal hybrid; CD= direct cross; CR= reciprocal cross; FM= male flowering; AP= plant height; PV= volumetric weight; LMz= cob length; ACE= specific combinatorial aptitude.

In the first case, the cross with higher ACE and yield was the result of crossing two progenitors of high ACG, the second outstanding cross was the result of crossing a progenitor of low with one of high ACG, which responds to what was pointed out by Escorcia *et al*. (2010) and Guerrero *et al*. (2011), who point out that a simple cross is of high yield when its progenitors are of high ACG or at least one of them is, but have high positive ACE effects.

The 7 x 18 cross was also outstanding for its ACE in the variables of plant height (Table 6) and volumetric weight Table 7, these variables presented highly significant differences ($p \leq 0.01$). On the other hand, four reciprocal crosses presented highly significant differences and three were significant ($p \leq 0.01$ and $p \leq 0.05$), with yields from 4 859 to 8 140 kg ha^{-1}. The reciprocal cross with the highest ACE for the yield variable was 18 x 7 (IA324 x HVAA-9). The direct cross 17 x 18 (E5-6F2 x IA324) and the reciprocal cross 18 x 1 (IA324 x HVAA-10) although they did not present highly significant differences, their yield was among the highest (7 490, 7 430 and 7 212 kg ha^{-1}, respectively), these crosses are the result of the crossing between two progenitors of high ACG.

Table 7. Effect of specific combinatorial aptitude (ACE) of 10 direct crosses and 10 reciprocal crosses, in the crossing of five varieties of yellow grain maize, for yield components, evaluated in six environments. Spring-Summer 2017-2019.

Type of cross	HVE	Volumetric weight		Cob length	
		ACE	(kg hl^{-1})	ACE	Cm
CD	1 x 7	-0.24	73	0.22	15
CR	7 x 1	-0.19	73	0.14	15
CD	1 x 17	-0.83**	75	-0.71**	14
CR	17 x 1	1.28**	73	0.055	14
CD	1 x 18	-0.12	75	-0.11	15
CR	18 x 1	-0.8**	77	0.47**	15
CD	7 x 17	0.77**	75	0.32*	15
CR	17 x 7	0.47*	74	-0.19	15
CD	7 x 18	1.4**	77	0.43*	16
CR	18 x 7	0.25	76	0.22	15
CD	17 x 18	0.64**	77	0.15	15
CR	18 x 17	-0.11	78	0.25	15
CD	1 x 19	0.13	75	0.31*	16
CR	19 x 1	-0.44*	76	0.64**	15
CD	7 x 19	0.98**	76	0.44**	15
CR	19 x 7	-0.14	76	-0.42*	16
CD	17 x 19	0.16	76	-0.14	15
CR	19 x 17	-0.88**	77	0.36*	14
CD	18 x 19	-1.37**	75	-0.12	15
CR	19 x 18	-1.22**	78	-0.08	15

Statistical significance **, *: $p \leq 0.01$ and $p \leq 0.05$, respectively; CD= direct cross; CR= reciprocal cross; PV= volumetric weight; LMz= cob length; HMz= rows per cob; ACE= specific combinatorial aptitude.

For days to male flowering for crosses that presented highly significant differences ($p \leq 0.01$), the additive effect was the one that prevailed in their progeny when the progenitor IA351 was used as a female; which *per se* was the most precocious yellow grain variety among the progenitors evaluated (74 days to male flowering) and this was reflected in its direct crosses (74 to 75 days to FM), when this variety is used as a male, that is, if reciprocal crosses are made, flowering is delayed by three to four days (77 to 78 days at FM).

For the volumetric weight variable, the presence of progenitor V2 (HVAA-9-) reduces the grain density of its progeny (73 to 75 kg hl^{-1}, values below the general average), although the ACE of two of its direct crosses is highly significant (0.77 and 0.98), with the exception of the direct cross 7 x 18, where the density of the progenitor IA324 (77 kg hl^{-1}) that serves as a male progenitor is maintained, but the opposite occurs, that is, the density decreases when IA324 is used as a female (76 kg hl^{-1}), although it remains at the value of the general average (Table 7).

Reciprocal effects (ERec) are a relevant factor in the genetic improvement of maize, where the expression of these effects given by the genetic diversity of the progenitors must be taken into account (Khehra and Bhalla, 1976).

Conclusions

In varietal hybrids, the effects of general combinatorial aptitude (additive effects) were more important than those of specific combinatorial aptitude in most agronomic characters. There was presence of maternal and reciprocal effects, therefore, the characteristics evaluated were determined by nuclear and cytoplasmic inheritance, which allowed the development and use of the direct and reciprocal cross 7 x 18 and 18 x 7, as well as 1 x 18 and 18 x 1. The direct cross with the highest ACE for the yield variable was HVAA-10 x IA324. The second direct cross HVAA-9 x IA324 was outstanding for its ACE for yield, plant height and volumetric weight. The reciprocal cross with the highest ACE for yield was 18 x 7 (IA324 x HVAA-9).

The use of progenitors of contrasting ACG (high and low) allowed the expression of their progeny with favorable agronomic characteristics. Yellow grain varieties with high ACG effects can be used to develop synthetic varieties or continue advancing more improvement cycles, taking into account that the lines with high ACG observed in early tests retain their additive values in advanced generations, while the crosses with high ACE can be used for hybridization.

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