Combining abilities in green corn genotypes for yield and industrial quality traits

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Abstract
The general and specific combining abilities and the reciprocal effects of seven hybrids and two open pollination varieties of green corn were evaluated, aiming the formation of base populations to be used as a source of superior inbred lines. For the purpose of this study, two experiments were carried out in Maringá/PR and Sabáudia/PR, during the crop season of 2014/15. The experiments were evaluated in incomplete block design alpha lattice, with three replications. The parents AM811, HTMV1, Cativerde 02 and AL Piratininga were selected based on their $\hat{g}_i$ and the following hybrid combinations AM811 x CD316, AM811 x AG1051, AM811 x HTMV1, AM606 x Cativerde 02 and Al Piratininga x AG4051 presented the most desirable $\hat{s}_{ij}$ effects. Regarding the reciprocal effects, the genotype AM811 is recommended to be used as male parent in further hybrid combinations

KeyWords *Alpha lattic; diallel analysis; reciprocal effect.*

Introduction

Green corn is obtained by harvesting the ears early, and the kernels are used as canned and dehydrated industrial products or in the preparation of traditional cooking recipes (Rodrigues et al., 2009). To be suitable for both the canning industry and the *in natura* consumption market, a genotype must have an unhusked ear yield greater than 12 t ha-1, a production cycle between 90 and 110 days, a commercial ear length greater than 15 cm and a diameter larger than 3 cm (Pereira Filho, 2003; Albuquerque et al., 2008). Thus, dent corn genotypes with a light yellow to cream color, no caterpillar damage, a good husk covering and straight rows are preferred (Cancellier et al., 2011).

The lack of genotypes in the market that aggregate both agronomic and quality traits results in lower-quality products that fail to meet the expected requirements of the consumer market. To illustrate this situation, only 17 of the 477 maize cultivars available to producers in Brazil present desirable traits for use as green corn (Cruz et al., 2015); therefore, the generation of new genotypes, especially for small farmers, is imperative for the growth of this market.

The correct choice of germplasm to form base populations is an essential step in any breeding program, since the quality of the inbreds extracted to generate new hybrids will be directly related to the presence of certain alleles and their frequencies in these populations (Hallauer et al., 2010). Among the diversity of available genotypes, breeding programs have chosen commercial maize hybrids to form their base populations, primarily because they present a wide range of adaptation and a higher frequency of favorable alleles for desirable traits (Oliboni et al., 2013; Senhorinho et al., 2015).

Diallel analysis is one of the most-used tools for obtaining genetic information in any breeding program. This controlled mating system enables the estimation of the general combining ability (GCA) and the specific combining ability (SCA), which are associated with the additive and non-additive genetic effects, respectively, as well as the reciprocal effect (RE), which enables the extrachromosomal and maternal effects to be estimated (Cruz et al., 2012). According to the genetic basis of the parents involved in the crossings, the results of the diallel analysis allow the base populations to be selected and formed to extract superior inbred lines and, consequently, form new genotypes.

Several authors have reported the use of diallel analysis of commercial genotypes to improve grain yield (Pfann et al., 2009; Oliboni et al., 2013; Senhorinho et al., 2015), but there is a shortage of studies regarding the GCA, SCA and RE effects for traits related to green corn in commercial maize hybrids. Therefore, the objective of the present study was to evaluate the GCA and SCA, as well as the RE of nine commercial field corn genotypes in relation to the yield and quality of green corn, with the aim of forming base populations to extract superior inbred lines.

Materials and Methods

Nine commercial genotypes from different companies were used as parents in a complete diallel design with reciprocal effects (Table 1). The F_1 hybrids and reciprocals were obtained in the second season of 2014. The experiments were performed during the 2014/15 main crop season at Fazenda Experimental de Iguatemi (lat 23° 25′ S; long 51° 57′ W and alt 550 m asl) in Maringá/PR and at Unidade Experimental Sementes Balu (lat 23° 19′ S; long 51° 33′ W and alt 725 m asl) in Sabáudia/PR.

Table 1. Description of the genotypes evaluated in this study

Genotypes	Genetic base	Cycle	Company	Kernel type	Grain colour	Aptitude
AG 1051	DH[1]	SME5	Agroeste	Dent	Yellow	F[9]/S[10]/GC[12]
AG 4051	TH[2]	SME	Agroeste	Dent	YC[7]	F/S/GC
AL Piratininga	OPV[3]	SME	CATI	Semi-dent	YO[8]	F/S/GC
Cativerde 02	OPV	SME	CATI	Dent	Yellow	S/GC
CD 316	SH[4]	SE[6]	Coodetec	Semi-flint	Yellow	F
CD 393	SH	SE	Coodetec	Flint	Orange	F
AM 606	SH	SE	M.A.[12]	Semi-flint	Orange	F/S/GC
AM 811	SH	SE	M.A.	Semi-dent	Orange	F/S/GC
HTMV1	TH	SME	Embrapa	Semi-dent	Yellow	F/S/GC

[1] DH: Double-cross hybrid; [2] TH: triple-way hybrid; [3] OPV: open pollinated variety; [4]SH: Single hybrid; [5]SME: Semi-early; [6] SE: Super-early; [7] YC: Yellow cream kernel; [8] YO: Yellow orange kernel; [9] F: used as field corn; [10] S: used as silage; [11] GC: used as green corn; [12] Melhoramento Agropastoril.

The experiments were performed in an alpha lattice incomplete block design with three replications, in which eight plots were assigned to each of seven blocks, and nine plots were assigned to two blocks in each replication. Thirty-six hybrids were evaluated alongside their 36 reciprocals and two controls, a three-way dent hybrid from EMBRAPA and a single-cross flint maize from Sementes Balu, for a total of 74 treatments. Each plot consisted of two 5-m rows spaced 0.90 m apart, resulting in a usable area of 9 m². Each plot was thinned at 30 days to a density of 5 plants m^{-1}, resulting in a population of approximately 55,500 plants ha^{-1} at harvest time.

Yield and quality analyses

Green corn harvesting and the evaluation of quality characteristics began at the R3 stage (kernel milk) when the moisture content was between 70 and 80%. The following traits were evaluated in both environments (E): average plant height (PH, cm), average main ear height (EH, cm), and yield of unhusked ears (YU, kg ha^{-1}). The following traits were only evaluated in Maringá/PR: yield of commercial ears (YC, kg ha^{-1}), average length (LG, cm) and diameter (DM, mm) of ten commercial ears, fresh grain mass (GM, g) of five ears and corrected to a 75% moisture content, pericarp texture (PT, in N), and the grain color (GC) of five commercial ears, according to the scale proposed by Albuquerque et al. (2008).

To evaluate PT, 200 g of fresh grains from each plot were canned similarly to the process used by the canning industry. The texture analysis was performed using a model TA.TX Plus texturometer (Stable Micro System, Surrey, England) with a HDP/WBR probe. Five grains of uniform size were used for each test, and the test was replicated five times in each plot. For the analysis, it was considered the average of the peak force necessary to break the grains in the five tests.

Statistical analysis

Analysis of variance was performed for each environment, and the effects were considered significant when p<0.05. Adjusted treatments and environments were considered as fixed effects, and the degrees of freedom of the adjusted treatments were partitioned into hybrid combinations (F_1), reciprocals (RC), checks (C) and the interactions F_1 vs RC and (F_1+RC) vs C. For all traits evaluated in both environments, a joint analysis of variance was performed, in which the degrees of freedom of the adjusted treatment vs environment interaction were partitioned into F_1 vs E, RC vs E, Checks vs E, (F_1 vs RC) vs E and [(F_1+RC) vs C] vs E.

Considering only the diallel analysis from Maringá, the sums of squares of the adjusted treatments were partitioned into GCA, SCA and RE according to Griffing's (1956) diallel analysis method 3, which considers only hybrid combinations and their reciprocals. For the traits evaluated in both environments, the sums of squares of the Adjusted Treatments x E were partitioned into GCA vs E, SCA vs E and RE vs E. All analysis was performed using the software's SAS 9.4 (2013) and Genes (Cruz, 2013).

Results and discussion

The least square means of the treatments resulted significantly different (p<0.05) for PH, EH and YU (Table 2). Hybrids and their reciprocal combinations differed from each other, an indication of genetic variation between the genotypes obtained from parental crosses. The F_1 x RE contrast was not considered significant in this study (p>0.05); therefore, it is possible to conclude that the order of the parents in the crossings does not influence the traits. Based on the significant effects of the D x C contrast, the means of the checks were higher than those of the hybrid combinations for PH and YU but lower for EH.

Table 2. Joint analysis of variance and joint diallel analysis for plant height (PH), ear height (EH) and yield of unhusked ears (YU)

		Joint analysis of variance		
		MS		
SV	DF	PH	EH	YU
Rep/Environment	4	431.13	626.75	8619120
Bl/Rep/E	48	315.06	293.83	7909715
Environment (E)	1	22305227.54*	7590016.83*	119051494094*
Treatm. (Adj.)	73	306178.31*	306178.31*	1644597151.13*
Diallel (D)	71	761.47*	761.47*	13894543.23*
F_1	35	736.02*	736.02*	14333747.52*
Reciprocal Effect (RE)	35	794.35*	794.35*	13129229.86*
F_1 *vs RE*	1	501.55	501.55	25308360.75
Checks (C)	1	525.10*	525.10	2454360.75
D vs C	1	22296426.73*	22296426.73*	119066625102*
Treatm. (Adj.) x E	**73**	**252.59***	**252.59**	**3929993**
Diallel x E	71	134.85*	134.85	3953415
F_1 *x E*	35	80.30	80.30	3410057
RE x E	35	192.89*	192.89*	4591394
(F_1 *vs RE) x E*	1	12.69	12.69	641718
Checks x E	1	326.25	326.25	1590251
(D vs C) x E	1	8538.91*	8538.91	4606765
Effective mean error	**244**	**86.60**	**94.51**	**3496486**
VC (%)	-	4.15	7.44	11.42
Diallel mean	-	218.04	130.84	15.899
Check mean	-	223.88	127.57	17.595
Lattice Efficience (%)	-	143.37	134.67	120.74
		Joint diallel analysis		
		MS		
SV	**DF**	**PH**	**EH**	**YU**
Diallel	71	761.47*	558.01*	13.894.543.22*
GCA	8	4.936.71*	3.215.25*	42.797.287.55*
SCA	27	313.20*	307.63*	16.049.531.54*
RE	36	169.85	155.29	5.855.469.92
Environment	1	8.391.52*	12.77*	4.116.065.33*
Diallel x E	**71**	**134.85***	**125.71**^{ns}	**3.953.415.94**^{ns}
GCA x E	8	197.51*	140.77^{ns}	3.729.908.82^{ns}
SCA x E	27	98.56^{ns}	144.12^{ns}	39.859.063.08^{ns}
RE x E	36	148.13*	108.56^{ns}	3.978.716.58^{ns}
Error	**244**	**86.60**	**94.51**	**34.96.486.00**

The interaction between treatments and environments (Table 2) was significant only for PH, reflecting the differential performance of the genotypes in both environments and indicating that selection for this trait must be separate for each environment. Considering plant and ear height, Pfann et al. (2009) found non-significant interactions between 49 genotypes and two environments. In contrast, Senhorinho et al. (2015) showed significant effects between genotypes and environments for grain yield, plant and ear height using a partial diallel analysis of 22 commercial maize hybrids evaluated in two distinct seasons.

The analysis of variance for traits related to yield and quality of commercial ears (Table 3) indicated significant effects (p<0.05) for F_1 and RE, although, when considering the reciprocal effect, the difference was only significant in YC (p<0.05), indicating that the order of the parents used in the crosses significantly affects this trait. The checks evaluated in this study differed from each other in PT, demonstrating the influence of grain type over pericarp texture. Considering the comparison of the checks to the hybrid combinations in this study, YC, LG, DM and PT exhibited significant differences (p<0.05), with the overall means indicating superiority of the checks over the hybrid combinations.

Table 3. Individual analysis of variance and diallel analysis considering only the Maringá/PR environment, for the following traits: yield of commercial ears (YC); length of commercial ears (LG); diameter of commercial ears (DM); fresh grain mass (GM); grain colour (GC) and pericarp texture (PT)

		Analysis of variance					
		M.S.					
S.V.	D.F.	YC	LG	DM	GM	GC	PT
Replications	2	4095938	0.80	2.40	0.01	0.22	210.39
Bl/Rep (adj.)	24	4741070	0.60	2.57	0.07	0.38	188.22
Treatm. (Adj.)	73	3418754*	1.57*	7.62*	0.10*	0.60*	581.49*
Diallel (D)	71	3393769*	1.55*	7.67*	0.10*	0.61*	552.76*
F_1	35	2758396*	1.44*	6.91*	0.10*	0.73*	476.86*
RE	35	3918127*	1.70*	8.60*	0.10*	0.49*	638.68
F1vsRE	1	7279306*	0.18	1.75	0.13	0.06	201.96
Checks. (C)	1	38592	0.01	1.53	0.01	0.01	14295.14*
D vs C	1	8572874*	4.27*	9.80*	0.14	0.68	24950.76*
Effective error	122	1119901	0.70	2.13	0.04	0.19	229.56
VC (%)	-	16.04	4.33	3.09	16.03	15.32	21.12
Diallel mean	-	6.560	19.29	47.21	1.28	2.83	64.63
Check mean	-	7.772	20.15	48.51	1.44	2.49	76.49
Lattice ef. (%)	-	153.15	97.77	103.5	116.00	122.17	97.04
		Diallel analysis					
		M.S.					
S.V.	**D.F.**	**YC**	**LG**	**DM**	**GM**	**GC**	**PT**
Diallel	71	3393769*	1.55*	7.67*	0.10*	0.61*	552.76*
GCA	8	6106037*	5.75*	34.07*	0.55*	3.60*	1064.73*
SCA	27	4.886122*	1.25*	6.02*	0.04	0.26	492.98*
RE	36	1671778*	0.84	3.04	0.04	0.19	480.29*
Error	**122**	**1119901**	**7.00**	**2.13**	**0.04**	**0.18**	**229.55**

The joint diallel analysis (Table 2) indicated significant differences (p<0.05) in GCA and SCA, but RE did not display such an effect for any trait. The non-significant effect for RE was also reported by Mendes et al. (2015) using a diallel analysis of traits related to grain yield and forage quality of commercial hybrids.

PH trait was significantly influenced by the GCA x Environment and RE x Environment interactions, while the SCA x Environment interaction was not significant for all evaluated traits. These results indicate that apart from the order in which they are present in the crosses, the best parents should be selected for each environment only when considering PH.

Considering EH and YU traits, the mean squares of the GCA, SCA and RE interactions with the environments in which the experiments were performed, showed no significant effects, indicating that the parents can be selected based on these effects because the average environment only affects the GCA and SCA.

The experimental coefficients of variation in both the individual and joint analysis were considered low to medium magnitude, when compared to other reported studies for green corn (Albuquerque et al., 2008; Rodrigues et al., 2009; Cancellier et al., 2011), as well when considering the ones proposed by Fritsche-Neto et al. (2012) for maize, indicating an excellent experimental precision. The adoption of the alpha lattice as the experimental design for this study was satisfactory since the lattice efficiency coefficient was higher than 110% for all traits except LG and PT (Pimentel Gomes, 1990).

Considering the traits related to yield and quality of commercial ears (Table 3), there was significant differences ($p<0.05$) in the effects related to GCA. These results allow the inference that the genetic contributions in these traits differed according with each parent. Conversely, the SCA effects were only significant for YC, DG, DM and PT, a direct result of the differential performance of the hybrid combinations evaluated for these traits compared to what expected from the GCA of their parents, an indication of the contribution of non-additive effects of genes over these traits. The reciprocal effect differed significantly for YC and PT, evidence that these traits exert extranuclear gene effects; it is possible to take advantage of these effects by choosing the appropriate female genotype for future crossings.

Breeding programs for green corn seek genotypes that combine high yield of unhusked ears and good quality traits, such as a grain color ranging from light yellow to cream, no damage from insects and disease, dent-type kernel with a tender pericarp (Albuquerque et al., 2008; Rodrigues et al., 2009; Cancellier et al., 2011). Therefore, the GCA estimation enables the best parents to be selected based on the additive genetic effects to form a composite with a higher frequency of favorable alleles, which increases the potential to extract inbred lines and consequently obtain high-performance hybrids.

Considering PH trait (Table 4), the parents AM606 and AM811 can be recommended for Sabáudia and Maringá, respectively, as base materials for intrapopulational breeding according to their negatives estimates of $\hat{g}_i$, in order to reduce this trait in future populations. For GY, the AM811 parent displayed the highest estimated $\hat{g}_i$, a direct reflection of a higher frequency of favorable alleles with additive effects, which has great importance for obtaining superior inbred lines useful for green corn breeding.

The parent AM811 stood out for its GCA effects (Table 4) on YC, while the parent HTMV1 displayed higher estimated $\hat{g}_i$, values for LG and DM; therefore, these parents could be used to increase both the length and diameter of marketable ears. The parents HTMV1, A1 Piratininga and AG4051 were selected for displaying high $\hat{g}_i$ estimations for GM. The color scale proposed by Albuquerque et al. (2008) ranges from 1 (cream color) to 5 (orange); therefore, since the in natura consumer market prefers light-colored kernels, it is necessary to select parents with negative GCA effects. As a result, the parents A1 Piratininga, Cativerde 02 and AG1051 should be selected to form base populations for light-colored kernels.

Regarding PT trait, the more promising genotypes should also be selected based on the lowest GCA estimations because according to Mamede et al. (2015), higher pericarp texture values are related to lower kernel moisture and softness.

It is important to select hybrid combinations that

Table 4. Estimations for all nine parents, regarding traits related to yield in Sabáudia, Maringá and average environment, and also for green corn quality in Maringá

Genotypes	PH[2]		EH[3]	YU[4]
	Sabáudia	Maringá	AE[1]	AE
AM606	-13.75	-8.868	-5.234	94.167
AM811	-4.845	-10.413	-7.976	1.729.952
HTMV1	-3.092	-5.248	-3.174	-235.798
AL PR.	8.871	5.572	6.353	-29.833
CAT 02	10.664	12.995	8.824	117.381
CD316	-5.975	-5.071	-4.579	-457.905
CD393	-1.161	-0.428	-3.322	4.06
AG1051	3.622	5.317	7.144	-765.44
AG4051	4.99	6.146	1.964	-456.583

Genotypes	YC[5]	LG[6]	DM[7]	GM[8]	GC[9]	PT[10]
AM606	-259.96	-0.365	-0.535	-0.200	0.481	-0.781
AM811	776.536	-0.752	0.603	-0.030	0.283	3.510
HTMV1	-68.214	0.551	1.175	0.132	-0.159	6.561
AL PR.	103.258	-0.065	0.360	0.119	-0.347	-2.378
CAT 02	285.332	0.146	0.020	0.015	-0.257	-4.837
CD316	-243.445	0.075	-0.816	-0.111	0.210	-4.961
CD393	-33.454	0.15	-1.783	-0.08	0.177	-6.374
AG1051	-578.792	0.095	0.469	0.052	-0.266	2.438
AG4051	18.737	0.163	0.506	0.102	-0.122	6.823
SD ($\hat{g}_i$)	153.953	0.121	0.212	0.03	0.063	2.204
SD ($\hat{g}_i$ - $\hat{g}_j$)	230.929	0.182	0.318	0.045	0.094	3.306

[1]AE: Average environment; [2]PH – Plant height (cm), [3]EH – Ear height (cm); [4]YU – Yield of unhusked ears (kg ha^{-1}); [5]YC – Yield of commercial ears (kg ha^{-1}); [6]LG – Length (cm); [7]DM – Diameter (mm), [8]GM – Grain mass (g), [9]GC – Grain color, [10]PT – Pericarp texture.

Table 5A Specific combining ability (SCA) and reciprocal effect (RE) estimations for traits related to yield in Maringá, Sabáudia, average environment and quality traits in Maringá

Genotype	SCA				RE			
	PH[2]		EH[3]	YU[4]	PH		EH	YU
	Sab	Mar	AE[1]	AE	Sab	Mar	AE	AE
AM606 x AM811	4.10	1.81	0.743	-121.786	6.31	4.76	4.37	455.50
AM606 x HTMV1	-6.71	1.09	-2.924	806.214	1.93	-0.53	1.34	223.75
AM606 x AL PR.	2.74	2.99	-3.486	-281.75	2.63	1.99	1.78	267.75
AM606 x CAT 02	-8.30	-6.73	-6.357	-333.714	2.56	1.04	3.77	449.00
AM606 x CD316	0.66	1.99	8.916	-701.679	0.72	0.38	-8.40	1258.25
AM606 x CD393	0.94	-3.03	-1.321	147.357	-0.48	1.89	1.22	662.25
AM606 x AG1051	12.14	3.53	6.046	336.107	0.13	-0.21	-1.50	-336.50
AM606 x AG4051	-5.18	-1.62	-1.617	149.25	2.53	-7.35	-2.83	-406.50
AM811 x HTMV1	4.73	4.31	3.886	1.057.679	-8.03	5.86	1.33	-60.00
AM811 x AL PR.	-0.64	0.57	1.286	-330.536	-7.49	-9.40	-3.78	66.75
AM811 x CAT 02	-1.99	-4.42	-3.965	-368.25	-0.21	-0.20	-1.60	239.25
AM811 x CD316	-3.74	-7.15	-4.915	-751.464	1.01	1.58	0.64	-948.75
AM811 x CD393	0.85	-0.10	0.176	-551.179	-0.52	-2.38	-1.18	709.00
AM811 x AG1051	-2.49	-6.45	0.962	1.073.571	5.86	10.91	2.27	-761.75
AM811 x AG4051	-0.81	11.42	1.107	-8.036	-1.08	0.40	3.77	-79.00
HTMV1 x AL PR.	-0.50	1.01	0.931	-416.286	-3.59	-4.51	-5.48	67.25
HTMV1 x CAT 02	4.69	-0.17	1.905	1.532.25	3.7	5.18	2.59	669.00
HTMV1 x CD316	-1.34	-5.25	-4.134	-2.457.964	10.1	6.81	5.51	-1995.50
HTMV1 x CD393	3.59	4.74	3.808	581.571	-1.22	-4.50	3.20	1232.00
HTMV1 xAG1051	-2.39	6.92	1.933	698.821	4.04	-6.11	-4.32	459.75
HTMV1 xAG4051	-2.46	-12.65	-5.405	-1.802.286	-8.91	-3.82	2.27	479.00
AL PR. x CAT 02	-0.95	-9.57	-2.714	-545.214	-0.54	3.17	-6.15	1029.00
AL PR. x CD316	-0.71	6.23	-0.987	2.334.071	5.86	2.23	2.56	-358.50
AL PR. x CD393	3.25	0.10	5.381	720.607	-2.01	7.79	7.83	737.50
AL PR. x AG1051	-3.78	-1.38	-2.272	-1.089.893	-4.73	-13.01	-5.31	888.50
AL PR. x AG4051	0.16	0.37	1.861	-391.00	6.03	12.65	-1.19	209.25
CAT 02 x CD316	4.47	3.61	2.197	-782.893	5.39	3.10	3.35	-26.25
CAT 02 x CD393	1.75	9.76	4.27	230.643	10.95	-7.05	0.45	-289.25
CAT 02 x AG1051	4.94	10.15	9.029	580.643	1.98	-0.38	-0.51	370.25
CAT 02 x AG4051	-4.62	-2.25	-4.366	-313.464	-1.25	6.11	3.40	569.50
CD316 x CD393	-2.64	0.25	-3.017	818.179	1.54	8.64	-0.83	1282.00
CD316 x AG1051	-3.07	-1.05	-3.15	459.929	-0.99	2.49	0.25	288.25
CD316 x AG4051	6.38	1.37	4.37	1.081.821	6.27	1.34	-1.01	8.00
CD393 x AG1051	-9.97	-13.72	-12.947	-2.645.036	-3.26	0.03	5.28	293.25
CD393 x AG4051	2.29	2.12	3.65	697.857	3.09	-0.37	3.38	1164.00
AG1051 xAG4051	4.63	2.01	0.399	585.857	3.22	4.09	1.38	-103.50

[1]AE: Average environment; [2]PH – Plant height (cm), [3]EH – Ear height (cm); [4]YU – Yield of unhusked ears (kg ha^{-1}); [5]YC – Yield of commercial ears (kg ha^{-1}); [6]LG – Length (cm); [7]DM + Diameter (mm), [8]GM – Grain mass (g), [9]GC – Grain color, [10]PT – Pericarp texture

display with favorable $\hat{s}_{ij}$ estimations that involve at least one parent with a favorable $\hat{g}_i$ effect for the trait. In this sense, the best hybrids should be those for which at least one of the parents was selected based on its $\hat{g}_i$ estimation, thereby presenting a higher frequency of favorable alleles than the average frequency of the parents involved in the crosses (Cruz et al., 2012).

Current maize breeding programs aim the formation of hybrids with reduced seedling-flowering period, associated with lower average plant and ear heights (PH and EH, respectively).Therefore, it is recommended to select hybrid combinations with lower $\hat{s}_{ij}$ for these traits to form base populations. Verifying the $\hat{g}_i$ effects for PH and EH, the parents AM606, AM811 and CD316 were selected, and the hybrid combinations of AM606 x CAT02, AM811 x CD316 and CD316 x AG1051 displayed lower-magnitude $\hat{s}_{ij}$ effects. As the reciprocal effect was positive, the order of the parents in the crosses should be maintained.

Table 5 (A and B) displays the specific combining ability and the reciprocal effect for the evaluated traits. Considering YU, the parent AM811 was selected for its GCA effects (Table 2). Thus, the hybrid combination with the highest $\hat{s}_{ij}$ effect was AM811 x AG1051. Lastly, there were no significant differences for the reciprocal effects and the interaction with the environments for this trait, which means that the order of the parents in the crosses does not affect the production of unhusked ears,

The genotype AM811 was also superior for the traits YC, LG and DM due to its additive effect (Table 3). The AM811 x HTMV1 hybrid combination was considered superior in terms of the effect of non-additive genes (Table 5). As the reciprocal effect was negative for YC and considered not significant for LG and DM, the genotype HTMV1 should be used as a female parent while the parent AM811 should be used as a pollen donator, thereby taking advantage of maternal or extranuclear inheritance for production of commercial ears without affecting the other traits.

Regarding the PT traits, five out of nine parents were selected based on their GCA, which included both dent and flint kernel types. However, there is a market preference for dent types; therefore, interpopulational crosses should predominantly be performed with *dent* types. The hybrid combinations AM606 x Cativerde 02, AL Piratininga x AG4051, Cativerde 02 x AG4051 and CD393 x AG1051 present the best $\hat{s}_{ij}$ estimations (Table 5). The reciprocal effect indicates that it is only necessary to switch the last cited combination such that parent AG1051 should be used as the female and parent CD393 as the pollen donator.

The traits GM and GC did not exhibit any signifi-

Table 5 B Specific combining ability (SCA) and reciprocal effect (RE) estimations for traits related to yield in Maringá, Sabáudia, average environment and quality traits in Maringá

Genotype	SCA						RE					
	YC[5]	GM[8]	LG[6]	DM[7]	GC[9]	PT[10]	YC[5]	GM[8]	LG[6]	DE[7]	GC[9]	PT[10]
AM606 x AM811	-160.64	-0.01	0.37	-0.17	-0.28	1.64	425.83	-0.02	-0.23	0.37	0.22	-11.11
AM606 x HTMV1	123.38	-0.05	-0.20	-1.14	0.30	-3.00	-192.42	0.05	-0.23	-1.14	0.25	23.30
AM606 x AL PR.	-228.87	0.05	0.04	1.47	-0.04	-5.81	180.80	-0.03	-0.13	1.45	0.29	1.15
AM606 x CAT 02	425.09	-0.05	0.07	-0.73	-0.23	-9.84	771.12	0.05	0.17	-0.24	-0.22	1.17
AM606 x CD316	-165.44	0.04	0.10	-0.77	-0.13	-5.65	484.56	-0.07	-0.12	-0.35	-0.01	-4.32
AM606 x CD393	-75.13	0.03	-0.35	0.66	0.06	2.55	270.80	-0.02	-0.07	-0.91	0.20	3.18
AM606 x AG1051	524.10	0.07	0.02	0.78	-0.10	16.25	-440.25	0.15	0.91	-0.05	0.03	10.98
AM606 x AG4051	-442.49	-0.08	-0.05	-0.09	0.41	3.86	204.19	-0.02	-0.18	0.29	-0.11	-2.66
AM811 x HTMV1	1672.84	0.06	-0.17	0.84	0.14	1.71	-438.75	0.11	0.62	0.59	-0.06	2.57
AM811 x AL PR.	-529.08	-0.18	-0.12	-0.46	-0.02	-4.85	101.00	0.03	-0.36	-0.46	-0.01	1.62
AM811 x CAT 02	-453.52	-0.07	0.02	-0.88	0.37	0.04	-570.82	0.10	-0.65	0.22	0.11	2.05
AM811 x CD316	-351.74	-0.05	-0.51	-1.08	0.04	-3.56	-261.34	-0.14	0.21	-0.49	-0.14	0.34
AM811 x CD393	-270.52	0.03	-0.12	0.50	-0.16	-6.08	1507.35	0.12	-0.36	0.26	-0.38	2.70
AM811 x AG1051	437.85	0.15	0.45	0.77	0.10	-5.26	-452.91	-0.08	0.19	0.33	0.05	-9.44
AM811 x AG4051	-345.19	0.06	0.07	0.47	-0.20	16.36	220.14	0.04	-0.06	0.04	-0.09	23.07
HTMV1 x AL PR.	-887.30	-0.05	-0.22	0.12	-0.21	9.54	353.18	-0.06	-0.07	-0.40	-0.10	-9.61
HTMV1 x CAT 02	1411.45	0.08	0.06	0.75	-0.22	6.02	864.12	-0.07	-0.16	0.26	-0.14	-1.92
HTMV1 x CD316	-1165.8	-0.05	0.06	0.47	0.05	10.25	-701.52	-0.01	0.15	-0.80	-0.27	-7.98
HTMV1 x CD393	310.28	0.08	0.79	0.31	-0.08	-0.02	-151.88	-0.04	-0.36	-0.26	-0.20	-4.55
HTMV1 x AG1051	167.4	-0.08	0.05	-0.67	0.13	-10.85	389.14	-0.10	0.22	0.40	-0.27	3.37
HTMV1 x AG4051	-1632	-0.01	-0.37	-0.67	-0.11	-13.66	134.33	0.04	-0.72	-0.83	-0.29	4.35
AL PR. x CAT 02	-695.84	-0.02	-0.31	-1.52	-0.08	-2.89	923.50	-0.09	-0.10	-0.81	-0.07	-0.63
AL PR. x CD316	1814.06	0.12	0.23	0.21	0.06	3.17	-408.96	0.04	-0.55	-0.72	0.06	2.55
AL PR. x CD393	-208.40	-0.01	0.59	0.09	0.33	3.31	146.61	0.01	0.41	0.71	-0.19	3.92
AL PR. x AG1051	-293.27	0.02	0.06	-0.30	0.22	5.78	904.80	0.19	0.41	0.75	-0.15	-2.40
AL PR. x AG4051	1028.71	0.06	-0.27	0.38	-0.26	-8.26	-238.44	0.17	-0.19	0.27	-0.15	17.54
CAT 02 x CD316	-672.28	-0.05	-0.34	-0.50	0.22	9.35	222.85	0.08	0.25	1.24	-0.01	-0.83
CAT 02 x CD393	-228.35	0.10	-0.08	1.76	-0.01	-1.04	462.79	0.04	-0.46	-0.54	0.10	1.60
CAT 02 x AG1051	471.80	-0.01	0.65	1.16	-0.15	2.96	-366.72	0.01	-0.16	-0.29	-0.03	-3.67
CAT 02 x AG4051	-258.35	0.02	-0.07	-0.04	0.10	-4.60	103.18	0.04	0.54	0.89	-0.14	14.86
CD316 x CD393	886.92	0.01	0.11	0.33	-0.20	-4.42	620.16	0.08	-0.33	0.24	0.11	-12.6
CD316 x AG1051	-339.36	-0.03	0.29	0.34	-0.05	2.43	540.92	0.06	0.50	-0.17	0.24	-15.7
CD316 x AG4051	-6.30	-0.01	0.06	1.00	0.02	-11.57	161.34	-0.12	-0.52	-0.20	0.33	7.60
CD393 x AG1051	-1519.5	-0.16	-1.54	-2.33	-0.07	-11.74	925.40	0.21	0.41	2.17	0.33	-6.81
CD393 x AG4051	1104.76	-0.09	0.60	-1.31	0.13	17.44	149.04	0.06	-0.26	0.90	0.02	-10.1
AG1051 x AG4051	551.04	0.04	0.03	0.26	-0.09	0.43	-234.34	0.12	0.18	0.53	0.07	4.32

[1]AE: Average environment; [2]PH – Plant height (cm), [3]EH – Ear height (cm); [4]YU – Yield of unhusked ears (kg ha-1); [5]YC – Yield of commercial ears (kg ha-1); [6]LG – Length (cm); [7]DM – Diameter (mm),[8]GM – Grain mass (g), [9]GC – Grain color, [10]PT – Pericarp texture.

cant differences regarding their non-additive effects. Therefore, the SCA effects obtained in the hybrid combinations reflect what would be expected from the GCA of the parents.

Conclusions

The parents AM811, HTMV1, Cativerde 02 and AL Piratininga were selected based on their $\hat{g}_i$ for grain yield and green corn quality related traits, and should be used in the formation of base populations aiming the extraction of superior inbred lines.

The hybrid combinations AM811 x CD316, AM811 x AG1051, AM811 x HTMV1, AM606 x Cativerde 02 and Al Piratininga x AG4051 showed desirable SCA, and should be inserted in interpopulational breeding programs for green corn. Based in the reciprocal effect results, the parent AM811 could be employed as male parent in future hybrid combinations.

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