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Partial diallel analysis among maize lines for characteristics related to the tassel and the productivity

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Diallel crosses are important to the prediction of the best combinations among different heterotic groups of maize lines. The work objective was to estimate the combining ability among inbred lines from two heterotic groups to predict the best combinations in traits related to tassel and grain yield, conducted in five environments in the southern region. The inbred lines of the two heterotic groups are from the company KSP seeds. The tests were conducted based on crosses with partial diallel, using 15 female parents and male parents 8, 2011/2012 agricultural harvest in five environments in randomized blocks design with three replications. The variables analyzed were tassel length (TL), distance from the last node to the first branch of the tassel (DLN), distance from the flag leaf to the first branch of the tassel (DFL), number of tassel branches (NB), mass thousand grains (MTG) and grains yield (GY). The data were submitted the individual and joint variance analysis, after were realized analyze partial diallel analysis. The additive effects were more important for group II, already to the group I the non-additive effects were more pronounced, for the traits tassel and of yield. The GCA (group I) of lines inbred 15; 4 and 3-4 (group II) are favorable for increasing the grains yield. The crosses promising tassel traits been: 1-3, 2-4, 3-3, 4-4, 7-3, 8-3, 9-3, 10-3, 10-4, 11-4, 12-4, 14-3 and 15-4. The crosses promising increasing of grains yield been: 1-1, 1-4, 2-3, 3-1, 3-4, 4-3, 4-6, 4-7, 5-3, 5-4, 6-3, 6-4, 7-4, 8-4, 9-4, 10-5, 11-3, 12-3, 14-4, 15-2, 15-5 e 15-8.

Key words: Combinatorial capacity, genic effect, diallel crosses, grain yield.

INTRODUCTION

Corn is one of the most cultivated cereal in the world; mainly due to its diversity of applications, both in food and feed, the crop promotes several agro-industrial complex, with great social and economic importance (Ku et al., 2010). According to the survey from Conab (2015) for the corn crop 2014/2015, Brazil presented a

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production of over 78 million tons, being the states of Mato Grosso (23.1%) and Paraná (18.52%) accounted for more than 40% of the national production of corn.

The success of a genetic breeding program is conditioned by the efficient choice of parents, which when crossed produce superior hybrids. In this sense, the diallel crosses have great importance in predicting the best heterotic combinations (Paterniani and Viegas, 1987; Hallauer et al., 2010; Cruz et al., 2012).

In order to predict the behavior of the parents, the diallel crosses are employed in the study of genetic parameters, in the combining ability and in the gene actions that are involved in the character expression. Thereby, providing crucial information to meet the maximum heterotic expression in combinations (Hallauer et al., 2010). The use of techniques, such as diallels, which are intended to assist breeders in identifying the parents/lines with higher combining ability in different heterotic groups (partial diallel) are of great importance for the development of elite hybrids, with competitiveness in the market.

The main models of diallel analysis employed are the balanced diallels, where all the possible combinations are performed, the peculiarity of this model is the limitation of working with a large number of parents. The partial diallels involve two heterotic groups of parents, allowing to maximize the information about the study groups with a lower number of crossings, yet the reciprocal effects are generally not estimated, allowing loss of additional information. Circulating diallels are represented in the design by the same number of crossings, but less than p-1, reducing the number of total combinations, however losses of information occur regarding certain hybrid combinations, for being absent. Incomplete diallels are represented by a variable number of crossings, this design is a consequence of combinations losses. In the unbalanced diallels are estimated all hybrid combinations and also the other generations are represented, but in variable frequency due to the unequal number of replicates per treatment (Cruz et al., 2012).

To Paterniani and Viegas (1987), the genetic breeding programs have been working with the joint selection of characters and directing attention to plant architecture for increased photosynthetic efficiency and use of photoassimilates. These changes, whether spontaneous or not, have provided changes in the morphological characteristics, especially of the tassel (Neto and Miranda-Filho, 2001). Apical structures have priority in the use of available resources, especially when subjected to conditions of stress (Sangoi et al., 2006). It were also identified, by techniques of biometric analysis in diallel crosses, associations of the tassel characters with characters such as ear height, ear placement, prolificacy, leaf angle, which in turn relate directly with mass of corn kernels (Mickelson et al., 2002; Jung et al., 2007; Andrade and Miranda-Filho, 2008).

Thus, the morphological characteristics of the tassel have been gaining more attention from plant breeders in the prediction of crossings of inbred lines for tassel size reduction, due to the increased energy expenditure and the morphological changes associated with other phenotypic characteristics, as well as the gene actions that are involved in the expression of the characters (Neto et al., 1997; Sangoi et al., 2002; Westgate et al., 2003; Edwards, 2011). Allied with these reasons, this study aimed to estimate the combining ability of maize inbred lines belonging to two heterotic groups by partial diallel analysis, to predict the best combinations, in the characters related to the tassel and grain yield, and identification of predominant gene effects for the characters in five environments.

MATERIALS AND METHODS

The inbred lines of the two heterotic groups used in the diallel crosses are from the breeding program of the company KSP Seeds Ltd., based in the city of Pato Branco - PR. The tests were conducted based on crossings with partial diallel scheme, using 15 (female lineages) and eight (male lineages) from homozygous lines (S_9). After performing artificial crosses, the F_1 seeds were obtained, which were sown in the 2011/2012 harvest.

The sowing of F_1 hybrids was conducted in the 2011/2012 harvest in five separate areas of the three states of southern Brazil. In Rio Grande do Sul, the test was conducted in the city of Frederico Westphalen, with the coordinates 27°23'80" South latitude and 53°25'26 " West longitude, with 480 m of altitude in the trial site, the region is located in the north of the state and has as main climate features average annual temperature of 18.8°C and average temperature of the coldest month of 13.3°C, with sub-temperate, sub-humid type of climate. In Santa Catarina, the test was conducted in the municipality of Itapiranga, situated in the far west of Santa Catarina, with the coordinates 27°10'10 "South latitude and 53°42'44" West longitude, with 206 m of altitude, and temperatures in the coldest month of 13 and 30°C in the hottest month, with average monthly rainfall of 150 mm. In the state of Paraná, the tests were conducted at three sites. In Pato Branco, with the coordinates 26°13'44" South latitude and 52°40'15" West longitude, with 760 m of altitude in the trial place, with average temperature of the hottest month above 22°C, and of the coldest month, 18°C, with humid subtropical climate. Ampére with the coordinates 25°54'65" South latitude and 53°25'39" West longitude with 580 m above sea level in the place of the test, with minimum temperature of 13°C and maximum of 29°C, and average monthly rainfall of 170 mm. Clevelândia with the coordinates 26°21'52" South latitude and 52°28'22" West longitude, with 860 m of altitude at the site of the test, minimum temperature of 11°C and maximum of 27°C, monthly average rainfall of 170 mm.

In the five environments, the partial diallel was conducted in experimental design of complete blocks with treatments at random, with three replications per location. The experimental unit consisted of two rows of five meters in length, spaced 0.70 m. The sowing lines were marked with no-till system seeder, thus, hybrid seeds from the crosses were sown by hand. Sowing was performed according to the agricultural zoning of each site (September 20 in Frederico Westphalen, September 22 in Itapiranga, September 25 in Pato Branco, September 27 in Clevelândia and September 29 in Ampére). The soil management and cultivation were the same for the five sites, respecting the phenological stages and the requirement of the crop. After emergence and initial establishment of maize, it was held the manual adjustment of the population of the plots to 42 plants per experimental unit, equivalent to 60.000 plants ha^{-1}.

Table 1. Joint partial diallel analysis resulting from the crossing of two heterotic groups with 15 lines of Group I and 8 lines of Group II, evaluated at five environments in the southern region. Frederico Westphalen-RS. 2015.

SV	Mean square						
	DF	DFL	DLN	TL	NB	TGW	GY
Crossing (C)	119	557.26**	1238.25**	9115.97**	625.39**	279617.05**	293738328.97**
G.C.A. I	14	346.33**	723.64**	5771.39**	326.21**	184592.99**	188655708.23**
G.C.A. II	7	2415.01**	5638.75**	40388.46**	3005.97**	1225917.91**	1360391542.52**
S.C.A.	98	454.69**	997.44**	7360.01**	498.09**	225598.99**	232560616.68**
Environment (E)	4	1.58^{ns}	19.41**	56.39**	10.71^{ns}	15716.27**	125541311.89**
C x E	476	1.17^{ns}	3.32^{ns}	8.10^{ns}	2.83^{ns}	856.38^{ns}	5077896.23^{ns}
GCA I x E	56	1.28^{ns}	3.18^{ns}	6.93^{ns}	2.98^{ns}	578.18^{ns}	3446717.79^{ns}
GCA II x E	28	1.70**	7.99^{ns}	15.72^{ns}	3.25^{ns}	2744.78**	18703010.06**
SAC x E	392	1.11^{ns}	3.01^{ns}	7.77^{ns}	2.78^{ns}	761.24^{ns}	4337699.30 ^{ns}
Waste	1200	1.08	6.73	11.42	5.58	1155.74	6947083.83
Overall Average		14.94	22.23	60.41	15.67	333.14	11142.86

DFL: Distance from the flag leaf to the insertion of the first branch of the tassel. DLN: Length of the last node to the first branch of the tassel. TL: Tassel length. NB: Number of tassel branches. TGW: thousand grain weight. GY: Grain yield. ** Significant at 1% probability of error. ^{ns} Non-significant

The evaluated traits were tassel length (TL) in centimeters, distance from the last node of the stem to the first branch of the tassel (DLN) in centimeters, distance from the flag leaf to the first branch of the tassel (DFL) measured in the stem at the height of collar of the flag leaf to the insertion of the first branch in the tassel in centimeters, number of branches on the main stem of the tassel (NB), in units, thousand grain weight (TGW) measured by manual count of eight repetitions of 100 seeds, in grams and grain yield (GY), accomplished by manual harvesting of all experimental units and expanded to Kg ha^{-1}.

The data were submitted to individual variance analysis to verify the homogeneity of variances. Then, it was carried out joint analysis of variance to verify the significance of all sources of variation. Subsequently, the joint partial diallel analysis was performed, where, having interaction for combinatorial x environmental capacity, estimates were disrupted by environment, in the absence of interaction, estimates were snared by the average of environments. The analyzes were developed in the computer program Genes (Cruz, 2013).

For the diallel analysis, it was followed by the model IV of Griffing (1956), adapted by Geraldi and Miranda-Filho (1988) for partial diallel, involving two groups of parents. For the joint diallel study, it was followed the statistical model, where;

$$Y_{ij} = \mu + g_i + g_j + s_{ij} + A_k + GA_{ik} + GA_{jk} + SA_{ijk} + \bar{e}_{ij}$$

RESULTS AND DISCUSSION

Analysis of variance showed significant effects by F test for DFL character for the hybrid and hybrid x environment variation sources, the TL character revealed significance for environment and hybrid x environment. The characters DLN, NB, TGW and GY showed significance for all variation sources of hybrid, environment and hybrid x environment, respectively. In all traits evaluated, the F test showed significance for hybrid x environment interaction. The presence of significance for interaction is often, due to the narrow genetic base of simple hybrids (Pinto et al., 2007; Oliboni et al., 2013).

The joint diallel analysis showed significance for the source of variation of crossing for the characters tassel and yield. In the dismemberment of the source of variation, crossing, general combining ability (GCA I and II) and specific combining ability (SCA), it were found significant effects for all combining abilities (Table 1). This characteristic indicates that the set of lineages contribute differently to the crossings in which they are involved and also that the performance of hybrids differed to the expected based on the effects of the general capacity of parents (Oliboni et al., 2013).

The group II of lineages showed the highest estimates of GCA mean squares for the characters tassel and grain yield, indicating that there was a predominance of additive gene effects in all lineages of group II, being their estimates higher than the group I of lineages and the SCA estimates (Table 1). Estimates of the mean squares of SCA were higher than the GCA of the group I of lineages, indicating that the non-additive effects are most important for the variation in this set of hybrids, similar to the results of Machado et al. (2009). In addition, the significant effects of specific combining ability (SCA) reported that there were different degrees of complementarity between the two heterotic groups for the assessed traits (Pinto et al., 2007).

The joint diallel analysis reveals significant interaction effects for GCA II x environments for distance of the flag leaf to the first branch of the tassel (DFL), TGW and yield, this effect contributes to the results of Rodrigues et al. (2009), which state that the significance of the interaction indicates that the lineages contribute differently in the expression of the characters in distinct environments. The number of tassel branches, distance from the last node to the first branch and the length of the tassel do not interfere with the environment for both

Table 2. Estimates of the average general combining ability for group I and II of lines evaluated at five environments in the southern region. Frederico Westphalen-RS. 2015.

Group I	**DFL**	**DLN**	**TL**	**NB**	**TGW**	**GY**
1	0.938	0.722	2.420	0.425	14.752	545.655
2	-1.296	-1.436	-5.052	-1.085	-29.031	-943.148
3	0.542	0.997	2.425	0.717	14.941	391.494
4	2.577	4.216	10.863	3.139	56.637	1618.84
5	0.922	0.975	2.107	0.669	16.461	635.227
6	0.578	0.964	2.558	0.889	11.529	403.860
7	-1.327	-1.881	-4.957	-1.219	-29.799	-877.159
8	-1.283	-1.829	-5.057	-1.386	-30.811	-989.409
9	-1.341	-2.010	-5.334	-1.447	-28.944	-826.219
10	-1.251	-2.007	-5.393	-1.454	-25.820	-1091.592
11	-1.260	-1.569	-4.780	-1.189	-30.119	-1065.149
12	-1.333	-2.124	-5.535	-1.275	-26.825	-776.867
13	0.504	0.848	2.512	0.344	16.067	531.717
14	-1.201	-1.807	-4.616	-0.822	-31.213	-882.808
15	4.231	5.940	17.841	3.694	102.175	3325.557
Group II						
1	-	-1.679	-4.483	-1.198	-	-
2	-	-3.219	-8.571	-2.536	-	-
3	-	7.567	19.16	5.774	-	-
4	-	8.511	23.707	5.972	-	-
5	-	-1.820	-4.508	-1.361	-	-
6	-	-3.026	-8.332	-2.199	-	-
7	-	-3.072	-8.382	-2.071	-	-
8	-	-3.262	-8.591	-2.382	-	-

-- Characters with interaction GCA II x environment, results shown in Tables 3 and 4. *DLN: distance from the last node to the first branch of the tassel, TL: tassel length, NB: number of branches and for the group I to the characters distance from the flag leaf to the first branch of the tassel (DFL), thousand grain weight (TGW) and grain yield (GY).

heterotic Groups I and II, which gives opportunity to interpretations in a single environment. The SCA x E interaction revealed no significant effects for the characters tassel and yield, in this way there is no need to explore specific combinations for each location (Oliboni et al., 2013).

With respect to the estimates of general ability (Group I) for the characters distance from the flag leaf to the first branch of the tassel (DFL) and distance from the last node to the first branch of the tassel (DLN), the lines 2, 7, 8, 9, 10, 11, 12 and 14 have negative estimates (Table 2). Thus, the intersections of these lines would contribute to reduction of these tassel characters, according to Sangoi et al. (2002), minor amounts of nutrients and photoassimilates would be required by the hybrids, and besides, it would reduce the production of auxin, resulting in reducing the inhibitory effect on the growth and development of the female structure.

Regarding the assessment of the effects of GCA (Group I) for the tassel length (TL), the lines 12 and 2 had negative estimates (Table 2), which are favorable from an agricultural point of view. On the other hand, lines 1, 3, 4, 5, 6, 13 and 15 showed positive magnitude, indicating the presence of additive alleles for expression of longer length of tassel, a characteristic that is little desired in the production of simple hybrids due to the higher energy demand by the reproductive structure, and because the apical meristem has priority on the partition of photoassimilates, thus, crossings that result in hybrids with smaller tassel are sought (Sangoi et al., 2006).

In the evaluation of the effects of GCA (Group I) to the number of tassel branches (NB), the lines 2, 7, 8, 9, 10, 11, 12 and 14 had negative estimates (Table 2), a factor which enables use in breeding for the production of simple hybrids with fewer branches. According to Neto et al. (1997), this character has taken attention of breeders in breeding programs, showing that the reduced size of the tassel is favorable for the increase of grain production, mainly to the adverse conditions of stress. The current hybrids have already suffered major reductions in the number of tassel branches, which is directly related to lower production of pollen per area. According to Westgate et al. (2003), the hybrids can further reduce the pollen production by tassel, providing more energy to the cob and boosted grain yield.

For Group II, lines 1, 2, 5, 6, 7 and 8 have negative estimates for the number of branches. Edwards (2011) reports that the selection for reducing the number of branches, the lower leaf angle and synchrony between male and female flowering, contribute to the increase in grain yield. In the same context, Câmara et al. (2007) reported that the breeding programs for tolerance to abiotic stresses regard for character selection purposes as the number of branches, the period between the male and female flowering, prolificacy and delayed senescence of leaves (stay green).

With respect to thousand grain weight (TGW), lines 1, 3, 4, 5, 6, 13 and 15 (Group I) showed positive effects of GCA (Table 2), being the magnitude of the lines 4 (56.637) and 15 (102.175) highlighted among the others, which leads to increased TGW and, consequently, grain yield, because of the close relationship between the two characters, where, getting favorable magnitudes for one of the characters, possibly the magnitudes will be favorable to the other character (Lopes et al., 2007; Khayatnezhad et al., 2010). In the grain yield analysis (Group I), lines 1, 3, 4, 5, 6, 13 and 15 showed favorable assumptions for the trait (Table 2). It may be emphasized that the same lines that showed positive effects on the increase in the TGW showed it for the grain yield.

In assessing the DFL to the lines of group II, in relation to the five environments (Table 3), with the exception of lines 3 and 4, all other have shown negative effects, being lines 2, 6, 7 and 8 with more pronounced negative effects for all environments, which contributes to lower DFL, characteristic that is desired in the generation of progenies.

Regarding TGW characters and yield (Group II), estimates of CGA of lines 3 and 4 are positive for both characters. The crossing of these lines with the lines of the 4 and 15 of group I would add frequencies favorable for greater mass and grain yield, but to do so, the analysis of the specific interactions of the SAC is required to verify the complementarity of the genetic effects that are acting.

WIth respect to the SAC (*si*) for the tassel length (Table 4), the promising specific combinations for reduction in tassel size, are between the pairs 1-3, 2-4, 3-3, 4-4, 7-3, 8-3, 9-3, 10-3, 11-4, 12-4, 14-3 and 15-4, since the estimates *si* are high and negative, and the lines 10 and 12 (Group I) also showed negative effects for GCA. Negative estimates should be observed due to the fact that modern hybrids, developed with high grain yield, present smaller tassel, thus reducing the effect of apical dominance in stress conditions, which favors the best grain filling (Sangoi et al., 2006).

As to the evaluation of the SAC for the distance of the flag leaf to the insertion of the first branch of the tassel (Table 4), promising specific crossings to reduce the character are among the lines 1-3, 2-4, 3-3, 4- 4, 7-3, 8-3, 9-3, 10-3, 10-4, 11-4, 12-4, 14-3, 15-1 and 15-4, for having negative estimates of *si*. The lines 2, 7, 8, 9, 10, 11 and 12 (Group I) also revealed adverse effects for *gi*. Combinations of *si* are far superior to the effects of *gi*, predicting the predominance of genes of non-additive effect on the character of expression. The other pairs of specific crosses had low values and close to those observed for *gi*, which refers to hybrids presenting the performance as expected in the *gi*, (Cruz et al., 2012).

With respect to SAC estimates for the distance of the last node to the first branch of the tassel (DLN), the promising crossings are between the pairs of lines 1-3, 2-4, 3-3, 4-4, 7-3, 8-3, 9-3, 10-3, 10-4, 11-4, 12-4, 14-3, 15-1 and 15-4 (Table 4). In group II, the lines 3 and 4 showed favorable combinations with a greater number of lineages. The magnitude of the estimates *si* are again above the *gi* estimates, pointing out that the non-additive gene effects are more pronounced.

Regarding the number of branches (NB) to the estimates of the SAC, the most promising crossings to obtain hybrids with fewer branches are revealed between the pairs of lines 1-3, 2-4, 3-3, 4-4, 7-3, 8-3, 9-3, 10-3, 10-4, 11-4, 12-4, 14-3 and 15-4 (Table 5), it should also be considered that lines 2, 7, 8, 9, 10, 11, 12, and 15 (Group I) have negative effects for the GCA. Based on the superiority of estimates *si* over *gi*, it is assumed that non-additive gene actions occur in controlling the number of branches in the tassel.

For the component of thousand grain weight (TGW) yield, promising crosses are for the pairs of lines 1-1, 1-4, 2-3, 3-3, 3-4, 4-3, 4-6, 4-7, 5-3, 5-4, 6-3, 6-4, 7-4, 8-4, 9-4, 10-5, 11-3, 12-3, 13-3, 13-4, 14-4, 15-2, 15-5 and 15-8 (Table 5), being its estimates positive and also considering the effects of GCA (Group I) of the lines 15 and 4 with the highest positive estimates. Comparison with estimates *gi* indicate superiority of the estimates *si* with non-additive effects in the character control. The lines 3 and 4 used as a parent are responsible for most of the positive effects to increase TGW for demonstrating combining ability with a large number of lineages of group I. Lineages that present these magnitudes of combining ability are important for genetic breeding programs of hybrids, in which are high the specific complementarity actions with ample heterotic group.

With regard to the estimates of specific combining ability for grain yield (GY), promising specific crossings for increasing yield are among the combinations 1-1, 1-4, 2-2, 2-3, 2-6, 2-7, 2-8, 3-1, 3-4, 4-3, 4-6, 4-7, 5-3, 5-4, 6-3, 6-4, 7-2, 7-4, 7-6, 7-7, 7-8, 8-2, 8-4, 8-6, 8-7, 8-8, 9-2, 9-4, 9-6, 9-7, 9-8, 10-2, 10-5, 10-6, 10-7, 10-8, 11-2, 11-3, 11-6, 11-7, 11-8, 12-2, 12-3, 12-6, 12-7, 12-8, 13-3, 13-4, 14-2, 14-4, 14-6, 14-7, 14-8, 15-2, 15-3, 15-5 and 15-8, in which are assigned the crossings 1-1, 1-4, 2-3, 3-1, 3-4, 4-3, 4-6, 4-7, 5-3, 5-4, 6-3, 6-4, 7-4, 8-4, 9-4, 10-5, 11-3, 12-3, 14-4, 15-2, 15-5 and 15-8 as the most promising in the exploration of dominance effects. The most pronounced SAC estimates indicate that parents may generate hybrids with higher heterosis (Oliboni et al., 2013),

Table 3. Estimates of the general combining ability of individual for the interaction GCA II x environment evaluated at five environments of the southern region. Frederico Westphalen-RS. 2015.

Group II*	**DFL**					
	Ampére	**Clevelândia**	**Itapiranga**	**Pato Branco**	**Frederico**	**Mean**
1	-0.939	-1.208	-1.068	-0.882	-0.745	-0.968
2	-2.128	-2.156	-2.180	-2.156	-2.156	-2.155
3	4.646	5.181	4.897	4.233	4.507	4.693
4	5.713	5.666	5.628	5.966	5.944	5.783
5	-1.305	-0.978	-0.980	-1.286	-1.393	-1.188
6	-2.068	-2.045	-2.113	-2.030	-2.141	-2.080
7	-2.009	-2.245	-2.120	-2.038	-1.986	-2.079
8	-1.909	-2.215	-2.065	-1.808	-2.030	-2.005
SD (GCA II)	0.132	0.175	0.174	0.092	0.134	
SD (GCA II - GCA II')	0.200	0.264	0.263	0.139	0.203	
Group II**	**TGW**					
1	-26.084	-26.327	-22.001	-25.821	-25.293	-25.105
2	-39.254	-53.755	-45.241	-46.923	-46.431	-46.321
3	104.544	123.528	103.722	119.049	106.213	111.411
4	108.906	149.110	118.267	122.258	126.648	125.038
5	-18.267	-30.276	-19.671	-17.484	-23.051	-21.750
6	-42.826	-54.393	-45.960	-50.187	-45.167	-47.707
7	-44.066	-53.162	-42.019	-50.007	-45.540	-46.959
8	-42.953	-54.726	-47.097	-50.886	-47.379	-48.608
SD (GCA II)	4.984	4.493	4.833	5.514	3.685	
SD (GCA II - GCA II')	7.534	6.793	7.306	8.337	5.571	
Group II***	**GY**					
1	-862.121	-1083.438	-826.827	-680.536	-638.13	-818.21
2	-1460.28	-2138.494	-1457.879	-1539.36	-927.29	-1504.66
3	3589.077	4947.278	3301.854	4207.595	2305.70	3670.30
4	4134.745	5818.478	4460.024	3861.601	2825.03	4219.97
5	-758.349	-1266.472	-813.054	-992.234	-537.01	-873.42
6	-1650.842	-2128.144	-1562.557	-1668.461	-968.28	-1595.65
7	-1559.994	-2055.389	-1457.727	-1749.267	-1069.72	-1578.42
8	-1432.237	-2093.819	-1643.834	-1439.337	-990.31	-1519.91
SD (GCA II)	178.276	283.078	245.234	694.923	142.96	
SD (GCA II - GCA II')	269.528	427.973	370.759	1050.624	216.14	

DFL: distance from the flag leaf to the first branch of the tassel, TGW: thousand grain weight and GY: grain yield. *Results of the interaction for general combining ability for the length of the flag leaf to the first branch of the tassel of group II of lines, in the five environments. **Results of the interaction for general combining ability for the thousand grain weight of group II of lines, in the five environments. ***Results of the interaction for general combining ability for grain yield in group II of lines, in the five environments.

being SAC manifested by virtue of the non-additive effects and differences in allelic frequencies of the parents for the loci involved in character expression (Valério et al., 2009; Hallauer et al., 2010).

The lines 4 and 15, as female parents, and 3 and 4, as male parentes, have shown favorable estimates and combining ability with a larger number of lines of the other heterotic group. The female parents 4 and 15 and the male parents 3 and 4 presented high estimates for both general capacity and for specific capacity combination.

Conclusions

The additive effects were more important for the Group II

Table 4. Average specific combining ability from the crossings of two heterotic groups (group I, fifteen, and group II, eight strains), evaluated at five environments in the southern region. Frederico Westphalen-RS. 2015.

Group I / Group II	TL							
	1	2	3	4	5	6	7	8
1	49.199	-6.434	-34.166	21.610	-10.498	-6.674	-6.623	-6.414
2	-3.050	1.038	33.570	-31.240	-3.025	0.799	0.849	1.058
3	51.285	-6.439	-34.170	19.550	-10.502	-6.678	-6.628	-6.419
4	-18.965	-14.877	18.136	-47.156	-18.941	48.682	47.978	-14.857
5	-10.209	-6.121	23.584	21.700	-10.184	-6.360	-6.310	-6.101
6	-10.660	-6.572	25.109	22.883	-10.635	-6.811	-6.761	-6.552
7	-3.145	0.943	-26.788	29.687	-3.120	0.704	0.754	0.963
8	-3.045	1.043	-26.688	28.987	-3.020	0.804	0.854	1.063
9	-2.768	1.320	-26.412	27.052	-2.743	1.081	1.131	1.340
10	-2.709	1.379	-26.352	-30.899	54.852	1.140	1.190	1.399
11	-3.322	0.766	35.478	-31.513	-3.298	0.526	0.577	0.786
12	-2.567	1.521	30.190	-30.757	-2.542	1.282	1.332	1.541
13	-10.614	-6.526	25.564	22.150	-10.589	-6.765	-6.715	-6.506
14	-3.486	0.602	-27.130	32.079	-3.462	0.362	0.413	0.622
15	-25.943	38.357	10.075	-54.133	37.705	-22.094	-22.044	38.077
Group I / Group II				**DFL**				
1	14.167	-1.891	-8.739	5.293	-2.857	-1.966	-1.966	-2.040
2	-0.843	0.344	7.987	-7.595	-0.623	0.268	0.268	0.194
3	12.162	-1.495	-8.343	4.923	-2.462	-1.570	-1.570	-1.645
4	-4.716	-3.530	4.256	-11.468	-4.496	11.816	11.817	-3.679
5	-3.061	-1.874	7.679	6.020	-2.841	-1.950	-1.950	-2.024
6	-2.718	-1.531	6.021	5.619	-2.498	-1.606	-1.606	-1.681
7	-0.812	0.374	-6.473	6.681	-0.592	0.299	0.299	0.225
8	-0.856	0.330	-6.518	6.990	-0.636	0.255	0.255	0.181
9	-0.798	0.388	-6.459	6.583	-0.578	0.313	0.313	0.239
10	-0.889	0.298	-6.550	-7.640	14.187	0.223	0.223	0.148
11	-0.879	0.308	8.237	-7.630	-0.659	0.232	0.232	0.158
12	-0.807	0.380	7.732	-7.558	-0.587	0.305	0.305	0.230
13	-2.643	-1.456	5.852	5.339	-2.423	-1.532	-1.532	-1.606
14	-0.939	0.248	-6.600	7.565	-0.719	0.173	0.173	0.098
15	-6.370	9.106	1.919	-13.121	7.783	-5.259	-5.259	11.201
Group I / Group II				**DLN**				
1	17.936	-2.135	-12.921	7.356	-3.534	-2.328	-2.282	-2.092
2	-1.516	0.024	14.804	-11.707	-1.376	-0.170	-0.124	0.066
3	18.728	-2.410	-13.196	8.214	-3.809	-2.603	-2.557	-2.368
4	-7.168	-5.628	6.878	-17.359	-7.028	18.268	17.624	-5.586
5	-3.927	-2.387	10.358	7.203	-3.787	-2.581	-2.535	-2.345
6	-3.916	-2.376	9.159	8.336	-3.776	-2.570	-2.524	-2.334
7	-1.072	0.468	-10.318	10.748	-0.931	0.275	0.321	0.510
8	-1.123	0.417	-10.369	11.108	-0.983	0.223	0.269	0.459
9	-0.943	0.597	-10.189	9.844	-0.802	0.404	0.450	0.639
10	-0.946	0.594	-10.192	-11.137	20.197	0.401	0.447	0.636
11	-1.383	0.157	13.871	-11.574	-1.243	-0.037	0.009	0.199
12	-0.829	0.711	9.992	-11.020	-0.688	0.518	0.564	0.753
13	-3.801	-2.261	8.996	7.808	-3.660	-2.454	-2.408	-2.219
14	-1.146	0.394	-10.392	11.264	-1.005	0.201	0.247	0.437
15	-8.893	13.836	3.518	-19.084	12.425	-7.546	-7.500	13.245

TL: tassel length, DFL: distance from the flag leaf to the insertion of the first branch of the tassel and DLN: distance from the last node to the insertion of the first branch of the tassel.

Table 5. Specific combining ability from the crossing of two heterotic groups (group I, fifteen, and group II, eight strains), evaluated at five environments in the southern region. Frederico Westphalen-RS. 2015.

Group I / Group II	**NB**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	12.876	-1.153	-9.463	4.483	-2.328	-1.490	-1.618	-1.307
2	-0.981	0.357	9.479	-8.151	-0.818	0.020	-0.108	0.203
3	12.841	-1.445	-9.754	6.268	-2.620	-1.782	-1.909	-1.598
4	-5.205	-3.867	5.178	-12.375	-5.042	11.774	13.558	-4.021
5	-2.735	-1.397	9.976	1.873	-2.572	-1.734	-1.861	-1.550
6	-2.955	-1.617	7.073	6.097	-2.792	-1.954	-2.082	-1.770
7	-0.847	0.491	-7.818	8.339	-0.684	0.154	0.027	0.338
8	-0.680	0.658	-7.651	7.171	-0.517	0.321	0.193	0.505
9	-0.619	0.719	-7.590	6.744	-0.456	0.382	0.255	0.566
10	-0.612	0.726	-7.584	-7.782	14.030	0.389	0.261	0.572
11	-0.877	0.461	8.751	-8.047	-0.714	0.124	-0.004	0.307
12	-0.791	0.547	8.149	-7.961	-0.628	0.210	0.082	0.393
13	-2.410	-1.073	4.751	5.153	-2.248	-1.410	-1.537	-1.226
14	-1.244	0.094	-8.215	11.119	-1.081	-0.243	-0.371	-0.059
15	-5.760	6.500	4.719	-12.930	8.470	-4.759	-4.887	8.647
Group I / Group II	**TGW**							
1	259.918	-38.073	-195.805	146.512	-62.644	-36.687	-37.435	-35.786
2	-15.506	5.710	172.865	-165.649	-18.861	7.096	6.348	7.997
3	289.365	-38.261	-195.994	118.196	-62.833	-36.876	-37.624	-35.974
4	-101.173	-79.957	103.266	-251.316	-104.529	250.454	260.926	-77.670
5	-60.997	-39.781	156.879	123.287	-64.353	-38.396	-39.144	-37.494
6	-56.066	-34.85	143.540	107.037	-59.421	-33.464	-34.212	-32.563
7	-14.737	6.478	-151.254	153.860	-18.093	7.864	7.116	8.766
8	-13.726	7.490	-150.242	146.779	-17.081	8.876	8.128	9.777
9	-15.592	5.624	-152.109	159.844	-18.948	7.009	6.261	7.911
10	-18.717	2.499	-155.233	-168.859	328.501	3.885	3.137	4.787
11	-14.417	6.799	165.245	-164.560	-17.773	8.184	7.436	9.086
12	-17.712	3.504	188.308	-167.855	-21.067	4.890	4.142	5.791
13	-60.604	-39.388	162.189	115.615	-63.959	-38.002	-38.750	-37.101
14	-13.324	7.892	-149.84	143.964	-16.679	9.278	8.530	10.179
15	-146.712	224.315	58.186	-296.855	217.740	-124.11	-124.858	192.294
Group I / Group II	**GY**							
1	9010.057	-1295.755	-6470.716	4390.669	-1926.992	-1204.757	-1221.996	-1280.507
2	-493.401	193.049	5510.975	-5531.586	-438.187	284.046	266.807	208.296
3	8727.939	-1141.593	-6316.555	3747.819	-1772.830	-1050.596	-1067.835	-1126.346
4	-3055.393	-2368.942	3413.272	-8093.578	-3000.179	7608.582	7849.934	-2353.695
5	-2071.776	-1385.326	5448.563	4001.079	-2016.563	-1294.328	-1311.568	-1370.079
6	-1840.410	-1153.959	4999.943	3061.498	-1785.196	-1062.962	-1080.201	-1138.712
7	-559.389	127.060	-5047.901	5423.223	-504.176	218.057	200.818	142.307
8	-447.139	239.310	-4935.651	4637.473	-391.926	330.307	313.068	254.557
9	-610.330	76.119	-5098.842	5779.808	-555.117	167.117	149.877	91.366
10	-344.956	341.493	-4833.468	-5383.142	9015.590	432.491	415.251	356.740
11	-371.400	315.049	4656.972	-5409.586	-316.187	406.047	388.807	330.296
12	-659.682	26.767	6674.944	-5697.867	-604.469	117.765	100.526	42.015
13	-1968.267	-1281.817	5337.785	3490.800	-1913.054	-1190.819	-1208.058	-1266.569
14	-553.740	132.709	-5042.252	5383.680	-498.527	223.706	206.467	147.956
15	-4762.106	7175.834	1702.929	-9800.292	6707.818	-3984.658	-4001.898	6962.373

NB: number of tassel branches, TGW: thousand grain weight and GY: grain yield.

of lines, for group I of lines, the non-additive effects were more important in the range of all characters. The improvement of hybrids for lower tassel size can be performed simultaneously, since the estimates of general combining ability remain constant in the lines of the two heterotic groups for all characters of the tassel. For the characters tassel lenght, distance from the last node and of the flag leaf to the first branch of the tassel, promising crosses are 1-3, 2-4, 3-3, 4-4, 7-3, 8-3, 9-3, 10-3, 10-4, 11-4, 12-4, 14-3 and 15-4.

The promising crosses to increase yield are 1-1, 1-4, 2-3, 3-1, 3-4, 4-3, 4-6, 4-7, 5-3, 5-4, 6-3, 6-4, 7-4, 8-4, 9-4, 10-5, 11-3, 12-3, 14-4, 15-2, 15-5 and 15-8. Among the most promising crosses to SAC, at least two parents have high GCA.

Conflict of Interests

The authors have not declared any conflict of interests.

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