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Effect of generations and environments in the analysis of a partial diallel to improve bean earliness

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ABSTRACT. The objective of this study was to select genitors based on F_1 and F_2 generations, evaluated in different environments, to obtain segregating populations for the identification of strains showing improved earliness, yield, and carioca-type grains. Nine bean strains were crossed in a partial diallel scheme (4 x 5), in which group 1 included 4 strains with early cycles and group 2 included 5 elite strains. The F_1 and F_2 generations and the genitors were assessed in Coimbra and Viçosa in randomized blocks with 3 replications. The following characteristics were evaluated: days between sowing and emergence, and grain yield. We observed an interaction between the effects of general combining ability and specific combining ability with the environments (crop, location, and generation) for both grain earliness and yield. Genetic analysis of earliness revealed a predominance of additive effects and grain yield dominance effects. The strain Goiano Precoce may be used as a genitor in breeding programs to improve earliness, while strains RP1 and VC33 can be used to increase grain

yield. We observed genetic complementation between strains Goiano Precoce and RP1, BRSMG Madrepérola and BRS Estilo for earliness and between RP1 and Rosinha Precoce for grain yield.

Key words: Flowering; Partial diallel; *Phaseolus vulgaris* L.

INTRODUCTION

Over the past several years, bean breeders in Brazil have been attempted to develop early strains (Tulmann Neto and Sabino, 1994; Dalla Corte et al., 2005), with a cycle shorter than the average of 90 days of available cultivars. Early cultivars allow for cultivation at intervals of harvest as well as the sowing of other species. This increases profitability by cultivated area and number of crops per year, reduces the consumption of water and energy used for irrigation, and allows the avoidance of biotic and abiotic stresses (Buratto et al., 2007). Additionally, new bean cultivars should be productive, and emphasis has been given to carioca beans, as they are preferred by Brazilian consumers and represent approximately 79% of the Brazilian consumption of beans (Carneiro et al., 2012).

To develop bean cultivars with the desired ideotype (earliness, carioca grain, and high grain yield), hybridization methods can be used. The selection of genitors to be crossed is crucial because it determines the success of others and, consequently, the efficiency of the breeding program (Bertan et al., 2007; Pereira et al., 2007). A strategy commonly used for genitor selection is diallel crossing. This method provides information regarding the general combining ability (GCA) and specific combining ability (SCA), which are useful parameters for directing crossing to maximize performance and genetic variability in segregating populations (Bernardo and Bohn, 2007), as the alleles of interest are generally found in distinct genitors.

In bean cultivation, the use of diallel crossings is limited by the small amount of seed available in the F_1 generation because of difficulties in conducting the crossings and the limited number of hybrid seeds obtained by pollination. An alternative would be to use the F_2 generation. However, in a complete diallel, considering that in each generation advanced from F_1, dominance deviation is reduced to half, the effect of SCA may not be significant in subsequent generations, making it impractical because the information regarding gene complementation between the genitors would be lost (Pimentel et al., 2013). In this case, the use of a partial diallel may be more appropriate; according to Viana (2007), in partial diallel, the magnitude of GCA, in addition to quantifying the frequency of favorable alleles, indicates the genetic diversity between the genitor of a group and those of the opposite group. Furthermore, the F_2 or F_3 generations offer more seeds, providing the opportunity to assess the diallel in different environments, making it possible to obtain information about interaction of the parameters estimated in the diallel with environmental effects (Bhullar et al., 1979; Masood and Kronstad, 2000). Thus, these generations allow for a more efficient choice of genitors to obtain promising segregating populations to identify superior strains of bean crop, particularly those that are better adapted to a wider range of environmental conditions.

The aim of this study was to select genitors using F_1 and F_2 generations evaluated in more than one environment to obtain promising segregating populations and identify superior strains for traits of earliness, yield, and standard of carioca-type grain.

MATERIAL AND METHODS

Nine bean strains were crossed in a partial diallel scheme (4 x 5); group I consisted of 4 strains (Goiano Precoce; Xan112; Carioca1070; Rosinha Precoce) with an early cycle and group II consisted of 5 elite strains, with a normal cycle, high yield potential, and carioca-type grain (RP1, VC15, VC33, BRSMG Madrepérola, and BRS Estilo). The F_1 hybrids and the genitors were assessed from the crop of the 2013 drought at the Experimental Station of Coimbra, MG (690 m altitude, 20°45' S latitude and 42°51' W longitude) and at the Experimental Station of Horta Nova, in Viçosa, MG (648 m altitude, 20°45'14" S latitude and 42°52' W 55" W longitude). The experimental design was a randomized block with 3 replications. The parcels consisted of 2 lines 1.0 m in length with spacing of 0.50 m and 10 seeds/m. In 2013, we evaluated the F_2 generation of each hybrid along with the genitors in the winter crop in Coimbra and water crop in Viçosa. A randomized block design with 3 replications was also used, but with parcels of 4 lines of 4.0 m in length and spacing of 0.50 m.

Fertilization and crop pest controls were performed according to the recommendations for cultivation in the region. Cycle and grain yield in kg/ha (YLD) were evaluated. Plant cycle evaluation was based on the number of days between sowing and emergence (DSE) (50% of plants in the parcels with at least 1 open flower).

Data were subjected to individual and combined analysis of variance and the effect of treatments was decomposed according to the Griffing model (1956), adapted to partial diallel by Geraldi and Miranda-Filho (1988). The effect of treatments was considered as fixed and the effect of environments was considered as random. The model used was:

$$Y_{ij} = \mu + \frac{1}{2}(d_1 + d_2) + g_i + g'_j + s_{\bar{ij}} + \bar{\varepsilon}_{ij}$$

where Y_{ij} is the mean of the crossing involving the ith genitor of group I and the jth genitor of group II; Y_{i0} is the average of the i*th* genitor of group I (i = 0,1, ... p); Y_{0j} is the mean of the jth genitor of group II (j = 0,1, ... q); μ is the general mean of diallel; d_1, d_2 are the contrasts involving the means of groups I and II and the general average; g_i is the effect of general combining ability of the ith genitor of group I; g_j is the effect of GCA of the jth genitor of group II; s_{ij} is the effect of SCA; and $\bar{\varepsilon}_{ij}$ is the experimental mean error.

Statistical analyses were performed using the GENES program (Cruz, 2013).

RESULTS AND DISCUSSION

Summaries of the individual (Coimbra and Viçosa) and combined analyses of variance of the partial diallel for the number of DSE and YLD evaluated in the 9 genitors and their 20 F_1 hybrids are presented in Table 1. The 9 genitors and F_2 generations are presented in Table 2. The effect of treatments on individual analysis was significant in both generations (Tables 1 and 2), which was observed in GCA in groups I (GCA I) and II (GCA II) and SCA for the F_1 and F_2 generations.

The square sums of GCAs of the genitors (GCA I + GCA II), compared to the square sum of the SCA of the hybrids (Table 1) showed a predominance of additive effects in Coimbra and dominance in Viçosa for DSE. In the F_2 generation (Table 2), there was predominance of additive effects in both Coimbra and Viçosa. For grain yield, there was a predominance of dominance effects in the genetic control in both environments for the F_1 generation (Co-

imbra and Viçosa) (Table 1). In F_2, there was a predominance of additive effects in Coimbra and dominance in Viçosa. These results revealed a greater effect of dominance effects on the genetic control of YLD regarding DSE, as the dominance deviations decreased by half with each generation by self-fertilization. Moreover, over generations, an increase in the frequency of homozygous loci was expected, as well as an increase in the participation of additive variance at the expense of dominance variance. Characters such as grain yield are controlled by a large number of genes (Ribeiro et al., 2008) and require a higher degree of homozygosity to reduce the effects of dominance. Thus, selections aiming to improve the earliness trait can be manipulated in initial generations because of the predominance of additive effects for DSE in F_2, while selections aiming to improve YLD should be manipulated in advanced generations.

Table 1. Summary of individual and combined analyses of variance for the characters: days between sowing and emergence (DSE) and grain yield (YLD) of 9 genitors and their 20 F_1 hybrids, evaluated in Coimbra and Viçosa, MG. Drought of 2013.

Individual variance	d.f.	Mean square			
		Coimbra		Viçosa	
		DSE	YLD	DSE	YLD
Treatments	28	46.27**	943408**	146.68**	745751**
Groups	1	484.94**	6529532**	468.39**	139089^{ns}
GCA I	3	169.11**	1590122**	132.75 **	892643*
GCA II	4	6.45^{ns}	377695*	127.87**	944356*
SCA	20	13.87**	680237**	136.44**	714330**
Residues	56	5.16	144247	7.00	302604
Mean	-	37.36	2336	40.52	2187
CV (%)	-	6	16	9	25

Combined variance	d.f.	Mean square	
		DSE	YLD
Treatments (Treat)	28	97.85^{ns}	818280^{ns}
Groups	1	07.00^{ns}	2381321*
GCA I	3	283.48*	1343529^{ns}
GCA II	4	49.81^{ns}	570338^{ns}
SCA	20	84.50^{ns}	710929^{ns}
Environments (Env)	1	0.31^{ns}	526^{ns}
Treat x Env	28	95.10**	870879**
Groups x Env	2	476.63**	2143649**
GCA I x Env	3	18.37**	1139236**
GCA II x Env	4	84.50*	751713**
SCA x Env	20	82.70**	683638**
Residues	112	6.00	223425
Mean	-	38.94	2261
CV (%)	-	8	20

d.f. = degrees of freedom; GCA = general combining ability; SCA = specific combining ability; CV = coefficient of variance. ^{ns}, *, **Not significant, significant at 5% and significant at 1% probability, respectively, by the F-test.

The effect of the environment was not significant in F_1 (Table 1) and F_2 (Table 2) in the combined analysis, but all interactions with the environments were significant in both generations except the group x environment interaction and GCA I x environments in F_2 (Table 2) for grain yield. Pixley and Bjarnason (1993) reported an interaction between GCA and SCA parameters with environment effects for grain yield and disease resistance in maize.

Based on estimated GCA of the genitors in (GCA I for DSE, the Goiano Precoce strain stood out with negative and significant values in both evaluated generations, F_1 (Table 3) and F_2 (Table 4), and in both locations (Coimbra and Viçosa). Negative values are informative

because the earliest plants present lower DSE. These results indicate a high concentration of favorable alleles in this strain for the reduction of the bean cycle.

Table 2. Summary of individual and combined analyses of variance for the characters: days between sowing and emergence (DSE) and grain yield (YLD) of 9 genitors and their 20 F_2 hybrids, evaluated in Coimbra and Viçosa, MG. 2013.

Individual variance	d.f.	Mean square			
		Coimbra-winter		Viçosa-water	
		DSE	YLD	DSE	YLD
Treatments	28	44.03**	417682**	29.64**	780827**
Groups	1	423.74**	2292099**	1.20^{ns}	1173009**
GCA I	3	191.33**	1152108**	81.19**	769771**
GCA II	4	27.48*	608577**	32.81**	1112880**
SCA	20	6.2^{ns}	175619^{ns}	22.70**	696466**
Residues	56	9.43	146567	5.12	179956
Mean	-	44	3306	37	2365
CV(%)	-	6	11	6	18

Combined variance	d.f.	Mean square	
		DSE	YLD
Treatments (Treat)	28	48.60*	745296^{ns}
Groups	1	235.06**	3372266**
GCA I	3	221.70^{ns}	1718332^{ns}
GCA II	4	34.93^{ns}	921658^{ns}
SCA	12	16.04^{ns}	432720^{ns}
Environments (Env)	1	6.61^{ns}	45807^{ns}
Treat x Env	28	25.08**	453214**
Groups x Env	2	94.94**	4642^{ns}
GCA I x Env	3	50.81**	203547^{ns}
GCA II x Env	4	25.36**	799799**
SCA x Env	12	12.92**	439365**
Residues	112	7.27	163261
Mean	-	41	163262
CV (%)	-	6	15

^{ns}, *, **Not significant, significant at 5% and significant at 1% probability, respectively, by the F-test. For abbreviations, see Table1.

Table 3. Estimates of the effects of general combining ability (GCA) of 9 bean strains and specific combining ability (SCA) of their 20 F_1 hybrids evaluated as for days between sowing and emergence in Coimbra and Viçosa, MG. Drought of 2013.

			Coimbra-drought			
Genitors	1	2	3	4	5	GCA I
1*	-5.06^{A}**	1.30^{ns}	-0.06^{ns}	1.18^{ns}	0.06^{ns}	-3.44*
2*	0.93^{ns}	-0.69^{ns}	-1.06^{ns}	-3.81**	0.06^{ns}	2.5*
3*	1.04^{ns}	1.42^{ns}	-0.95^{ns}	-0.70^{ns}	2.04^{ns}	0.44^{ns}
4*	2.04^{ns}	-0.57^{ns}	3.04*	-0.70^{ns}	1.04^{ns}	0.45^{ns}
GCA II	-0.27^{ns}	0.35^{ns}	-0.27^{ns}	-0.52^{ns}	0.71^{ns}	
			Viçosa-drought			
Genitors	1	2	3	4	5	GCA I
1*	3.58^{ns}	3.45^{ns}	-2.04^{ns}	0.20^{ns}	5.70**	-3.13**
2*	4.24*	4.12^{ns}	-2.37^{ns}	-1.12^{ns}	3.37^{ns}	1.19^{ns}
3*	7.58**	10.45**	1.95^{ns}	-2.70^{ns}	1.70^{ns}	1.86*
4*	3.35^{ns}	3.23^{ns}	-2.26^{ns}	-2.01^{ns}	9.48**	0.08^{ns}
GCA II	-2.00**	-1.87**	2.62*	2.37*	-1.12^{ns}	

Genitors of group 1: 1* - Goiano Precoce; 2* - Xan112; 3* - Carioca1070; 4* - Rosinha Precoce. Genitors of group 2: 1 - RP1; 2 - VC15; 3 - VC33; 4 - BRSMG Madrepérola; 5 - BRS Estilo. ^{A}SCA value. ^{ns}, *, **Not significant, significant at 5% and significant at 1% probability, respectively, by the *t*-test.

Table 4. Estimates of the effects of general combining ability (GCA) of 9 bean strains and specific combining ability (SCA) of their 20 F_2 populations evaluated for number of days between sowing and emergence, Coimbra and Viçosa, MG, 2013.

Coimbra-winter						
Genitors	1	2	3	4	5	GCA I
1*	0.43^{Ans}	-2.68^{ns}	-0.68^{ns}	-0.18^{ns}	0.18^{ns}	-3.88*
2*	-0.56^{ns}	0.31^{ns}	-0.68^{ns}	-1.18^{ns}	-2.81^{ns}	2.11*
3*	0.88^{ns}	-0.24^{ns}	-1.24^{ns}	-1.74^{ns}	1.63^{ns}	0.66^{ns}
4*	0.43^{ns}	0.31^{ns}	3.11^{ns}	0.81^{ns}	-0.81^{ns}	1.11^{ns}
GCA II	1.17^{ns}	0.30^{ns}	-1.69*	-0.2	0.42	
Viçosa-water						
Genitors	1	2	3	4	5	GCA I
1*	0.88^{ns}	0.73^{ns}	0.39^{ns}	-6.73*	-3.48*	-1.36**
2*	-3.9*	2.37^{ns}	1.50^{ns}	0.37^{ns}	1.62^{ns}	2.52*
3*	1.89^{ns}	-1.73^{ns}	0.39^{ns}	-0.73^{ns}	0.51^{ns}	-0.36^{ns}
4*	-0.66^{ns}	-3.29^{ns}	1.83^{ns}	1.70^{ns}	0.95^{ns}	-0.80^{ns}
GCA II	1.37*	-1.0^{ns}	-0.12^{ns}	1.0^{ns}	-1.25**	

Genitors of group 1: 1* - Goiano Precoce; 2* - Xan112; 3* - Carioca1070; 4* - Rosinha Precoce. Genitors of group 2: 1 - RP1; 2 - VC15; 3 - VC33; 4 - BRSMG Madrepérola; 5 - BRS Estilo. ^{A}SCA value. $^{ns, *, **}$Not significant, significant at 5% and significant at 1% probability, respectively, by the *t*-test.

For group II, based on the estimates of GCA (GCA II), the RP1 and VC15 strains in Viçosa stood out for the DSE in the F_1 generation (Table 3) and VC33 (in Coimbra) and BRS Estilo (in Viçosa) in the generation F_2 (Table 4). These results corroborate the influence of the environments (crops and location) on the estimates of GCA. Notably, the effect of environments can be mistaken for the one of the generations.

Based on the estimates for SCA, the hybrid combination Goiano Precoce/RP1 stood out in the reduction of DSE in Coimbra in the crop of the 2013 drought for the F_1 generation (Table 3). In Viçosa, in the same crop and generation, no hybrid combination stood out because all combinations with the Goiano Precoce strain showed no significant SCA. These results indicate that gene complementation occurred between the genitors Goiano Precoce and RP1 for the reduction of the cycle only in Coimbra, which also indicates the relationship between location and cycle.

Based on the estimates for SCA in the F_2 generation (Table 4) the hybrid combinations Goiano Precoce/BRSMG Madrepérola and Goiano Precoce/BRS Estilo stood out, presenting negative and significant estimates of SCA in Viçosa for the water crop of 2013. SCA was not significant in the same generation for the winter crop of Coimbra. These results indicate the effects of the interaction between SCA and the environment, and in this case, includes the effect of crops.

There are no published reports of studies using partial diallel in beans to analyze more than one generation from the number of days to begin flowering and cycle. Javaid et al. (2001) examined the efficiency of the F_2 generation of wheat to estimate GCA and SCA for cycle, yield per plant, and thousand grain weight.

Considering the estimates of GCA (GCA I) for YLD in the F_1 generation, the strain Rosinha Precoce showed positive and significant values in Viçosa, while in Coimbra, no strain showed positive and significant values (Table 5). Based on the F_2 generation (Table 6), the strain Xan112 showed positive and significant values in Coimbra and Carioca1070 in Viçosa. These results confirm the effects of the interaction with the environment when estimating GCA. The interaction between genotypes and environments in bean cultivation for grain yield has been reported by several authors (Carmo et al., 2007; Bertoldo et al., 2009; Coimbra et al., 2009).

Table 5. Estimates of the effects of general combining ability (GCA) of 9 bean strains and specific combining ability (SCA) of their 20 F_1 hybrids evaluated for grain yield in kg/ha, in Coimbra and Viçosa, MG. Drought of 2013.

Coimbra-drought						
Genitors	1	2	3	4	5	GCA I
1*	-1222[A]**	394[ns]	254[ns]	588**	85[ns]	-358*
2*	240[ns]	98[ns]	-192[ns]	119[ns]	183[ns]	168[ns]
3*	108[ns]	197[ns]	195[ns]	-173[ns]	316[ns]	125[ns]
4*	696**	212[ns]	498**	-100[ns]	189[ns]	65[ns]
GCA II	115*	85[ns]	-55[ns]	-190*	45[ns]	
Viçosa-drought						
Genitors	1	2	3	4	5	GCA I
1*	16[ns]	-516[ns]	-881**	339[ns]	126[ns]	-68[ns]
2*	20[ns]	-181[ns]	-117[ns]	195[ns]	-95[ns]	-121[ns]
3*	-239[ns]	-681*	397[ns]	133[ns]	-284[ns]	-81[ns]
4*	432[ns]	-439[ns]	884**	-23[ns]	39[ns]	270*
GCA II	260*	-254*	47[ns]	74[ns]	-127[ns]	

Genitors of group 1: 1* - Goiano Precoce; 2* - Xan112; 3* - Carioca1070; 4* - Rosinha Precoce. Genitors of group 2: 1 - RP1; 2 - VC15; 3 - VC33; 4 - BRSMG Madrepérola; 5 - BRS Estilo. [A]SCA value. [ns], *, **Not significant, significant at 5% and significant at 1% probability, respectively, by the *t*-test.

Table 6. Estimates of the effects of general combining ability (GCA) of 9 bean strains and specific combining ability (SCA) of their 20 F_2 populations evaluated for grain yield in kg/ha, in Coimbra and Viçosa, MG, 2013.

Coimbra-winter						
Genitors	1	2	3	4	5	GCA I
1*	-171[Ans]	-331[ns]	-195[ns]	-24[ns]	-46[ns]	-302*
2*	-108[ns]	332[ns]	24[ns]	88[ns]	121[ns]	156*
3*	-53[ns]	167[ns]	-204[ns]	313[ns]	177[ns]	89[ns]
4*	25[ns]	283[ns]	93[ns]	-409[ns]	-196[ns]	57[ns]
GCA II	182*	-22[ns]	-11[ns]	94[ns]	-243*	
Viçosa-waters						
Genitors	1	2	3	4	5	GCA I
1*	-80[ns]	-468*	218[ns]	-243[ns]	227[ns]	-220*
2*	276[ns]	-248[ns]	196[ns]	337[ns]	576**	-15[ns]
3*	563**	-497*	-10[ns]	-596**	551**	183*
4*	-454*	-162[ns]	22[ns]	-347[ns]	340[ns]	52[ns]
GCA II	102[ns]	-316**	262*	-71[ns]	23[ns]	

Genitors of group 1: 1* - Goiano Precoce-; 2* - Xan112; 3* - Carioca1070; 4* - Rosinha Precoce. Genitors of group 2: 1 - RP1; 2 - VC15; 3 - VC-33; 4 - BRSMG Madrepérola; 5 - BRS Estilo. [A]SCA value. [ns], *, **Not significant, significant at 5% and significant at 1% probability, respectively, by the *t*-test.

Based on the estimates of GCA for the genitors in group II (GCA II) to YLD in the F_1 generation (Table 5) and in the F_2 generation (Table 6), the RP1 strain stood out. Only in the F_2 generation in Viçosa, this strain showed no significant effect of GCA in the water crop of 2013 (Table 6). In this crop, the VC33 strain showed positive and significant estimates of GCA.

In F_1 generation (crop of the 2013 drought in Coimbra), only the combination Rosinha Precoce/RP1 showed a positive and significant effect of SCA for YLD (Table 5). In Viçosa, for this same crop and generation, no hybrid combination stood out because all combinations with the RP1 strain showed no significant estimates for SCA. These results indicate gene complementation between RP1 and Rosinha Precoce genitors for the increase in grain yield as well as

an interaction between the location and grain yield, as the F_1 generation was evaluated in the same crop but in different locations.

In the F_2 generation, the SCA for YLD was not significant in Coimbra in the winter crop of 2013 (Table 6). Although the SCA to YLD was significant in Viçosa in the water crop in 2013, no population showed a significant effect of SCA when the VC33 strain was crossed; the VC33 strain stood out in this crop and generation for the estimate of GCA.

The 3 hybrid combinations of Goiano Precoce/RP1, Goiano Precoce/BRS Madrepérola, and Goiano Precoce/BRS Estilo are the most promising for obtaining early strains and share the Goiano Precoce strain as the common genitor. Only in Viçosa in the F_2 generation, the combinations Goiano Precoce/BRSMG Madrepérola and Goiano Precoce/BRS Estilo flowered at 30 and 31 days, respectively, and exceeded the Goiano Precoce strain that flourished at 32 days (Table 7). The cultivar IPR Andorinha, which is considered as early and was launched in 2012, shows an average flowering time of 35 days (Külzer, 2012).

Table 7. Average of 9 strains, their 20 F_1 hybrids and 20 F_2 populations for the number of days between sowing and emergence (DSE) and grain yield (YLD) in kg/ha, in Coimbra and Viçosa, MG, 2013.

	Treatment	F_1				F_2			
		Coimbra		Viçosa		Coimbra		Viçosa	
		DSE	YLD	DSE	YLD	DSE	YLD	DSE	YLD
Group I	1- Goiano precoce	27	1949	30	2521	34	2782	32	1881
	2- Xan112	37	1827	40	2046	47	3088	41	1549
	3- Carioca1070	32	1645	34	2324	42	2984	36	2511
	4- Rosinha Precoce	31	1797	35	2294	42	3222	35	2457
Group II	1'- RP1	39	3021	41	2462	50	4107	41	2619
	2'- VC15	36	2421	39	2455	50	3318	37	2622
	3'- VC33	40	2203	43	2009	46	3707	35	2779
	4'- BRSMG Madrepérola	42	2104	42	1833	49	3792	42	2849
	5'- BRS Estilo	37	2412	39	1906	50	3076	35	1767
Hybrid combinations	1'/1	29	2232	33	2337	42	3004	38	2159
	1'/2	40	2733	43	2288	47	3527	37	2722
	1'/3	38	2558	43	2067	47	3515	40	3208
	1'/4	39	3085	41	3091	47	3562	37	2059
	2'/1	35	2330	38	1888	38	2639	34	1352
	2'/2	39	2561	43	2570	47	3763	41	1778
	2'/3	38	2618	44	2009	45	3531	34	1728
	2'/4	37	2572	41	2003	46	3616	32	1933
	3'/1	33	2045	37	1924	38	2786	36	2619
	3'/2	38	2124	41	1936	44	3466	41	2802
	3'/3	36	2470	36	2491	42	3170	37	2794
	3'/4	40	2712	40	3330	44	3436	38	2897
	4'/1	34	2248	39	2473	40	3063	30	1822
	4'/2	35	2306	42	2276	45	3636	41	2608
	4'/3	36	1970	41	2354	43	3794	37	1873
	4'/4	36	1982	42	2449	46	3039	39	1992
	5'/1	34	1985	39	2057	41	2704	31	2389
	5'/2	40	2609	43	2182	44	3332	40	2943
	5'/3	40	2700	42	1933	47	3321	36	3117
	5'/4	39	2512	41	2309	45	2916	36	2776

The hybrid combination Rosinha Precoce/RP1 was the most promising for production potential, surpassing the genitor with higher yield in the F_1 generation, strain RP1 (Table 7), indicating that the SCA effects were significant both in Viçosa and Coimbra (Table 5). In the F_2, this combination did not exceed the average of their genitors in Coimbra and showed 398 kg/ha lower yield than their genitor with the lower yield average (Rosinha Precoce) (Table 7).

These results indicate the presence of dominance deviations in the control of grain yield and an interaction between SCA effects and environment for this characteristic (Table 6).

We observed an interaction between the effects of GCA and SCA and generations and environments (crops and location) for both earliness and grain yield.

In the genetic control of earliness, we observed a predominance of additive effects, while in grain yield, dominance effects were observed.

The strain Goiano Precoce can be used as the genitor in breeding programs aiming to improve earliness, while strains RP1 and VC33 can be used to increase grain yield.

Gene complementation was observed for earliness in the crossings of Goiano Precoce with RP1, BRSMG Madrepérola and BRS Estilo strains, and grain yield between RP1 and Rosinha Precoce.

Conflicts of interest

The authors declare no conflict of interest.

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