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Genetic potential of common bean parents for plant architecture improvement

Vanessa Maria Pereira e Silva[1,§]*, Pedro Crescêncio Souza Carneiro[1], José Ângelo Nogueira de Menezes Júnior[2,§] Vinícius Quintão Carneiro[1], José Eustáquio de Souza Carneiro[2], Cosme Damião Cruz[1], Aluizio Borém[2]

[1]UFV – Depto. de Biologia Geral – Av. Peter Henry Rolfs, s/n, Campus Universitário – 36570-000 – Viçosa, MG – Brasil.
[2]UFV – Depto. de Fitotecnia.
*Corresponding author <vanessa@iapar.br>

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ABSTRACT: In common bean (*Phaseolus vulgaris* L.) breeding, plant selection that associate erect plant architecture, high yield, and grains with good commercial acceptance has been the choice of breeders. Thus, this study aimed to evaluate potential parents, to obtain promising segregating populations that associate high yield, erect plant architecture and carioca grain type, as well as to obtain information on heterosis, general and specific combining ability of these parents regarding grain yield and traits related to plant architecture. Fourteen common bean lines were crossed under a partial diallel scheme. Group 1 was composed by eight erect plant lines and group 2 by six carioca grain type lines. The F_1's plants from the crosses and the 14 parents were evaluated during spring (Mar. sowing) for plant architecture grade, diameter of the hipocotyl, plant mean height, and grain yield. Predominance of additive effects was observed for plant architecture grade and diameter of the hypocotyls. For grain yield and plant mean height, there was a greater contribution of the dominance effects. Thus, selection of erect plants, with a larger diameter of the hypocotyl can be carried out in early generations; while for grain yield and plant mean height, it must be delayed, preferably, to later generations.

Keywords: *Phaseolus vulgaris* L., general and specific combining ability, partial diallel, quantitative genetics

Introduction

In common bean (*Phaseolus vulgaris* L.) breeding, selection of individuals with erect plant architecture has been a strategy adopted of many breeders to foster high grain yield (Adams, 1982; Brothers and Kelly, 1993; Coyne, 1980; Dawo et al., 2007; Izquierdo and Hosfield, 1983; Kelly and Adams, 1987; Kelly, 2001). Such plant types ease the use of cultural practices, allow mechanized harvest and prevent pods to come in contact with the ground, ensuring better seed quality. Plants with this architecture can also reduce the incidence of some diseases, such as white mold.

Besides erect plant architecture, selection must also aim at high grain yield and commercial grains. Those traits are not commonly present in a single parent. In this case, hybridization is the most indicated breeding strategy to combine them in a single improved line. Thus, selection of parents with good complementing traits is paramount. Diallel crossing is a method to select parents based on their genetic values, and especially, on their combining ability (Allard, 1960; Griffing, 1956).

Its use originates from the development of concepts of general and specific combining ability established by Sprague and Tatum (1942). General combining ability (GCA) refers to the mean behavior of each parent in crosses with all other parents and, it is associated with the additive genetic effects and the frequency of favorable alleles. The specific combining ability (SCA) is interpreted as the deviation of the hybrid performance in relation to what would be expected based on the GCA of their parents, and it provides information on the non-additive effects (Falconer, 1981; Hallauer and Miranda Filho, 1988). These estimates help to learn about potential good parents and whether selection must be delayed in function of the dominance deviations and epistasis interactions.

The use of diallel crosses is often limited due to the large number of crosses required to evaluate a particular group of parents. Besides, it is not always necessary to evaluate all possible combinations through a complete diallel. Therefore, the use of partial diallels is more desirable (Kempthorne and Curnow, 1961). Within this context, the this study aimed to evaluate the potential of 14 bean parents in a partial diallel, aiming to obtain promising segregating populations for high grain yield, good plant architecture, and carioca grain type, as well as to obtain information on heterosis, general and specific combining ability of those parents, related to plant architecture.

Materials and Methods

Fourteen common bean lines were crossed in a partial diallel scheme (Table 1). The parents were divided into two contrasting groups, based on their plant architecture, yield and grain type. The first group was composed by eight parents, three black grain and erect plants (BRS Valente, BRS Supremo and IPR Uirapuru), three of carioca grain type and also erect plants (BRS Horizonte, CNFC 9466 and A805), but presenting poor yield and/or grain type, and two erect plant lines of mulatinho grain type (A170 and A525). Group 2 was composed by six carioca grain beans, with three originated from crosses with isoline Rudá-R, a source of different genes resistant to anthracnose, angular spot and rust (Ragagnin et al., 2009) (UTF 0013 × Rudá-R, GEN 12-2 × Rudá-R and CNFC 9437 × Rudá-R), denominated in this work as L1, L2, L3, and lines VC6, BRSMG

[§]Present Address: IAPAR – Área de Melhoramento Genético, Rod. Celso Garcia Cid, km 375, C.P. 301 – 86001-970 – Londrina, PR – Brasil.

Table 1 – Origin, grain type, plant type and plant architecture of 14 parents used in the partial diallel crosses.

Parent[a]	Origin	Grain type	Plant type	Plant Architecture
BRS Valente	Embrapa	black	II	Erect
BRS Supremo	Embrapa	black	II	Erect
IPR Uirapuru	IAPAR	black	II	Erect
BRS Horizonte	Embrapa	carioca	II	Erect
CNFC 9466	Embrapa	carioca	II	Erect
A805	CIAT	carioca	II	Erect
A170	CIAT	mulatinho	II	Erect
A525	CIAT	mulatinho	II	Erect
VC6	UFV	carioca	II/III	Semi-prostrate
BRSMG Majestoso	Agreement[b]	carioca	II/III	Semi-prostrate
BRSMG Madrepérola	Agreement[b]	carioca	III	Prostrate
L1	UFV	carioca	II/III	Semi-prostrate
L2	UFV	carioca	III	Prostrate
L3	UFV	carioca	III	Prostrate

[a]The 8 first parents constituted group 1 and the others, group 2 for the diallel crosses. [b]Agreement UFLA/UFV/Epamig/Embrapa.

Majestoso and BRSMG Madrepérola. The group 2 lines present good yield and grains with good commercial aspects, but poor plant architecture (Table 1).

The F_1's seeds were later sown in the field with the parents, in an experiment with 62 treatments (48 hybrids + 14 parents). Evaluation was carried out during spring (Mar. sowing) in a randomized complete block design with three replications. The plots were three lines of 1.4 m, with planting density of 12 seeds m^{-1} and 0.50 m between rows. The experiment was conducted in Viçosa, State of Minas Gerais, Brazil (690 m a.s.l., 20°45′ S, 42°51′ W). The cultural practices adopted were those recommended for the bean crop in the region.

In the field, plant mean height (cm) was evaluated, and plant architecture was rated by a grade scale ranging from 1 to 5, according to Collicchio et al. (1997). In this range, grade 1 refers to type II plant, erect, with a single stem, and high first pod insertion; grade 2 refers to type II plant, erect, and with some ramifications; grade 3, to type II or III plant, erect, with many ramifications and tendency to prostrate growth; grade 4, to type III plant, semi-erect, partially prostrated; and grade 5, to type III plant, with long internodes and very prostrated.

After harvest, other traits related to plant architecture were also evaluated: diameter of the hypocotyls, height of first pod insertion, total number of pods, number of pods in the branches and number of branches. These traits were measured in ten plants removed from the central line from each plot, using their means for the statistical analysis.

The pair-wise genotypic correlations between plant architecture grade, plant mean height, diameter of the hypocotyl, height of insertion of first pod, number of total pods, number of pods in the branches, number of branches and grain yield were estimated to explore the possibility of using them in the selection of more erect plants. The significance of genotypic correlations was tested using the bootstrap a 5 % probability, with 5000 simulations (Davison and Hinkley, 1997).

The mean of the parents and F_1's plants were analyzed according to the partial diallel model proposed by Geraldi and Miranda Filho (1988) and Miranda Filho and Geraldi (1984), adapted from the models proposed by Griffing (1956) and Gardner and Eberhart (1966), respectively. The statistical analyses were carried out using the software GENES (Cruz, 2006).

The model proposed by Geraldi and Miranda Filho (1988), adapted from the model of Griffing (1956) is as follows:

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

where: Y_{ij}: is the mean of the cross involving the i-th parent of group1 and the j-th parent of group 2; Y_i: is the mean of the i-th parent of group 1 (i = 0, 1, 2 ...8); Y_j: is the mean of the j-th parent of group 2 (j = 0, 1, 2 ...6); μ: general mean of the diallel; d_1,d_2 contrast involving means of groups 1 and 2 and the general mean; g_i: effect of general combining ability of the i-th parent of group 1; g_j: effect of general combining ability of the j-th parent of group 2; s_{ij}: effect of specific combining ability; and $\bar{\varepsilon}_{ij}$: experimental error average.

The adaptation of the model of Gardner and Eberhart (1966), proposed by Miranda Filho and Geraldi (1984), is used for detailed study of heterosis in partial diallel, according model described follows:

$$Y_{ij} = u + \alpha d + \frac{1}{2}(v_i + v_j) + \theta(\bar{h} + h_i + h_j + s_{ij}) + \bar{\varepsilon}_{ij}$$

where: Y_{ij}: is the mean of the cross involving the i-th parent of group1 and the j-th parent of group 2; Y_{i0}: is the mean of the i-th parent of group 1 (i = 0, 1, 2 ...8), with α = 1 and θ = 0; Y_{0j}: is the mean of the j-th parent of group 2 (j = 0, 1, 2 ...6), with α = -1 and θ = 0; u: constant associated with the model; d: measure of the difference between mean of the two groups; v_i: effect of the i-th parent of group 1 v_j: effect of the j-th parent of group 2; $\bar{h}$: effect of average heterosis; h_i: effect of heterosis assigned to the i-th parent of group 1; h_j: effect of heterosis assigned to the j-th parent of group 2; s_{ij}: effect of specific heterosis resulting from crosses between parents of order i and j, groups 1 and 2, respectively; $\overline{\varepsilon}_{ij}$: experimental error average.

Results and Discussion

Correlations among characteristics related to plant architecture

Diameter of the hypocotyl and plant mean height were correlated with plant architecture grade (Table 2), indicating that those traits are promising for selection of plants with better architecture. The traits height of the first pod insertion, total number of pods, number of pods in the branches and number of branches presented low correlation with plant architecture grade. Acquaah et al. (1991) identified not only the diameter of the hypocotyl but also plant height as the major indicators of bean plant architecture.

General and Specific Combining Ability

Analysis of variance of the characteristics plant architecture, diameter of the hypocotyl, plant mean height and grain yield indicated the existence of variability among the 14 parents ($p \leq 0.01$) (Table 3). The source of variation treatments was decomposed into effects of general and specific combining ability and contrast for the two groups of parents (G_1 *vs* G_2) were performed. Difference ($p \leq 0.05$) was found between the means of the groups (G_1 *vs* G_2) and between the GCA of group 1 (GCA_1) for all the traits. Difference ($p \leq 0.01$) for the GCA of group 2 (GCA_2) was detected for plant architecture grade, diameter of the hypocotyl and plant mean height. For SCA, difference ($p \leq 0.01$) was observed for plant mean height and grain yield (Table 3).

GCA predominated over SCA for plant architecture grade and diameter of the hypocotyl, suggesting predominance of the additive effects, expressed by the superiority of the sum of the GCA squares. The opposite can also be observed for plant mean height and grain yield, indicating a greater contribution of the effects of dominance for these traits. In this case, the superiority of the sum of squares of SCA was observed for GCA (Table 3). Predominance of non-additive effects associated with grain yield and plant height in common bean was also found by Gonçalves-Vidigal et al. (2008). Also studying GCA and SCA in segregating F_2 populations derived from a complete diallel, Machado et al. (2002) observed predominance of SCA for grain yield. However, some researchers report that additive genetic effects for grain yield and its primary components are predominant in

Table 2 – Estimates pair-wise genotypic correlations between plant architecture grade (PAG), plant mean height (PMH), diameter of the hypocotyl (DH), height of insertion of first pod (HIFP), number of total pods (TP), number of pods in the branches (PB), number of branches (NB) and grain yield (YIELD), in common beans.

	PAG	PMH	DH	HIFP	TP	PB	NB	YIELD
PAG	-	-0.791^{+}	-0.799^{+}	0.185	0.092	0.578	0.387	0.452^{+}
PMH		-	0.783^{+}	-0.157	0.213	-0.285	-0.487^{+}	-0.639^{+}
DH			-	0.229	0.422	-0.307^{+}	-0.414^{+}	-0.164
HIFP				-	0.395^{+}	-0.036	-0.321^{+}	0.408
TP					-	0.346	-0.192	0.091
PB						-	0.647	0.165
NB							-	0.279
YIELD								-

$^{+}$ significant at 5 % using bootstrap with 5000 simulations.

Table 3 – Summary of the analysis of variance for plant architecture grade (PAG), diameter of the hypocotyl (DH), plant mean height (PMH), and grain yield (YIELD) of group 1 and 2 (G_1 and G_2) and of their hybrid combinations, adapted to partial diallel.

Source of variation		PAG		DH		PMH		YIELD	
	df	SS	F	SS	F	SS	F	SS	F
Treatment	61	46.80	4.66**	0.482	8.17**	7550.37	7.98**	32903337.81	5.35**
GCA_1	7	11.42	9.90**	0.202	29.86**	1272.70	11.72**	10031975.60	14.20**
GCA_2	5	11.55	14.03**	0.132	27.27**	1528.19	19.69**	981237.89	1.95^{ns}
SCA	48	8.27	1.05^{ns}	0.061	1.32^{ns}	2738.26	3.68**	21326598.71	4.40**
G_1 *vs* G_2	1	15.56	94.46**	0.087	89.76**	2011.21	129.61**	563525.60	5.59*
Residual	122	20.09		0.118		1893.18		12309626.66	
CV(%)		16.79		5.34		9.73		9.05	

**, *Significant at 1 % and 5 % probability by the F test; ^{ns}non significant; SS: sum squares.

common bean (Kurek et al., 2001; Nienhuis and Singh, 1988). Similar results were found in other species as rice (*Oryza sativa* L.), in which the additive genetic effects prevailed over those of dominance for yield related traits (Torres and Geraldi, 2007).

The prevalence of dominance effects for grain yield, resulting in hybrids with higher yields than that of the best parent, can be due to a divergent selection carried out for grain yield and erect plant architecture between the parents of the two groups of this study. Group 1 was obtained with selection prioritizing plants with better architecture, which may have fixed alleles for grain yield, different from those fixed in group 2, in which selection emphasized high yielding individuals.

The significance of the contrast between mean of the groups (G_1 *vs* G_2) for all the traits (Table 3), confirms that the two groups of parents differ from each another. Group 1 has erect lines while group 2 possesses elite cultivars as far as yield and carioca grain type.

GCA estimates depend on the genetic difference of the parents and on the mean effect of allelic substitution in the other group and are associated with additive effects. SCA, in partial diallel, is a function of the dominance effects and of the product of the differences of allelic frequencies of the parents of the opposite group, making the SCA related to the dominance and epistasis effects (Hallauer and Miranda Filho, 1988).

Line A525, of group 1, and line VC6, of group 2, stand out in relation to the GCA estimates for diameter of the hypocotyl, plant mean height and plant architecture grade (Table 4). For the latter variable, the lowest value is the most desirable, since lower grades indicate plants with more erect architecture. As for grain yield, group 1 A170 line and group 2 BRSMG Madrepérola were outstanding for GCA. Those parents (A525, VC6, A170 and BRSMG Madrepérola) have a higher frequency of favorable alleles for these traits, considering that the allelic frequencies in the parents of one group are relative to that of the parents of the other group.

According to the SCA estimates for grain yield, the most outstanding hybrids were A170 × VC6 and A525 × BRSMG Majestoso (Table 5). For breeding purposes, hybrid combinations with high SCA estimates and involving at least one parent with high GCA are of great importance. Hence, cross A170 × VC6 tends to be more promising because of the high GCA presented by the A170 parent.

For plant architecture grade SCA estimates with negative and high values indicate more erect plants. This was observed for the crosses A170 × L2, A805 × BRSMG Majestoso and BRS Horizonte × L3, with emphasis for the cross A805 × BRSMG Majestoso, in which A805 showed high GCA. On the other hand, for plant mean height, the highest SCA were for BRS Supremo × BRSMG Majestoso, followed by BRS Horizonte x VC6 and BRS Valente × L2, with parent VC6 also presenting a high GCA. For diameter of the hypocotyl, the highest SCA estimate was found for A170 × VC6, with VC6 having high GCA (Table 5).

Lines A170, A805 and A525 presented high SCA values, indicating larger genetic distance among those lines in relation to the other lines of their group. That those lines are from the International Center for Tropical Agriculture (CIAT), showing the importance of using lines from different origins in breeding programs.

Considering grain yield and plant architecture simultaneously, the populations from crosses CNFC 9466 × VC6, BRS Valente × BRSMG Madrepérola and A525 × L1 showed the most promising results. They are promising for the extraction of lines combining these

Table 4 – Estimates of the GCA effects among the parents of group 1 (GCA_1) and group 2 (GCA_2) for diameter of the hypocotyl (DH), plant architecture grade (PAG), plant mean height (PMH) and grain yield (YIELD).

Parents (Group 1)	GCA_1			
	PAG	DH	PMH	YIELD
BRS Valente	0.42	-0.022	-2.21	202.50
BRS Supremo	-0.14	0.009	1.35	37.87
IPR Uirapuru	0.14	0.035	0.52	161.02
BRS Horizonte	0.02	-0.051	-1.75	-182.32
CNFC 9466	0.14	-0.013	-2.35	108.43
A805	-0.23	-0.003	-0.51	-303.98
A170	-0.06	-0.001	-0.21	241.57
A525	-0.29	0.047	5.15	-265.09
Parents (Group 2)	GCA_2			
VC6	-0.35	0.028	3.62	-85.49
BRSMG Majestoso	0.01	-0.006	1.00	-79.32
BRSMG Madrepérola	0.34	-0.045	-4.88	81.33
L1	-0.15	0.024	1.09	-28.24
L2	0.23	-0.013	-1.63	56.94
L3	-0.08	0.012	0.81	54.78

Table 5 – Estimates of the SCA effects between the parents of groups 1 and 2 for plant architecture grade (PAG), diameter of the hypocotyl (DH), plant mean height (PMH) and grain yield (YIELD).

Cross	PAG	DH	PMH	YIELD
BRS Valente × VC6	0.162	-0.005	-2.018	-113.971
BRS Valente × BRSMG Majestoso	-0.033	-0.011	-3.407	157.634
BRS Valente × BRSMG Madrepérola	-0.200	0.016	0.148	328.467
BRS Valente × L1	0.120	-0.015	0.176	-6.410
BRS Valente × L2	0.079	0.001	4.898	41.739
BRS Valente × L3	0.217	0.014	1.788	308.714
BRS Supremo × VC6	0.062	-0.017	-0.585	-19.712
BRS Supremo × BRSMG Majestoso	-0.300	0.021	8.693	-486.996
BRS Supremo × BRSMG Madrepérola	0.034	-0.012	-1.085	-25.422
BRS Supremo × L1	-0.147	0.007	-1.391	-76.965
BRS Supremo × L2	0.311	-0.004	-3.002	213.775
BRS Supremo × L3	-0.216	0.001	-1.446	101.122
IPR Uirapuru × VC6	0.278	-0.029	1.582	140.473
IPR Uirapuru × BRSMG Majestoso	0.084	0.012	-2.474	-149.033
IPR Uirapuru × BRSMG Madrepérola	-0.249	-0.007	-0.251	144.022
IPR Uirapuru × L1	0.070	0.014	-1.223	35.072
IPR Uirapuru × L2	-0.138	0.003	-2.168	160.998
IPR Uirapuru × L3	0.167	0.021	-1.613	348.344
BRS Horizonte × VC6	-0.105	-0.031	5.515	-110.638
BRS Horizonte × BRSMG Majestoso	0.034	0.014	3.126	64.671
BRS Horizonte × BRSMG Madrepérola	0.034	0.025	1.348	398.468
BRS Horizonte × L1	0.019	0.014	-4.291	219.146
BRS Horizonte × L2	0.145	0.025	-0.902	152.480
BRS Horizonte × L3	-0.383	-0.035	1.321	-106.471
CNFC9466 × VC6	-0.222	-0.001	-4.885	367.140
CNFC9466 × BRSMG Majestoso	0.250	0.004	-1.274	151.708
CNFC9466 × BRSMG Madrepérola	-0.083	0.009	-1.385	389.208
CNFC9466 × L1	0.403	-0.004	0.309	-29.002
CNFC9466 × L2	-0.138	-0.030	0.698	-95.669
CNFC9466 × L3	0.001	0.014	0.254	4.640
A805 × VC6	0.312	-0.020	-1.718	135.103
A805 × BRSMG Majestoso	-0.383	-0.010	-3.774	158.560
A805 × BRSMG Madrepérola	-0.217	-0.018	-1.885	-9.496
A805 × L1	-0.063	0.019	1.476	-122.150
A805 × L2	0.229	-0.031	-2.135	242.665
A805 × L3	-0.132	0.003	0.421	96.677
A170 × VC6	-0.022	0.046	-0.018	796.955
A170 × BRSMG Majestoso	0.117	-0.009	-3.407	-318.477
A170 × BRSMG Madrepérola	-0.216	0.031	-3.518	-1.347
A170 × L1	-0.063	-0.021	-0.490	108.220
A170 × L2	-0.438	0.015	-3.768	217.480
A170 × L3	0.033	-0.001	-1.879	406.677
A525 × VC6	0.545	-0.008	-9.385	240.659
A525 × BRSMG Majestoso	0.018	-0.036	-4.774	756.708
A525 × BRSMG Madrepérola	0.017	0.003	-2.885	-328.015
A525 × L1	-0.164	-0.026	-0.191	374.146
A525 × L2	-0.039	0.006	-8.802	587.109
A525 × L3	0.101	-0.004	-0.913	89.270

two traits. Those crosses were not the ones showing the highest potential, considering each trait individually. Therefore, alleles important for yield could not be present in populations developed for plant architecture, such as A170 × VC6. Thus, an alternative to maximize the potential of the segregating populations as a source of promising lines aiming at both yield and plant architecture would be a double cross between the F_1's single crosses [(A170 × VC6) × (A805 × BRSMG Majestoso)].

Decomposition of the heterosis effect

The decomposition of the effect of SCA into medium heterosis, varietal heterosis, (attributed to the various genotypes within each group) and specific heterosis is justified only when it presents a statistical significant effect. Thus, for plant mean height and grain yield, heterosis decomposition was done and they are shown in Table 6.

Considering plant mean height, there were differences ($p \leq 0.01$) for heterosis medium and varietal heterosis of group 1 (G_1), and specific heterosis ($p \leq 0.05$), while for grain yield differences were obtained for all the effects ($p \leq 0.05$). For plant mean height, just group 1 lines presented heterotic effects, while, for grain yield, this conclusion is valid for lines of groups 1 and 2. The lines with higher varietal heterosis effect are more genetically distant from each other, or their alleles presented greater dominance deviations, compared to those of lower heterotic effect. Parents with greater genetic diversity are required in crosses aiming transgressive segregation. The significance of the effect of specific heterosis for grain yield and plant mean height shows that the parents presented non allelic genes with epistatic interaction. The interactions dominant × dominant, dominant × additive and additive × dominant are not inheritable, just being useful in hybrids.

Comparing hybrid means with those of the parents (Table 6), it can be observed that hybrids were higher yielding than the parents. For diameter of the hypocotyl and plant architecture grade, the means of the hybrids were similar to those of the parents and for plant mean height, the hybrids were shorter than the parents. These results indicate the existence of heterosis for grain yield and plant mean height, resulting from positive dominance deviations for the genes for grain yield and negative for plant mean height.

The heterosis values in the crosses varied in magnitude and signal (Table 7). In group 1, cross A525 × L2 is superior for grain yield. This cross presented heterosis of 1397 kg ha^{-1}, surpassing the mean of both parents in 56 %. The combinations A170 × VC6 (48.5 %) and A525 × BRSMG Majestoso (47.8 %) also presented high heterosis for grain yield.

The crosses with greater heterosis value for plant mean height were BRS Supremo × BRSMG Majestoso and BRS Horizonte × VC6, with a heterosis value of 7.17 cm (16.2 %) and 4.17 cm (9.6 %), respectively, (Table 7). However, the hybrids with greater heterosis did not always present the highest means due to the fact that the superiority of a hybrid depends on both the amount of heterozygous loci and on the means of the parents.

The estimates of the variety effects (v_i and v_j) of the parents of each group are presented in Table 8. The *per se* effect of a parent is an indicative of frequency of its favorable alleles. In the case of grain yield, varieties BRS Supremo (group1) and BRSMG Madrepérola (group 2) presented the highest *per se* effects, indicating a greater concentration of favorable alleles in those parents. For plant architecture grade, diameter of the hypocotyl, and plant mean height, group 1 line A525, and group 2 line VC6, presented the largest frequency of favorable alleles. For plant architecture grade negative effects is an indication of a great concentration of favorable alleles.

In group 1, considering the effects of varietal heterosis for grain yield (Table 8), A525, L2 and VC6 presented the highest values. While, for plant architecture grade and diameter of the hypocotyl, A170 and, for plant mean height, BRS Horizonte were superior. In group 2, BRSMG Madrepérola and L3 presented a greater estimate of varietal heterosis, being BRSMG Madrepérola the best for plant architecture grade and diameter of the hypocotyls, while L3 for plant mean height. Gonçalves-Vidigal et al. (2008) observed heterosis for common bean grain yield and also noted that the hybridization

Table 6 – Summary of analysis of variance, adapted to partial diallel, for plant architecture grade (PAG), diameter of the hypocotyl (DH), plant mean height (PMH) and grain yield (YIELD) of the parents of groups 1 and 2 (G_1 and G_2) and decomposition of heterosis of its hybrid combinations.

Source of variation	df	Mean Square			
		PAG	DH	PMH	YIELD
Treatments	61	0.77**	0.008**	123.78**	539398.98**
GCA_1	7	1.63**	0.029**	181.81**	1433139.37**
GCA_2	5	2.31**	0.026**	305.64**	196247.58^{ns}
G_1 vs G_2	1	15.56**	0.087**	2011.21**	563525.60*
Heterosis (SCA)	48	0.17^{ns}	0.001^{ns}	57.05**	444304.14**
Mean Heterosis	1	-	-	736.81**	9917738.92**
Varietal Heterosis (G_1)	7	-	-	133.29**	415808.08**
Varietal Heterosis (G_2)	5	-	-	23.81^{ns}	275347.76*
Specific Heterosis	35	-	-	27.13*	203470.41**
Residue	122	0.16	0.001	15.52	100898.58
Mean of the hybrids		2.434	0.580 cm	39 cm	3637 kg ha^{-1}
Mean of the parents		2.445	0.585 cm	44 cm	3081 kg ha^{-1}

**, *Significant at 1 % and 5 % of probability by the F test; ^{ns}non significant.

Table 7 – Heterosis (h) values in relation to the mean of the parents for grain yield (YIELD) and plant mean height (PMH).

Cross	YIELD		PMH	
	h (kg ha^{-1})	%	h (cm)	%
BRS Valente × VC6	424	13.71	-4.50	-10.19
BRS Valente × BRSMG Majestoso	420	12.46	-4.83	-11.93
BRS Valente × BRSMG Madrepérola	731	21.55	-1.83	-5.21
BRS Valente × L1	298	8.81	-0.83	-2.08
BRS Valente × L2	601	18.70	1.50	3.76
BRS Valente × L3	800	24.39	1.67	4.27
BRS Supremo × VC6	266	8.36	-3.17	-6.62
BRS Supremo × BRSMG Majestoso	-477	-13.77	7.17	16.23
BRS Supremo × BRSMG Madrepérola	125	3.59	-3.17	-8.15
BRS Supremo × L1	-25	-0.72	-2.50	-5.70
BRS Supremo × L2	520	15.76	-6.50	-14.94
BRS Supremo × L3	340	10.09	-1.67	-3.91
IPR Uirapuru × VC6	669	21.88	-2.83	-5.80
IPR Uirapuru × BRSMG Majestoso	105	3.13	-5.83	-12.92
IPR Uirapuru × BRSMG Madrepérola	538	16.00	-4.17	-10.46
IPR Uirapuru × L1	331	9.87	-4.17	-9.29
IPR Uirapuru × L2	711	22.35	-7.50	-16.85
IPR Uirapuru × L3	831	25.58	-3.67	-8.40
BRS Horizonte × VC6	403	14.74	4.17	9.58
BRS Horizonte × BRSMG Majestoso	303	10.05	2.83	7.11
BRS Horizonte × BRSMG Madrepérola	777	25.60	0.50	1.45
BRS Horizonte × L1	499	16.51	-4.17	-10.55
BRS Horizonte × L2	687	24.08	-3.17	-8.09
BRS Horizonte × L3	360	12.34	2.33	6.09
CNFC9466 × VC6	923	30.97	-9.33	-20.29
CNFC9466 × BRSMG Majestoso	432	13.26	-4.67	-11.02
CNFC9466 × BRSMG Madrepérola	810	24.68	-5.33	-14.41
CNFC9466 × L1	294	8.97	-2.67	-6.35
CNFC9466 × L2	481	15.52	-4.67	-11.20
CNFC9466 × L3	514	16.22	-1.83	-4.49
A805 × VC6	619	23.47	-6.50	-13.49
A805 × BRSMG Majestoso	368	12.58	-7.50	-16.85
A805 × BRSMG Madrepérola	340	11.55	-6.17	-15.74
A805 × L1	129	4.39	-1.83	-4.15
A805 × L2	748	27.10	-7.83	-17.87
A805 × L3	534	18.90	-2.00	-4.65
A170 × VC6	1458	48.48	-6.17	-12.37
A170 × BRSMG Majestoso	68	2.06	-8.50	-18.41
A170 × BRSMG Madrepérola	525	15.86	-9.17	-22.45
A170 × L1	536	16.25	-5.17	-11.27
A170 × L2	900	28.76	-10.83	-23.81
A170 × L3	1021	31.96	-5.67	-12.69
A525 × VC6	1030	43.37	-19.00	-32.39
A525 × BRSMG Majestoso	1270	47.84	-13.33	-24.24
A525 × BRSMG Madrepérola	326	12.18	-12.00	-24.16
A525 × L1	930	34.89	-8.33	-15.24
A525 × L2	1397	55.99	-19.33	-35.58
A525 × L3	831	32.47	-8.17	-15.27

of cultivars belonging to distinct commercial groups favors higher heterosis. Similar results were obtained by Foolad and Bassiri (1983), Gutiérrez and Singh (1985), Nienhuis and Singh (1986), who also verified heterosis for grain yield.

It can be concluded that grain yield and the traits related to plant architecture present great complexity, making selection of erect and high yielding plants difficult. However, the selection of erect plants with a higher diameter of the hypocotyls can be carried out at

Table 8 – Estimates of the effects of varieties (v_i and v_j) and varietal heterosis (h_i and h_j) associated to groups 1 and 2, respectively, for plant architecture grade (PAG), diameter of the hypocotyl (DH), plant mean height (PMH) and grain yield (YIELD).

	PAG		DH		PMH		YIELD	
Group 1	v_i	h_i	v_i	h_i	v_i	h_i	v_i	h_i
BRS Valente	0.67	0.15	-0.045	0.0019	-8.42	3.33	418.06	-10.88
BRS Supremo	-0.17	-0.10	0.017	0.0004	-1.08	3.16	593.98	-431.87
IPR Uirapuru	0.17	0.09	0.060	0.0086	0.92	0.10	353.24	-26.00
BRS Horizonte	0.17	-0.10	-0.111	0.0078	-9.75	5.22	-302.32	-51.93
CNFC 9466	0.17	0.09	-0.025	-0.0012	-4.75	0.48	193.98	19.06
A805	-0.33	-0.10	0.019	-0.0211	-0.42	-0.51	-487.50	-100.39
A170	0.17	-0.24	-0.035	0.0278	2.92	-2.78	249.54	194.68
A525	-0.83	0.20	0.123	-0.0242	20.58	-8.56	-1018.98	407.33
Group 2	v_j	h_j	v_j	h_j	v_j	h_j	v_j	h_j
VC6	-1.22	0.39	0.084	-0.0215	8.72	-1.12	-394.14	167.36
BRSMG Majestoso	0.11	-0.07	-0.008	-0.0028	1.39	0.47	168.82	-245.60
BRSMG Madrepérola	1.11	-0.32	-0.116	0.0203	-9.28	-0.37	209.57	-35.19
L1	-0.39	0.07	0.050	-0.0016	0.72	1.09	187.35	-182.87
L2	0.44	0.01	-0.023	-0.0021	0.06	-2.49	-151.54	199.07
L3	-0.06	-0.07	0.014	0.0077	-1.61	2.42	-20.06	97.22

early generations, due to the action of the additive effect genes. For grain yield and plant mean height, selection must be done preferably, in more advanced generations, as there is greater contribution of dominance effects for these traits. In the F_4 generation dominance deviations are reduced by 87.5 %. Thus, it recommended that bulks should be opened at this generation, aiming to select high yielding lines that also have erect plant architecture.

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