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Alternative procedures for parent choice in a breeding program for the common bean (*Phaseolus vulgaris* L.)

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ABSTRACT

Six common bean cultivars were crossed in diallel and the segregant populations were assessed in the F_2 and F_3 generations to compare methodologies for parental selection in a breeding program based on hybridization. The cultivars involved in the diallel were A 114, A 77, ESAL 686, Milionário, Carioca, and Flor de Mayo. The segregant F_2 and F_3 generations were assessed on the experimental campus of the Universidade Federal de Lavras, in July 1994. It was found that the cultivars differed in their general combining ability (GCA). Flor de Mayo, which belongs to the Durango race, had the largest positive GCA estimate for grain yield, and the cultivars from the Mesoamerican race, Milionário and A 114, the smallest GCA estimates. For flowering, the cultivar that most contributed to reduced plant cycle was ESAL 686. There was agreement among the results obtained from the diallel and the estimates of the parameter m + a of the populations. However, it was evident that the estimate of genetic variance of the populations should be considered as a condition to identify the hybrid population that will produce a line with high performance.

INTRODUCTION

Most cultivated species developed through artificial breeding achieve higher levels of productivity than wild species. The greatest challenge facing the breeders, however, is to obtain continuous improvement because the differences between materials submitted to selection become smaller and demand more refined experimental techniques to continue being successful.

Hybridization is the main method used in the majority of programs for breeding self-pollinating plant species. It combines desirable genes available in two or more different individuals into one. The choice of the parents is the most critical stage in applying the method, since a mistaken choice results in poor results and time and resources are wasted. Reports describing methodologies for choice of parents to cross have been published (Baenziger and Peterson, 1991; Otubo, 1994; Triller, 1994).

One of the recommended methods used for selecting self-pollinating plant populations with greater potential for line extraction relies on the estimate of m + a of the population (Vencovsky, 1987); m is the average of the contribution of the homozygous loci and a the algebraic sum of the effects of the homozigous loci measured as deviations from the mean. This procedure was recommended in self-pollinating species by Gallais (1979). There is little information, however, on its efficacy in selecting segregant populations. Our objective is to compare the efficiency of the estimate of m + a and the diallel crosses for choosing parents of the common bean for hybridization.

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MATERIAL AND METHODS

Six cultivars (Table I) were crossed in a diallel design, and their respective F_2 and F_3 generations studied. The assessment of the F_2 and F_3 segregant generations and the parents was determined in a randomized complete block design with four replications. For each F_2 and F_3 generation a separate experiment was used. The plot consisted of two 3-m and two 5-m rows in the F_2 and F_3 generations, respectively. The traits assessed were number of days to flowering and grain yield. At harvest a sample of 30 F_2 plants was taken to assess the phenotypic variance of the segregant population. The phenotypic variance of the respective parents was subtracted from this estimate and the genetic variance of the population in question was then obtained.

A diallel analysis was performed using the mean data and the Method IV proposed by Griffing (1956). The estimation of the parameters of the model was by least squares analysis because it was not possible to obtain all of the segregant populations (Vencovsky and Barriga, 1992).

The estimates of m + a were obtained by the contrast:

$m + a = 2 F_3 - F_2$, since $F_3 = m + a + 1/4\ d$ and $F_2 = m + a + 1/2\ d$. The comparison of the m + a estimates of the two segregant populations (ith and jth) was given by the contrast $Y_{ij} = (2\overline{F}_{3i} - \overline{F}_{2i}) - (2\overline{F}_{3j} - \overline{F}_{2j})$. The *t*-test was used to check the significance of this contrast.

RESULTS AND DISCUSSION

The generation effects are confounded with those of the experiment because the two generations were assessed in separate experiments. However, the environment difference between the experiments should be small, because the replications of the two experiments were alternated in the same experimental area. Thus, only the generation effects will be mentioned, disregarding possible environment differences between the experiments.

The mean number of days to flowering (53.7 days) was greater than normally reported for the common bean. The experiment was sown in July, in the middle of the winter season in the region. Low temperatures slow germination and emergence of the bean plant and the beginning of the vegetative development, which reflects directly on the cycle (Von Pinho, 1990).

The mean number of days to flowering of the F_2 generation (53.5 days) was 0.5 less than the F_3 generation (54.0 days). This difference, although significant (Table II), suggests that dominance was not important. Reports suggest flowering is controlled by one or two genes with dominance of the allele expressing earliness (Masaya, 1989; Teixeira *et al.*, 1995). There are also reports of polygenic control with a predominance of additive effects (White and Singh, 1991). This suggests that there must be some major genes associated with modifiers controlling time of flowering, and differences depend on the parents involved in the crosses.

The parents differed in grain yield (Tables II and III). It was expected that the introduced materials, less adapted, would be less productive. This happened in the case of cultivar A 114, but Flor de Mayo, another introduced cultivar, was the most productive cultivar, although not significantly different from the cultivars recommended for the region, Carioca and Milionário.

The source of variation, parents vs. hybrids, was not significant, indicating absence of average heterosis (Gardner and Eberhart, 1966) (the parental mean did not differ from the mean of the hybrids). Specific combining ability (SCA) also was not significant (Table II). Heterosis depends on the divergence between the parents and the presence of dominance (Falconer, 1987). Since the parents were divergent it can be deduced that there is no manifestation of dominance for grain yield. Absence of dominance in the genetic control of grain yield in the common bean plant has been reported (Santos *et al.*, 1985; Nienhuis and Singh, 1988).

A good agreement was observed between the mean performance of the parents and the estimate of the general combining ability (GCA). For the mean number of days to flowering, the earliest

Table I - Agronomic characteristics of the common bean cultivars used in the diallel.

Cultivars	Origin[1/]	Growth habit[2/]	Race	Grain color
Flor de Mayo	CIAT	III	Durango	Variegated pink
Carioca	IAC	III	Mesoamérica	Beige with brown stripes
Milionário	UFV	II	Mesoamérica	Black
A 114	CIAT	II	Durango	Variegated purple
A 77	CIAT	I	Mesoamérica	Beige with brown stripes
ESAL 686	UFLA	I	Nova Granada	Yellow

[1/]CIAT, Centro Internacional de Agricultura Tropical; IAC, Instituto Agronômico de Campinas; UFV, Universidade Federal de Viçosa; UFLA, Universidade Federal de Lavras.
[2/]I, Determinate growth habit; II, indeterminate growth habit with short guides; III, indeterminate growth habit with long guides.

Table II - Summary of the joint analysis of variance for the F_2 and F_3 generations for grain yields and flowering.

Source of variation	Degree of freedom	Mean square	
		Flowering	Yield
Bloc/Generation	6	2.90	383477.40
Generation (G)	1	15.34*	40828.65
Treatments (T)	17	86.29**	594823.77**
Between hybrids	11	30.45**	489443.94**
GCA	5	60.36**	748492.72**
SCA	6	5.52	273569.95
Between parents	5	226.37**	907288.56**
Parents vs. Hybrids	1	0.06	191677.88
T × G	17	4.86	323356.42
Between hybrids × G	11	3.63	343949.08
GCA × G	5	56.97**	184924.65*
SCA × G	6	1.69	476469.52
Parents × G	5	8.34	218633.09
Parents vs. Hyb. × G	1	14.20	620454.92
Error	102	3.88	159796.29
Average		53.70	1428.50
CV		3.67%	28.90%

**,* Indicate F test significant at the 1% and 5% levels of probability, respectively.

parent, ESAL 686, contributed most to reduce the cycle of the segregant populations, and Flor de Mayo, the highest yielding cultivar, had the greatest GCA estimate for grain yield (Table III). The estimates of the GCA for grain yield agree with those reported in the literature. The cultivars Carioca and Milionário, belonging respectively to gene pool 3 and 2, of the Mesoamerica race, had negative GCA estimates. Similar results were reported by Nienhuis and Singh (1988) and Singh and Urrea (1995). These same authors reported greater combining ability between materials belonging to different gene pools. They also emphasized that cultivars belonging to gene pool 5, race Durango, should have better combining ability with other gene pools. This conclusion was true for the cultivar Flor de Mayo but not for line A 114, which belongs to the same race. A 114 did not have a good performance *per se*, being little adapted to the conditions of southern Minas Gerais State. Poor adaptation must have contributed to its negative GCA estimate. Similar results were reported by Singh and Urrea (1995).

Cultivar ESAL 686 was expected to have good combining ability, because of great divergence from other cultivars. This inference could not be tested because it was not possible to obtain hybrid seeds from this cultivar in crosses with A 77, A 114, and Carioca. Crosses were not possible because of incompatibility for the crosses involving materials from gene pool 2 and 3 (A 77 and Carioca), which have small seeds. This incompatibility is common in crosses with large seeded beans, as was found for ESAL 686 when crossed with small seed lines (Coyne, 1965; Vieira *et al.*, 1989).

The diallel crossing scheme is an excellent tool for breeders in selecting parents and/or segregant populations in a breeding program of self-pollinating

Table III - Estimate of the general combining ability of the F_2 and F_3 generations and the mean of the two generations, for grain yield and flowering.

Trait	Cultivar	GCA			Average number of days to flowering
		F_2	F_3	Generations mean	
Flowering	A 77	-0.23 (0.49)	-0.67 (0.54)	-0.45 (0.25)[1]	52.25 b
	A 114	-0.06 (0.49)	0.83 (0.54)	0.38 (0.25)	56.75 a
	Milionário	1.51 (0.45)	0.71 (0.50)	1.11 (0.23)	57.12 a
	Carioca	1.77 (0.49)	1.25 (0.54)	1.51 (0.25)	58.62 a
	Flor de Mayo	-1.30 (0.45)	-0.79 (0.50)	-1.05 (0.23)	53.62 b
	ESAL 686	-3.48 (0.72)	-2.63 (0.81)	-3.05 (0.38)	44.00 c
					Mean Yield
Yield	A 77	-173.36 (108.15)	58.60 (99.70)	58.60 (73.55)	1292.10 b
	A 114	-166.35 (108.15)	-107.27 (99.70)	-107.27 (73.55)	943.50 c
	Milionário	35.16 (99.49)	-238.57 (91.71)	-238.57 (67.65)	1628.30 ab
	Carioca	-24.78 (108.15)	-89.99 (99.71)	-89.99 (73.55)	1409.10 abc
	Flor de Mayo	279.56 (99.49)	291.49 (91.71)	291.49 (67.65)	1868.50 a
	ESAL 686	-57.83 (161.54)	145.03 (148.91)	145.03 (109.85)	1119.60 bc

[1]Values within parentheses refer to the standard error of the estimates.
Means followed by different letters in the column are different at the 5% level of probability by the Duncan test.

species involving hybridization. The main restriction to diallels is that, depending on the number of parents, the work involved in hybridization and making assessments of the segregant populations is increased. This is because with n parents it will be necessary to evaluate $n(n - 1)/2$ hybrids.

The estimate of m + a in biparental crossings, where the allelic frequency on the loci is 0.5, assesses the segregant population potential for the fixed homozygous loci. Thus a population with a large m + a estimate has, in relation to the others, greater occurrence of loci with favorable homozygous alleles. The largest estimate of m + a was obtained in the cross between A 114 and Flor de Mayo (Table IV) and is, therefore, the population which has the greatest frequency of loci with favorable homozygous alleles. The opposite happened in the cross A 114 × Milionário, which showed a low m + a estimate.

Self-pollinating the two populations and calculating the contrast $(S_{1i} - S_{1j}) - 1/2\,(S_{0i} - S_{0j})$ is the same as comparing the combining ability of the two populations in crosses with a tester with allelic frequency t = 0.5 in all loci (Vencovsky, 1987). The contrast would be $(2F_{3i} - F_{2i}) - (2F_{3j} - F_{2j})$ when adapted for self-pollinating species. Table IV shows that population A 114 × Flor de Mayo had significant contrast ($P \leq 0.05$) in relation to four of the 12 populations (A 77 × Milionário, A 114 × Milionário, A 114 × Carioca and Milionário × Flor de Mayo). It can thus be inferred that this population would have a larger combining ability if assessed with a tester of 0.5 allelic frequency, since the expression which provides the estimate of the combining ability with a tester is: $(p_i - \overline{p})\,[\alpha + (1 - 2t)\,\delta]$ (Vencovsky, 1987). If $t = 1/2$, the expression of the combining ability is $(p_i - \overline{p})\alpha$. This contrast allows the detection of the population which has the largest frequency of favorable alleles. If the contrast is positive it indicates that $p_i > \overline{p}$. This is also valid when $\delta = 0$, absence of dominance, which was the case of the experiment, with any allele frequency of the tester.

The main advantage of this procedure is that it allows comparison of any number of segregant populations, demanding only that they be assessed in two generations, that is F_1 and F_2 or F_2 and F_3. When a two-way cross is used, as was the case in this research, the m + a estimate is equal to the mean of the parents. However, that estimate is different in crosses from more than two parents, which are very common in breeding of self-pollinated species. However, for the loci that are segregating (that is, those in which one parent complements the other and which, therefore, allow advances through selection) and are not detected by the estimation of m + a, it is necessary to associate this estimate with the genetic variance (σ^2_G) of the population. This is because populations with a large estimate of m + a identify the population with a great frequency of loci fixed with favorable alleles and σ^2_G allows the detection of those populations with a great frequency of segregant loci.

The estimates of genetic variance in the F_2 generation (Table IV) show that the population A 114 × Flor de Mayo, with a larger estimate of m + a, must have a smaller number of segregant loci, since its genetic variance was nil. Considering that the two parents involved belong to the same race, it is expected that they have less genetic divergence and less genetic segregation. Selection for grain yield in the population A 114 × Flor de Mayo, therefore, should be less efficient, i.e., the extracted lines would have performance similar to their parents. Carioca × Flor de Mayo and Milionário × A 114 were populations showing large genetic variance. The variance estimates at the plant level, however, are also associated with large errors. Nevertheless, it is important that the breeder pays attention to these estimates as they can contribute to greater efficiency in the selective process.

The procedure of Jinks and Pooni (1976) is used to predict the cross potential, using the mean and variance estimated from the initial generations. In the estimate of the mean of the line of the F_∞ generation, the

Table IV - Estimate of m + a of the F_2 and F_3 generations of the diallel cross for grain yield (above diagonal) and the estimate of the genetic variance for the F_2 generation (below the diagonal).

Cultivars	A 77	A 114	Milionário	Carioca	Flor de Mayo	ESAL 686	Mean m + a
A 77	-	1946.20	955.50	1069.90	2240.60	-	1553.00
A 114	1.025	-	239.70	762.70	2247.20	-	1298.90
Milionário	4.04	19.80	-	1553.60	664.80	1591.27	1000.90
Carioca	7.56	13.54	16.81	-	1488.60	-	1218.70
Flor de Mayo	0.00	0.00	5.49	18.81	-	1626.69	1653.50
ESAL 686	-	-	6.84	-	16.48	-	1609.00

Least significant difference by the *t*-test at the 5% level of probability - 1253.2 kg/ha.

mean of the F_3 generation has been used (Triller, 1994 and Otubo, 1994). In this case, the restriction of no dominance was adopted, as d = 0 was presumed. However, when using the estimate of m + a, no restriction is necessary in relation to the level of dominance. Thus, the association of the two procedures allows the breeder to assess the potential of segregant populations, with the above mentioned advantages. It is obvious that the success of this prediction will always be related to the assessment accuracy for reliable estimates of m + a, and the genetic variance.

RESUMO

Seis cultivares de feijão foram cruzadas em um esquema dialélico e as populações segregantes avaliadas nas gerações F_2 e F_3 visando comparar metodologias de escolha dos parentais em um programa de melhoramento por hibridação. Os materiais envolvidos no dialelo foram A 114, A 77, ESAL 686, Milionário, Carioca e Flor de Mayo. As populações segregantes nas gerações F_2 e F_3 foram avaliadas no campus experimental da Universidade Federal de Lavras, em julho de 1994. Constatou-se que as cultivares diferiram na capacidade geral de combinação (GCA). A Flor de Mayo, pertencente à raça Durango, foi a que mostrou maior estimativa positiva da GCA para a produtividade de grãos, e as cultivares da raça Mesoamericana, Carioca, Milionário e A 77 os maiores valores de GCA negativa. Para o florescimento, o parental que mais contribuiu para reduzir o ciclo foi a linhagem ESAL 686. Houve coerência nos resultados obtidos através dos cruzamentos dialélicos e da estimativa do parâmetro m + a das populações. Contudo, ficou evidenciada a importância de comparar também a estimativa da variância genética dentro das populações como condição para se identificar a população híbrida que irá produzir a linhagem de melhor desempenho.

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