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# Diallel analysis for grain yield and yield components in *Phaseolus vulgaris* L.

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**ABSTRACT.** Six common bean (*Phaseolus vulgaris* L.) cultivars and their 15 possible diallel hybrids were assessed for combining ability of yield and its components. A random block design was used with ten replications, in the state Paraná in 1997. Diallel analysis according to Griffing (1956) was used which indicated the predominance of additive gene effects for total number of pods per plant and mean seed weight characteristics. However, mean number of seeds per pod and grain yield characteristics, there was equivalence of the additive and non-additive gene effects. The Rudá, Aporé and Campeão-1 cultivars are indicated for obtaining superior genotypes by intrapopulation breeding from the estimates of the combining abilities for grain yield. The combinations LPSPI 93-19 x Rudá, Rudá x Campeão-1, FT-Nobre x Aporé, LPSPI 93-17 x FT-Nobre, and LPSPI 93-17 x Aporé, showed greater potential for generating promising segregants.

**Key words:** *Phaseolus vulgaris*, common bean, diallel analysis.

**RESUMO. Análise dialélica para produção de grãos e componentes de produção em *Phaseolus vulgaris* L.** Avaliaram-se seis cultivares de feijoeiro (*Phaseolus vulgaris* L.) e seus 15 híbridos dialélicos possíveis, para verificar a capacidade combinatória em relação à produção e seus componentes de rendimento. O delineamento experimental foi em blocos casualizados com dez repetições, no Estado do Paraná, em 1997. Utilizou-se a metodologia de análise dialélica conforme Griffing (1956), indicando, assim, a predominância de efeitos gênicos aditivos para as características número total de vagens por planta e peso médio de sementes. Entretanto, para as características número médio de sementes por vagem e produção de grãos, houve equivalência dos efeitos gênicos aditivos e não-aditivos. Pelas estimativas das capacidades combinatórias, para a produção de grãos, os cultivares Rudá, Aporé e Campeão-1 são os indicados para a obtenção de genótipos superiores por meio do melhoramento intrapopulacional. As combinações LPSPI 93-19 x Rudá, Rudá x Campeão-1, FT-Nobre x Aporé, LPSPI 93-17 x FT-Nobre, e LPSPI 93-17 x Aporé destacaram-se das demais, demonstrando potencial para gerar segregantes promissores.

**Palavras-chave:** *Phaseolus vulgaris*, feijão, analise dialélica.

The common bean (*Phaseolus vulgaris* L.) is one of the most economically and socially important agricultural products in Brazil (Ramalho *et al.*, 1993). Combined with rice it forms the nutritional base of the Brazilian people, especially the low-income classes (Vieira, 1988) and is also an important protein source in the population's diet (Yokoyama *et al.*, 1996).

The national productivity, however, is low (about 600 kg/ha$^{-1}$) and there have been significant imports of the product to meet the internal market needs (Demarchi, 1995).

The northwest of Paraná state has a contribution to the state production of less than 2% of the total (Demarchi, 1997). This underlines the need to develop cultivars with greater grain yield capacity with adaptation to the area.

Greater productivity from common beans could be obtained by the selection in segregating populations obtained from hybridization of superior cultivars. The procedure of diallel crosses is a viable alternative for this because it allows wide recombination of the genomes with greater possibilities of obtaining superior cultivars in segregant generations (Ayele, 1994; Cruz and Regazzi, 1994). The diallel analysis helps specifically to choose the most promising segregant populations for selection. Obtaining cultivars with better productive performance should be one of the primary objectives in common bean breeding programs. A viable alternative for this is the widening of the genetic base of the species by breeding programs using hybridization because the diversity shown within each population is generally inexpressive because of its selfpollination (Costa and Zimmermann, 1989).

The present study was carried out using a diallel cross system between six common bean cultivars to assess the general and specific combining abilities and discriminate the superior parents and hybrid combinations as a first step in developing a breeding program for the species, to increase productivity in northwestern Paraná.

## Material and methods

This study was carried out using a system of diallel crosses between six common bean parents. The common bean cultivars LPSPI 93-17, LPSPI 93-19, FT-Nobre, Aporé, Rudá and Campeão-1 were chosen because of their divergent morphoagronomic characteristics, as shown in Table 1.

The parents were crossed among each other, following a complete diallel cross scheme, without reciprocals. The method of mechanical emasculation using pincers as proposed by Vieira (1967) was used in the crosses of flower buds on the event of the antesis, followed by crossed pollination with mature pollen, from open flowers of the male parents.

**Treatment and experimental procedure.** The populations made up of the six parents and 15 $F_1$'s, totaling 21 treatments, were assessed in the greenhouse at the *Núcleo de Pesquisa Aplicada à Agricultura (Nupagri)*, at the Department of Agronomy, *Universidade Estadual de Maringá*, Maringá, PR, 1997. A randomized block design was used with ten replications. The seeds were sown in $5dm^3$ pots, containing substrate, with four seeds per pot. They were thinned seven days after emergence, and two plants were left per pot. Each pot with two plants constituted the experimental unit.

**The $F_1$'s and parents were evaluated in the following way:**

a) Total number of pods per plant (TNPP): obtained by total count of pods produced per plant, in each treatment.

b) Mean number of seeds per pod (MNSP): obtained by the ratio between the total number of seeds and the total number of pods produced per plant, in each treatment.

**Table 1.** Common bean cultivars used in diallel cross and some of their agronomic traits

| Cultivars | Growth habit[a] | Grain color | Reaction to disease[b] |
|---|---|---|---|
| LPSPI 93-17 | III | Cream with brown stripes | R - Powdery mildew<br>MR - Rust<br>MR - Anthracnose<br>S - Bacterial blight<br>S - Angular leaf spot |
| LPSPI 93-19 | III | Black | MR - Bacterial blight<br>MR - Powdery mildew<br>S - Anthracnose<br>S - Angular leaf spot |
| FT-Nobre | II | Black | MR - Anthracnose<br>MR - Angular leaf spot<br>MR - Rust<br>S - Bacterial blight |
| Aporé | III | Cream with brown stripes | R - Bean common mosaic virus<br>R - Rust<br>MR - Anthracnose<br>MR - Angular leaf spot<br>MR - Bacterial blight<br>S - Golden mosaic virus bean |
| Rudá | III | Cream with brown stripes | R - Rust<br>R - Bean common mosaic virus<br>MR - Bacterial blight<br>S - Anthracnose<br>S - Angular leaf spot<br>S - Bean golden mosaic virus |
| Campeão-1 | III | Cream with brown stripes | R - Anthracnose<br>R - Rust<br>MR - Angular leaf spot<br>MR - Bacterial blight |

[a] II = indeterminate, erect bush; III = indeterminate, with long vine stem; [b] R = resistance, MR = moderate resistance, S = susceptible

c) Mean seed weight (MSW): expressed in grams, obtained by weighting a sample of fifty seeds from each treatment.

d) Grain yield (GY): expressed in g/plant, obtained from the ratio between the total grain weight of the treatments and the respective number of plants.

**Genetics and statistical analysis.** Just all the data of each trait were used in the analysis of variance according to the following model:

$Y_{ij} = m + g_i + b_j + e_{ij}$

where:

$Y_i$ = observation of **i** treatment in block **j** (1 = 1, 2, ..., g = 6; J = 1,2,..., b = 10);

m = general mean;

$g_i$ = **i** $F_1$'s and parents;

$b_j$ = **j** block effect;

$e_{ij}$ = experimental error.

**Griffing's diallel analysis (1956).** The sum of the squares of the $F_1$'s and parents was split in the sum of the squares for general and specific combining abilities according to Griffing (1956) Method 2 (parents and $F_1$ hybrids), model 1 (fixed):

$$Y_{ij} = m + g_i + g_j + s_{ij} + \bar{\varepsilon}_{ij},$$

where:

$Y_{ij}$: mean of combining hybrids ($i \neq j$) or of progenitor ($i = j$);

m: general mean;

$g_i$ and $g_j$: general combining ability effects of i-ésimo and j-ésimo progenitor, respectively;

$s_{ij}$: specific combining ability effects for the crossing between the progenitor of order i and j;

$\bar{\varepsilon}_{ij}$: experimental error mean associated with observations of order i and j.

## Results and discussion

The means of each cultivar and its hybrids for every characteristic are shown in the Table 2.

The mean squares of the analysis of variance show significant differences of $F_{1's}$ and parents at 1% probability for the MNSP and MSW characteristics, while there was significance at the level of 5% by the F test for the TNPP and GY characteristics (Table 3).

The sum of the squares of general combining ability (GCA) was significant at the level of 1% probability by the F test for all the characteristics assessed (Table 3).

The characteristics TNPP, NMSP and MSW had significant differences for specific combining ability at the probability level of 5%, while GY did not show significance (Table 3).

The real significant difference from GCA and SCA obtained indicated that additive and non-additive genic effects are involved in the control of the characteristics, which allows prediction of the possibility of obtaining new cultivars from the segregating populations, and that some should be more promising that others.

Table 3 also shows that the mean effects of the GCA were greater than those for SCA for the assessed characters. Moreover, it is known that inferences from the mean squares are not recommended for self-pollinating species, because a GCA of magnitude superior to that of SCA does not always indicate predominance of additive genic action, according to Miranda (1987) and Maluf *et al.* (1989).

Thus it is more suitable to use the means of the squares of the effects to obtain the genetic quadratic components $\hat{\phi}\mathbf{g}$ and $\hat{\phi}\mathbf{s}$ for GCA and SCA, respectively; and based on them, assess the genic action involved in the expression of the characteristics.

**Table 2.** Mean of total number of pods per plant (TNPP), mean number of seeds per pod (MNSP), mean seed weight (MSW) and grain yield (GY) at one diallel cross scheme, involving six parents and 15 $F_{1's}$. Maringá, 1997

| Hybrids[1/] | TNPP | MNSP | MSW | GY |
|---|---|---|---|---|
| 1 x 1 | 18.25 | 5.68 | 12.92 | 26.99 |
| 1 x 2 | 20.00 | 5.09 | 15.07 | 30.12 |
| 1 x 3 | 21.70 | 5.70 | 13.35 | 32.54 |
| 1 x 4 | 21.35 | 5.46 | 14.82 | 34.21 |
| 1 x 5 | 21.55 | 5.51 | 13.56 | 32.34 |
| 1 x 6 | 22.75 | 5.13 | 13.51 | 31.91 |
| 2 x 2 | 19.10 | 4.61 | 15.15 | 26.52 |
| 2 x 3 | 21.35 | 5.39 | 13.01 | 29.84 |
| 2 x 4 | 20.70 | 5.11 | 15.20 | 32.09 |
| 2 x 5 | 24.05 | 5.49 | 17.71 | 35.92 |
| 2 x 6 | 21.20 | 5.42 | 13.97 | 31.46 |
| 3 x 3 | 23.40 | 5.31 | 11.50 | 28.46 |
| 3 x 4 | 23.55 | 5.47 | 13.49 | 35.20 |
| 3 x 5 | 24.50 | 5.54 | 12.22 | 33.07 |
| 3 x 6 | 21.20 | 5.58 | 13.74 | 32.18 |
| 4 x 4 | 22.30 | 4.95 | 14.99 | 32.56 |
| 4 x 5 | 21.15 | 5.73 | 13.93 | 33.65 |
| 4 x 6 | 21.15 | 5.85 | 14.15 | 34.86 |
| 5 x 5 | 24.35 | 5.32 | 12.50 | 31.83 |
| 5 x 6 | 24.80 | 5.40 | 13.83 | 36.70 |
| 6 x 6 | 20.08 | 5.38 | 14.16 | 31.80 |
| Mean | 21.87 | 5.39 | 13.75 | 32.08 |
| CV% | 19.30 | 10.91 | 8.42 | 19.30 |

[1/] 1 - LPSPI 93-17; 2 - LPSPI 93-19; 3 - FT-Nobre; 4 – Aporé; 5 - Rudá and 6 - Campeão-1

**Table 3.** Mean squares from diallel analyses of $F_1$ generation and parents

| | | Mean square[1/] | | | |
|---|---|---|---|---|---|
| SV | DF | TNPP | MNSP | MSW | GY |
| Treatments | 20 | 30.9610 * | 0.8271 ** | 9.7317 ** | 71.2287 * |
| GCA | 5 | 78.8922 ** | 1.2881 ** | 31.6651 ** | 127.2811 ** |
| SCA | 15 | 14.9840 * | 0.6734 * | 2.4205 * | 52.5446 ns |
| Error | 180 | 17.8023 | 0.3461 | 1.3427 | 38.3374 |
| Quadratic components | | | | | |
| GCA | | 0.7636 | 0.0117 | 0.3790 | 1.1117 |
| SCA | | 0.2818 | 0.0327 | 0.1077 | 1.4207 |

[1/] TNPP = total number of pods per plant; MNSP = mean number of seeds per pod; MSW = mean seed weight and GY = grain yield; **, * significant at 1% and 5% levels, respectively; ns = nonsignificant.

By the analysis of the quadratic components (Table 4), there was predominance of the additive genic effects for the TNPP and MSW characteristics, indicating that the best option is considering the average performance in the intrapopulational breeding programs.

The additive and non-additive genic effects were equally important for the MNSP and GY characteristics, as seen in the relative approximation of genetic effects for GCA and SCA (Table 3). This indicates that, for these characteristics, the parents assessed could be used with either intra or interpopulational breeding programs.

**General combining ability (GCA).** Table 4 shows the estimates of the GCA effects ($\hat{g}_i$) of the parents for the four assessed characteristics and the standard deviation (SD) between any two parents.

Only two cultivars had positive $\hat{g}_i$ values for the TNPP characteristic (Table 4), FT-Nobre and Rudá, with magnitudes of 0.7541 and 1.4604, respectively. Rudá is thus an interesting cultivar for programs to increase the number of pods per plant.

**Table 4.** General combining ability (GCA) effects of six parents in common bean

| Cultivars | Characteristics[1/] | | | |
|---|---|---|---|---|
| | TNPP | MNSP | MSW | GY |
| 1. LPSPI -93-17 | -1.1520 | 0.0694 | -0.0135 | -1.1761 |
| 2. LPSPI - 93-19 | -0.9458 | -0.2475 | 0.6260 | -1.5052 |
| 3. FT-Nobre | 0.7541 | 0.0728 | -0.9318 | -0.5955 |
| 4. Aporé | -0.0708 | -0.0238 | 0.6640 | 1.3272 |
| 5. Rudá | 1.4604 | 0.0753 | -0.5027 | 1.3544 |
| 6. Campeão-1 | -0.0458 | 0.0536 | 0.1580 | 0.5953 |
| DP ( $g_i$ - $g_j$) | 0.6671 | 0.0930 | 0.1832 | 0.9789 |

[1/] TNPP = total number of pods per plant; MNSP = mean number of seeds per pod; MSW = mean seed weight and GY = grain yield

The aim of the program is to obtain a greater number of seeds per pod, the LPSPI 93-19 and Aporé cultivars would not be recommended, as when the MNSP trait was assessed (Table 4), both had negative effects. Therefore, it may be inferred that segregant generations, originating from this cultivars, will tend to have fewer pods with heavier seeds, which shows that the first trait is not linked to the second, leaving the researcher to choose, within the mentioned cultivars, those which are most suitable according to the objectives of the program, when the two characteristics are part of the selection scope.

Regarding the GCA effects, high $\hat{g}_i$ estimates in absolute values normally occur in cultivars whose favorable allele frequencies are consistently higher or lower than the mean frequency of the favorable alleles in all the tested cultivars (Vencovsky, 1970).

The Aporé, LPSPI 93-19 and Campeão-1 cultivars, in this order, had the highest positive $\hat{g}_i$ values for the MSW characteristics, with respective magnitudes of 0.6640; 0.6260; and 0.1580 (Table 4). Thus when parents are required for intercrossing to increase the mean seed weight, such cultivars could contribute by amplifying the total variation.

The Aporé, Rudá and Campeão-1 cultivars had positive $\hat{g}_i$ values, respectively, 1.3272, 1.3544 and 0.5053 for grain yield. Therefore for obtaining high grain yield, these cultivars would be intercrossed to obtain superior lines in intrapopulational procedures. Therefore Aporé, Rudá and Campeão-1 are cultivars which should be included as parents in programs for yield increase.

**Specific combining ability (SCA).** The estimates of the SCA effect ($\hat{s}_{ii}$ and $\hat{s}_{ij}$), and the standard deviations for the $F_1$ effects with and without common parents and between two parents (Table 5).

The $\hat{s}_{ij}$ results show that, for the TNPP characteristic, the greatest effects were shown in the 1 x 6, 2 x 5, 5 x 6, 3 x 4 and 1 x 4, in this order. As only the FT-Nobre and Rudá parents had positive effects for $\hat{g}_i$ (Table 4) there was a satisfactory genic complementation effect which characterizes the combinations between the parents 1 x 6, 2 x 5 and 5 x 6 as promising, when lines with a higher number of pods are required.

The best combinations for the MNSP characteristic were 4 x 6 (0.4319), 4 x 5 (0.2942), 2 x 5 (0.2788), 2 x 6 (0.2305), 1 x 3 (0.1733) and 2 x 3 (0.1732) (Table 5).

Positive $\hat{s}_{ij}$ values were found in nine hybrids for the MSW characteristics (Table 5), as shown in the pairs 3 x 6 (0.7662), 1 x 2 (0.7110), 1 x 3 (0.5358), 5 x 6 (0.4211), 1 x 4 (0.4150), 1 x 5 (0.3242), 2 x 4 (0.1623), 4 x 5 (0.0161) and 3 x 5 (0.0072).

**Table 5.** Estimates of specific combining ability for characteristics of the $F_1$ population

| Effect [1/] | Characteristics estimate[2/] | | | |
|---|---|---|---|---|
| ($s_{ii}$ e $s_{ij}$) | TNPP | MNSP | MSW | GY |
| 1 x 1 | -1.3125 | 0.1577 | -0.8023 | -2.7328 |
| 1 x 2 | 0.2312 | -0.1172 | 0.7110 | 0.7312 |
| 1 x 3 | 0.2312 | 0.1733 | 0.5358 | 2.2405 |
| 1 x 4 | 0.7062 | 0.0270 | 0.4150 | 1.9897 |
| 1 x 5 | -0.6250 | -0.0181 | 0.3247 | 0.0835 |
| 1 x 6 | 2.0812 | -0.3804 | -0.3819 | 0.4206 |
| 2 x 2 | -0.8750 | -0.2812 | 0.1473 | -2.5446 |
| 2 x 3 | -0.3249 | 0.1723 | -0.4377 | -0.1343 |
| 2 x 4 | -0.1499 | -0.0019 | 0.1623 | 0.1908 |
| 2 x 5 | 1.6687 | 0.2788 | -0.1638 | 4.0016 |
| 2 x 6 | 0.3249 | 0.2305 | -0.5666 | 0.2997 |
| 3 x 3 | 0.0250 | -0.2220 | -0.3858 | -2.4231 |
| 3 x 4 | 0.9999 | 0.0317 | 0.0072 | 2.3961 |
| 3 x 5 | 0.4187 | 0.0034 | -0.0999 | 0.2408 |
| 3 x 6 | -1.3750 | 0.0632 | 0.7662 | 0.1030 |
| 4 x 4 | 0.5749 | -0.3915 | -0.0876 | -2.1716 |
| 4 x 5 | -2.1062 | 0.2942 | 0.0161 | -1.1018 |
| 4 x 6 | -0.6000 | 0.4319 | -0.4256 | 0.8682 |
| 5 x 5 | -0.4375 | -0.2200 | -0.2491 | -2.9511 |
| 5 x 6 | 1.5187 | -0.1182 | 0.4211 | 2.6780 |
| 6 x 6 | -0.9750 | -0.1135 | 0.0933 | -2.1848 |
| DP ($s_{ii}$-$s_{ij}$) | 1.3342 | 0.1860 | 0.3664 | 1.9579 |
| DP ($s_{ij}$-$s_{ik}$) | 1.7650 | 0.2461 | 0.4847 | 2.5901 |
| DP ($s_{ij}$-$s_{kl}$) | 1.6341 | 0.2278 | 0.4487 | 2.3980 |

[1/] (1) LPSPI 93-17, (2) LPSPI 93-19, (3) FT-Nobre, (4) Aporé, (5) Rudá and (6) Campeão-1; [2/] TNPP = total number of pods per plant; MNSP = mean number of seeds per pod; MSW = mean seed weight and GY = grain yield

In the two parent groups of Phaseolus vulgaris L., Viana *et al.*, (2000) observed that estimate of mean heterosis shows that dominance effects are predominantly positive, contributing to increase grain yield. The main information of SCA is to suggest the magnitude of variability to be expressed of each population, so it helps to choose those best segregant populations. Thirteen combinations were found with positive $\hat{s}_{ij}$ values for grain yield, and the most outstanding hybrids were: 2 x 5, 5 x 6, 3 x 4, 1 x 3 and 1 x 4, in order of the most promising to generate segregant populations for superior lines.

In conclusion, the additive genic effects were superior for the number of pods per plant and mean seed weight, and additive and non-additive genic effects were equivalent in the expression of the mean number of seeds per pod and grain yield. The cultivars Aporé, Rudá and Campeão-1 are indicated for intrapopulational breeding programs for genotype selection with greater yield potential. Among the 15 hybrids evaluated, the most promising ones are 13 which had a high potential yield to generate segregant populations for superior lines.

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