Crop Breeding and Applied Biotechnology 8: 339-344, 2008
Brazilian Society of Plant Breeding. Printed in Brazil

Estimates of compensation and stability parameters in common bean lines aiming at multilines

Flávia Barbosa Silva Botelho[1], Magno Antonio Patto Ramalho[2*], Ângela de Fátima Barbosa Abreu[3], and Breno Alvarenga Rezende[2]

Received 16 July 2008

Accepted 30 October 2008

RESUMO - *This study aimed to determine parameter estimates of compensation of common bean lines and verify if the stability of a mixture of lines is higher than of the line components. Six common bean lines were evaluated, pairwise, in equal proportions. The experiments were conducted in 11 environments, where the trait seed yield was evaluated (grams per plot). The positive* c_i *estimate (compensation ability of line* i*) of cultivar Talismã was highest, indicating the line for mixtures. The combination of the pair Carioca and MA-II-16, with the highest positive* s_{ij} *estimate (specific compensation ability for the pair of lines* i *and* j*), was satisfactory. It was observed that the mean contribution of mixtures to the interaction was in the mean lower than of lines in monoculture. The stability was highest in the mixture Talismã and MA-II-8 and the risk of adoption lowest. The estimates of these compensation and stability parameters in mixtures underlying additional information are a support in the choice of lines to compose a multiline.*

Key words: *Phaseolus vulgaris*, stability, line mixtures.

INTRODUCTION

In many regions of Brazil, farmers do not buy seeds for planting but rather use grain harvested in the previous season. These "cultivars" of farmers are actually mixtures of several lines, sometimes even with quite differently colored grains. Apparently, these mixtures of lines represent multilines and, so it seems, ensure greater yield stability.

The use of multilines has been suggested as a mechanism to decrease the selection pressure in pathogens, reducing the chances of an increase of uncommon races that could be more virulent (Wolfe 2000, Stuthman 2002). Furthermore, it has been found that cultivars that consist of a mixture of lines are more stable than most cultivars consisting of a single inbred line (Helland and Holland 2001, Bruzi et al. 2007). This fact is probably due to the occurrence of population homeostasis or tamponade inherent to mixed populations (Becker and Leon 1988). There are reports in the literature that show that a line mixture may even exceed the yield of inbred lines (Finckh and Mundt 1992, Zhu et al. 2000).

The recommendation of cultivars consisting of a mixture could be an improvement strategy for common bean in Brazil. In most regions, beans with carioca grain are preferred and there are a few hundred lines in breeding programs that could be mixed without affecting the appearance of the commercial product.

A question to this strategy is how to obtain the multiline, i.e., identify the lines that are to compose the

[1] Universidade Federal do Mato Grosso (UFMT), Campus de Sinop, Av. Alexandre Ferronato, 1200, 78550-000, Sinop, MT, Brazil
[2] Departamento de Biologia, Universidade Federal de Lavras (UFLA), C.P. 3037, 37.200-000, Lavras, MG, Brazil. *E-mail: magnoapr@ufla.br
[3] Embrapa Arroz e Feijão, UFLA

mixture. This information can be obtained based on estimates of the ability to exercise and support competition, which in turn can be determined in several ways. One would be to combine the lines pairwise, similar to a diallel system (Federer et al. 1982). This procedure has not yet been properly evaluated, mainly for lines used in Brazil.

Based on the foregoing considerations, this study was carried out to obtain estimates of compensation ability for common bean lines, and verify that line mixtures are more stable than their line components.

MATERIAL AND METHODS

For this study, we used six common bean lines with Carioca grain (Table 1), which differ in the cycle, growth habit and response to pathogens *Pseudocercospora griseola* and *Colletotrichum lindemuthianum*. These lines were mixed pairwise in equal proportions. The 21 treatments (six lines and 15 mixtures) were evaluated in 11 environments, at different locations and on different sowing dates (Table 2).

The experimental design was a randomized block design with three replications and the plots consisted of three 3-m rows, at a sowing density of 15 seeds per meter and spacing of 0.5 m between rows. The trait grain yield was evaluated in grams per plot and individual and joint analysis of variance was performed with the data, according to a procedure proposed by Ramalho et al. (2005). For all tests the program MSTAT-C (1991) was used.

Based on the mean data of each mixture, an analysis similar to the diallel crosses was performed, as proposed by Griffing (1956), adapted for competition studies by Federer et al. (1982), following the model: $Y_{ij} = \mu + c_i + c_j + s_{ij} + e_{ij}$ where: Y_{ij} observation of the line mixture i and j, μ is the general mean, c_i is the compensation ability of line i, c_j is the compensation ability of line j, s_{ij} is the specific compensation ability for the pair of lines i and j, and e_{ij} is the experimental error of observation Y_{ij}.

To determine the effect of a mixture on stability in comparison to pure lines, the ecovalence was estimated (Wricke 1965) as well as the risk of adoption of the lines or mixture, by the method of Annicchiarico (1992).

RESULTS AND DISCUSSION

The summary of the joint analysis of variance (Table 3) of the 11 environments showed that the experimental accuracy measured by the coefficient of variation was good (CV = 14.6%). This estimate is lower than that of common bean lines of the region (Matos et al. 2007). The environmental source of variation (combination of seasons and locations) was significant by the F test (P = 0.01). This is the primary condition for carrying out such tests. This was expected, due to the divergent environmental conditions under which the experiments were carried out.

Table 1. Description of the common bean lines used in the experiments, the *Colletotrichum lindemuthianum* pathotypes that induced resistance reaction and the respective reactions to *Pseudocercospora griseola*

Lines	Growth habit	Cycle	Pathotypes of *C. lindemuthianum*	Response to *P. griseola*
Carioca	III	Normal	Susceptible [1/]	Susceptible
BRSMG-Talismã	III	Early	89	Susceptible
RC-I-8	II	Normal	337	Susceptible
MA-II-8	III	Normal	81	Resistant
MA-II-16	III	Normal	87	Resistant
MA-II-22	III	Normal	65	Resistant

[1/] Susceptible to all inoculated races

Table 2. Geographic coordinates of the experimental sites, with the respective sowing dates

Location	Sowing date	Latitude	Longitude	Altitude (m asl)
Ijaci	Fev./07	21°10'S	44°75'W	832
Lavras	Jul./07, Nov./07, Fev./08	21º14'S	44°75'W	919
Lambari	Fev./07, Jul./07, Nov./07	21º58'S	45º21'W	887
Patos de Minas	Fev./07, Jul./07, Nov./07	18°34'S	46°31'W	832
Viçosa	Jul./07	20°44'S	42°50'W	650

Table 3. Summary of the joint analysis of variance of grain yield (g plot^{-1}) of common bean lines and mixtures in 11 environments

SV	df	MS
Environments (E)	10	1917438.636**
Blocks/environments	22	37756.569**
Treatments (T)	20	52137.942**
Lines (L)	5	21236.448
Mixtures (M)	14	66353.570**
GCA	5	85008.000**
SCA	9	55990.000**
L vs M	1	9019.458
T x E	200	68518.466**
L x E	50	64884.582**
M x E	140	63956.915**
GCA x E	50	52076.560**
SCA x E	90	70591.067**
L vs M x E	10	150549.60**
Error	440	23948.032
Mean	1061,6	

** significant at 1% probability by the F test

The experiments were irrigated in the dry season (sown in February) and winter season (sown in July). The temperatures in the dry season were higher. The characteristics of the evaluation sites were very distinct, mainly in terms of variation in soil fertility. The yield ranged from 605 g plot^{-1} in Lambari (sowing in July 2007) to 1401 grams per plot, at the same site (sowing in February 2007).

No significant differences were found between the lines (Table 3), although they are known for different reactions to *Colletotrichum lindemuthianum* and *Pseudocercospora griseola*, and differ in cycle (Table 1). In the case of disease the presence of pathogens was not intensive enough to discriminate the lines based on resistance.

The line x environment interaction was highly significant, indicating that the performance of the lines did not coincide in the different environments (Table 3). This reinforces the above observation that the lines differ in some attributes, resulting in differences under specific environmental conditions.

The mean yield of the mixture did not differ significantly from the mean of lines (Table 4). There are reports involving some methodologies where the performance of the mixture was superior to the line components, e.g., in soybean (Bisognin et al. 1995), oat (Helland and Holland 2001) and common bean (Mastrantonio et al. 2004). In some cases the performance in monoculture was higher than of the mixture (Silva et al. 2007).

Although the performance of the lines was similar in the mean of environments, it differed when mixed (Tables 3 and 5). By the Scott - Knott test (1974) the lines were clustered into two groups and the mixtures involving Talismã were almost always in the most productive group. Considering the five combinations in which it participated, the mean was by 4% higher than of the same line in monoculture, demonstrating that it benefited from the association. The most likely explanation is that this line, slightly earlier than the others, induced a longer period of flowering in the mixtures, resulting in an escape mechanism from climatic stresses during flowering.

To estimate the compensation ability it was not possible to use the procedure proposed by Federer et al. (1982), since in the mixtures of these authors the components were distinguishable by different grain colors. In this study, the grain type of all lines was carioca, with no reasonable chance of being identified in the mixture.

In the joint analysis, both the general compensation ability (GCC) as well as the specific compensation ability (SCA) were significant (Table 3). In principle, this indicates that the lines in a mixture differ in their compensation ability and that some pairs

Table 4. Mean grain yield (g plot^{-1}) of the common bean lines *per se* and of the line mixtures, in 11 environments

Environment		Lines	Mixtures
Season	Location		
February/2007	Ijaci	1307.78	1320.44
	Lambari	1408.33	1398.22
	Patos de Minas	1131.94	1060.44
July/2007	Lavras	536.39	843.57
	Lambari	675.00	577.00
	Patos de Minas	827.06	861.67
November/2007	Lavras	1345.56	1329.56
	Lambari	897.22	920.44
	Patos de Minas	1323.33	1329.44
	Viçosa	1400.83	1330.07
February/2008	Lavras	693.33	732.00
Mean		1049.71	1063.90

Table 5. Mean grain yield (g plot^{-1}) of the common bean mixtures in 11 environments

Lines	Talismã	RCI8	MAII8	MAII6	MAII22
Carioca	1103.6a	1064.9a	1065.9a	1079.9a	1031.8b
Talismã		1019.4b	1118.9a	1085.4a	1114.2a
RCI8			1077.2a	985.9b	1093.8a
MAII8				982.6b	1109.2a
MAII16					1025.9b

[1/]Means followed by the same letter belong to the same group, by the Scot-Knott test (P≤0.05)

exploit the association between lines in different ways.

The estimate of the general compensation ability (c_i) evaluates the lines with good or poor compensation ability, that is, if c_i is positive, the line is promising to compose the mixture, and contrariwise. For the mean of 11 environments, the positive estimate of the general compensation ability (c_i) was highest for Talismã (Table 6), demonstrating the potential of this line to be used in combinations, since it complements the other line well. It is worth emphasizing that in a study on plant-plant competition involving other lines than used here, Talismã also exerted less competition (positive c_i) than the others (Silva et al. 2007). The c_i estimate of MA-II-22, although of lower magnitude, did not differ significantly from Talismã (Table 6).

On the other hand, line MA-II-16 performed worst in the combination, with a negative c_i. It was observed that, in the mean, the performance of the mixtures in which it participated was reduced by 1.7%, compared to its performance *per se*. Another line without a good complement was RC-I-8 (c_i = -19.61) (Table 6). This is the only line evaluated here with type II growth habit, i.e., more upright plants with short vines. Since the growth habit of the other lines was type III, they occupied more space in the mixture, affecting the performance of plants of line RC-I-8.

The estimates of the specific compensation ability (SCA), considering the mean of 11 environments, are listed in Table 7. It is noteworthy that the value of a pair of lines with a poor combination is negative, as in the case of the lines Carioca and MA-II-22. The opposite is true for positive values, with a good exploration of the association, as for example the pairs Carioca and MA-II-16, RC-I-8 and MA-II-22 and Talismã and MA-II-16. These estimates indicate that, to develop a multiline, it is recommendable to evaluate a greater number of lines and identify pairs with positive s_{ij} and c_i of the corresponding, also positive, parents. If the pathogen severity is more intense than observed here, the discrimination of the pairs is probably clearer, supporting

Table 6. Estimate of parameters of the general compensation ability (c_i) for the mean grain yield (g plot^{-1}), in 11 environments and the error associated to the c_i-c_j estmates

Environment		Carioca	Talismã	RCI8	MAII8	MAII16	MAII22	Associate
Season	Location							Error of c_i-c_j
Feb/2007	Ijaci	51.33	123.58	40.08	-62.17	-148.92	-3.92	57.33
	Lambari	34.92	-43.58	-55.33	-26.33	73.92	16.42	66.12
	Patos de Minas	17.75	23.50	-77.50	32.75	58.50	-55.00	57.36
Jul/2007	Lavras	-88.92	-12.92	-26.67	82.58	-123.42	169.33	88.13
	Lambari	28.75	15.25	22.00	13.50	-67.00	-12.50	36.58
	Patos de Minas	126.75	38.00	36.25	-40.50	-101.75	-58.75	61.93
Nov/2007	Lavras	7.25	3.75	-36.00	39.00	-85.50	71.50	88.57
	Lambari	-12.92	79.33	31.83	-6.42	-98.17	6.33	52.68
	Patos de Minas	37.33	47.83	-53.92	-10.17	-35.67	14.58	45.99
	Viçosa	-69.75	89.00	-35.50	-24.00	69.75	-29.50	55.80
Feb/2008	Lavras	-58.25	-29.25	-61.00	95.75	18.50	34.25	48.86
Mean		6.75	30.41	-19.61	8.55	-39.98	13.89	18.66

Table 7. Mean estimates of the specific compensation ability (s_{ij}) for grain yield (g plot^{-1}), in 11 environments

Lines	Talismã	RCI8	MAII8	MAII16	MAII22
Carioca	2.68	13.97	-13.37	49.34	-52.62
Talismã		-55.50	15.88	30.95	6.00
RC-I-8			24.45	-18.48	35.56
MA-II-8				-49.91	22.95
MA-II-16					-11.89

the decision of choosing lines for the mixture.

Estimates of some stability parameters of the mixture, such as the contribution of each treatment to interaction (W_i^2) may also be involved in the analysis. It was estimated by W_i^2 that, in the mean, mixtures contributed with 4.53% to the genotype x environment interaction and the lines with 5.34% (Table 8). This difference may seem, in principle, small but accounts for 15.2% of the interaction, in the estimation of W_i^2. Cutting et al. (2001) and Bruzi et al. (2007) found similar results for common bean, since heterogeneous populations or those with most loci in heterozygosity were the most stable. In research with other species, a greater stability of the mixtures was reported as well (Stelling et al. 1994, Helland and Holland 2001).

The mixture of lines Talismã and MA-II-8 was the most stable, with a lower W_i^2 estimate (1.99%) (Table 8). It is worth mentioning that this mixture also had higher mean grain yield (1119 g plot^{-1}). This kind of stability was mentioned by Lin et al. (1986), designated agronomic stability (type II). The use of line mixtures with this stability is desirable, since it is usually associated with higher yields and greater adaptability.

An argument against the use of line mixtures is the difficulty of obtaining a mixture when all lines are high-yielding. In this study however, the performance of some mixtures was quite similar to that of the most productive line (Table 8). The performance of the mixtures Talismã and MA-II-8, RC-I-8 and MA-II-22 and Carioca and Talismã was similar to the best line, while the contribution to the genotype x environment interaction was lowest.

Another alternative that could be used as a criterion in the establishment of a multiline would be to estimate the risk of adoption of each pair of lines

Table 8. Mean grain yield (g plot^{-1}) of common bean lines and pairwise mixtures with the estimates of ecovalence (W_i^2) and confidence index (I_i)

Lines and mixtures	Mean yield	W_i^2	W_i^2 (%)	I_i
Carioca	1086.9 a[1/]	425452.42	3.55	97.77
Talismã	1046.9 b	466399.44	3.89	97.56
RC-I-8	1015.2 b	762562.19	6.37	88.47
MA-II-8	1058.0 a	708295.05	5.91	103.31
MA-II-16	1050.6 b	811149.15	6.77	92.70
MA-II-22	1077.9 a	663875.38	5.54	106.78
Carioca + Talismã	1103.6 a	258928.79	2.16	106.49
Carioca + RC-I-8	1064.9 a	591968.87	4.94	95.93
Carioca + MA-II-8	1065.9 a	285462.68	2.38	95.32
Carioca + MA-II-16	1079.9 a	610666.25	5.10	95.92
Carioca + MA-II-22	1031.8 b	747598.68	6.24	91.57
Talismã + RC-I-8	1019.4 b	823413.87	6.87	87.91
Talismã + MA-II-8	1118.9 a	238783.47	1.99	103.26
Talismã + MA-II-16	1085.4 a	716511.44	5.98	95.04
Talismã + MA-II-22	1114.2 a	670680.96	5.60	100.04
RC-I-8 + MA-II-8	1077.2 a	488920.90	4.08	97.93
RC-I-8 + MA-II-16	985.9 b	386142.78	3.22	88.78
RC-I-8 + MA-II-22	1093.8 a	281059.31	2.35	99.05
MA-II-8 + MA-II-16	982.6 b	701186.60	5.85	86.35
MA-II-8 + MA-II-22	1109.2 a	555768.76	4.64	99.70
MA-II-16 + MA-II-22	1025.9 b	784651.81	6.55	89.60

[1/]Means followed by the same letter belong to the same group by the Scott - Knott test (P=0.05)

(Annicchiarico 1992). Again, the mixtures of Carioca and Talismã and Talismã and MA-II-8 are noteworthy, with a low risk of adoption. In the worst case, the yield will be by 6.49% and 3.26% higher than the mean of the environment, respectively (Table 8). This inference is further evidence that the mixture of the lines Talismã and MA-II-8 would be a good option to compose a multiline.

The results evidence that the use of multilines consisting of bean with carioca grain is a good strategy to provide greater yield stability in Brazil. In breeding programs, a large number of lines are available with a very similar color pattern and with different reactions to the main crop pathogens, which could be mixed without affecting the commercial product, as done here. In addition, estimates of the combing ability parameters provide useful information for the selection of these lines to compose a multiline.

ACKNOWLEDGEMENTS

The authors are grateful to the CNPq and the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) for the support and funding.

REFERENCES

Annicchiarico P (1992) Cultivar adaptation and recommendation from alfafa trials in Nothern Italy. **Journal of Genetics and Breeding 46**: 269-278.

Becker HC and Léon J (1988) Stability analysis in plant breeding. **Plant Breeding 101**: 1-23.

Bisognin DA, Vernetti F de J, Gastal MF da C and Zonta EP (1995) Competição intergenotípica em soja. **Pesquisa Agropecuária Brasileira 30**: 947-955.

Bruzi AT, Ramalho MAP, Abreu, A de FB, Ferreira DF and Sena MR (2007) Homeostasis of common bean populations with different genetic structures. **Crop Breeding and Applied Biotechnology** 7: 111-116.

Corte HR, Ramalho MAP and Abreu, A de FB (2001) Estabilidade de populações segregantes e respectivos genitores. **Ciência e Agrotecnologia 25**: 900-908.

Federer WT, Connigale J C, Rutger JN and Wijesinha A (1982) Statistical analyses of yields from uniblends and biblends of eight dry bean cultivars. **Crop Science 22**: 111-115.

Finckh MR and Mundt CC (1992) Stripe rust, yield, and plant competition in wheat cultivar mixtures. **Phytopathology 82**: 905-913.

Griffing BA (1956) Concept of general and specific combining ability in relation to diallel crossing systems. **Australian Journal of Biological Sciences 9**: 463-493.

Helland SJ and Holland JB (2001) Blend response and stability and cultivar blending ability in oat**. Crop Science 41**: 1689-1696.

Lin CS, Binns MR and Lefrovitch LP (1986) Stability Analysis: Where do we stand? **Crop Science 26**: 894-899.

Mastrantonio JJ da S, Antunes IF, Zonta EP, Emygdio BM, Costa C, Lobato L, Silva SD dos A, Silveira EP (2004) Interferência em misturas de feijão. **Ciência Rural 34**: 373-377.

Matos JW, Ramalho MAP and Abreu AFB (2007) Trinta e dois anos do programa de melhoramento do feijoeiro comum em Minas Gerais. **Ciência e Agrotecnologia 31**: 1749-1754.

Mstat-C (1991) **A software program for the design, management and analysis of agronomic research experiments**. Michigan State University, Michigan.

Ramalho MAP, Ferreira DF and Oliveira AC (2005) **Experimentação em genética e melhoramento de plantas**. 2. ed. Editora UFLA, Lavras, 326 p.

Scott AJ and Knott M (1974) A cluster analysis method for grouping means in the analysis of variance. **Biometrics 30**: 507-512.

Silva VMP, Ramalho MAP, Abreu A de FB and Silva FB (2007) Estimation of competition parameters in common bean plants. **Crop Breeding and Applied Biotechnology 7**: 360-366.

Stelling D, Ebmeyer E and Link W (1994) Yield stability in faba bean, *Vicia faba* L. II. Effects of heterozygosity and heterogeneity. **Plant Breeding 112**: 30-39.

Stuthman DD (2002) Contribution of durable disease resistance to sustainable agriculture. **Euphytica 124**: 253-258.

Wolfe MS (2000) Crop strength through diversity. **Nature 406**: 681-682.

Wricke G (1965) Die Erfassung der Wechselwirkungen zwischen Genotyp und Umwelt bei quantitativen Eigenschaften. **Zeitschrift für Pflanzenzüchtung 53**: 266-343.

Zhu Y, Chen H, Fan J, Wang Y, Li Y, Chen J, Fan J, Yang S, Hu L, Leung H, Mew TW, Teng PS, Wang Z and Mundt CC (2000) Genetic diversity and disease control in Rice. **Nature 406**: 718-722.