Repeatability of adaptability and stability parameters of common bean in unpredictable environments

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Abstract – The objective of this work was to estimate the repeatability of adaptability and stability parameters of common bean between years, within each biennium from 2003 to 2012, in Minas Gerais state, Brazil. Grain yield data from trials of value for cultivation and use common bean were analyzed. Grain yield, ecovalence, regression coefficient, and coefficient of determination were estimated considering location and sowing season per year, within each biennium. Subsequently, a analysis of variance these estimates was carried out, and repeatability was estimated in the biennia. Repeatability estimate for grain yield in most of the biennia was relatively high, but for ecovalence and regression coefficient it was null or of small magnitude, which indicates that confidence on identification of common bean lines for recommendation is greater when using means of yield, instead of stability parameters.

Index terms: *Phaseolus vulgaris*, biometry, genotype by environment interaction, plant breeding, quantitative genetic.

Repetibilidade dos parâmetros de adaptabilidade e estabilidade do feijoeiro em ambientes imprevisíveis

Resumo – O objetivo deste trabalho foi estimar a repetibilidade dos parâmetros de adaptabilidade e estabilidade do feijoeiro entre anos, dentro de cada biênio de 2003 a 2012, em Minas Gerais, Brasil. Os dados de produtividade de grãos provenientes de ensaios de valor de cultivo e uso de feijoeiro-comum foram analisados. A produtividade de grãos, a ecovalência, o coeficiente de regressão e o coeficiente de determinação foram estimados quanto a local e época de semeadura por ano, dentro de cada biênio. Posteriormente, realizou-se análise de variância destas estimativas, e a repetibilidade foi estimada nos biênios. A estimativa de repetibilidade quanto à produtividade de grãos, na maioria dos biênios, foi relativamente alta, mas, quanto à ecovalência, ao coeficiente de determinação e ao coeficiente de regressão, foi nula ou de pequena magnitude, o que indica maior confiança na identificação de linhagens de feijão a serem recomendadas, quando se usam as medidas de produtividade, em vez dos parâmetros de estabilidade.

Termos para indexação: *Phaseolus vulgaris*, biometria, interação genótipo por ambiente, melhoramento de plantas, genética quantitativa.

Introduction

Common bean is grown throughout Brazilian territory over the entire year and, therefore, under diverse environmental conditions. In this situation, the genotype by environment interaction is expected to be expressive, as shown in the literature (Pereira et al., 2010; Silva et al., 2011; Torga et al., 2013). For that reason, the Ministério da Agricultura, Pecuária e Abastecimento (Mapa) requires that the trials of value for cultivation and use (VCU) must be conducted in various environments, including diverse growing conditions, for the selection of cultivars with greater phenotypic stability (Brasil, 2006).

The term "environment" includes the growing conditions, and this involves locations, sowing seasons, years, and cropping practices, among others, or even a combination of these factors. As to variations of environments, Allard & Bradshaw (1964) classified them as predictable and unpredictable. Predictable variations are those which occur in a systematic manner or are under human control. Unpredictable variations are those which fluctuate in an inconsistent manner, as for example, years, which may vary in regard to rainfall, temperature, relative humidity, and other factors.

Different methodologies are shown in the literature with a view towards the study of adaptability and stability (Cruz & Carneiro, 2004; Oliveira et al., 2006; Pereira et al., 2009; Bernardo, 2010; Ramalho et al., 2012b). Nevertheless, it is not enough to simply estimate the stability parameter. It is necessary to verify if it is inheritable, because cultivars are evaluated with the hope that their performance will appear in the future, when their use by farmers will occur under environmental conditions certainly different from those under which they were evaluated (Gauch Júnior & Zobel, 1988).

Information concerning the genetic control of stability parameters is not frequent. One method, sometimes used, makes it possible to estimate the repeatability of the adaptability and stability parameters, for which experiments should be conducted in each environment, with four replicates. Two analyses have to be performed, one with the data from the 1st and 2nd replicates, and the other with data from the 3rd and 4th ones. Thus, two groups of the parameter estimates are obtained in analyses involving the various environments. Analysis of variance in a randomized block design is then carried out, considering the results of each group of observation as replicates.

By this method, some estimates were obtained with common bean and other crops. For mean yield, repeatability ($r^2_{yy'}$) ranged from 0.40 to 0.98; for ecovalence ($W^2_i\%$), from -0.43 to 0.80; and for coefficient of determination (R^2), from 0.41 to 0.83 (Farias et al., 1998; Bruzi et al., 2007). The problem of this method, emphasized by the authors, is that the estimate of variation (V_P) that composes the numerator of the expression of repeatability, not only contains the component of genetic deviation, but it also contains permanent environmental variations, which means that temperature and moisture of a single location are common to all the replicates. These estimates are therefore overestimated. In addition, they did not involve years, which is an unpredictable environmental factor. It would be important to obtain information on genetic control of stability parameters mainly involving the effect of years, which is an unpredictable environmental factor.

The objective of this work was to estimate the repeatability of the adaptability and stability parameters of common bean between years, within each biennium from 2003 to 2012, in Minas Gerais State, Brazil.

Materials and Methods

Yield data from trials of value for cultivation and use (VCU) carioca (beige grain with brown stripes) common–bean were used. The trials were conducted in Minas Gerais state by Embrapa Arroz e Feijão, Universidade Federal de Lavras, Universidade Federal de Viçosa, and by the Empresa de Pesquisa Agropecuária de Minas Gerais, from 2003 to 2012 (four biennia).

Environments were chosen within each biennium in which locations and sowing seasons repeated in the two years (Table 1). The number of common bean lines varied among biennia, with 20 in 2003/2004, 25 in 2005/2006, 26 in 2008/2009, and 25 in 2011/2012.

The experiments were set up following the minimum requirements established by Ministério da Agricultura, Pecuária e Abastecimento (MAPA) (Brasil, 2006) for VCU testing of common bean, as: randomized block design with three replicates, and plots of four four-meter length rows. Grain yield data were obtained considering the two center rows. No disease or pest control was performed.

Data from each environment, location and sowing season were subjected to analysis of variance, and the mean values were obtained. Then, joint analysis

Table 1. Environments used in each biennium for value for cultivation and use testing of common bean from 2003 to 2012, in Minas Gerais state, Brazil.

2003/2004	2005/2006	2008/2009	2011/2012
Lavras/November[1]	Lambari/February	Lambari/November	Lavras/November
Lavras/February	Lavras/February	Lavras/November	Lambari/November
Patos de Minas/February	Patos de Minas/February	Patos de Minas/November	Patos de Minas/November
Lambari/February	Viçosa/February	Coimbra/July	Lavras/July
Viçosa/February	Patos de Minas/July	Lambari/July	Patos de Minas/July
Coimbra/February	Sete Lagoas/July	Uberlândia/July	Lambari/July
-	Uberlândia/July	Florestal/February	Sete Lagoas/July
-	-	Lambari/February	Coimbra/July
-	-	Lavras/February	Lavras/February
-	-	Patos de Minas/February	Lambari/February
-	-	Sete Lagoas/February	Patos de Minas/February
-	-	Uberlândia/February	Sete Lagoas/February
-	-	-	Coimbra/February

(1)Sowing month.

of variance per year was performed using R software (R Foundation for Statistical Computing, Vienna, AT), and Scott-Knott clustering test, at 5% probability, according to Ramalho et al. (2012a).

The stability parameters for each year were estimated. Eberhart & Russell (1966) stability analysis was carried by the following model: $y_{ij}=b_{0i}+b_{1i}I_j+V_{d_{ij}}+\varepsilon_{ij}$, in which: y_{ij} is the estimated average for the i cultivar, in the j environment; b_{0i} is the intercept or mean of the i cultivar; b_{1i} is the regression coefficient of the i cultivar; and Ij is the environmental index. The environmental index (I_j) uses the average of each environment ($y_{.j}$) as a measure of environmental fluctuation, and is determined by the following estimator: $I_j= (y_{.j}/t)-(y_{..}/tk)=y_{.j}-y$, in which: $y_{.j}$ is the total of the j environment; t is the number of environments; k is the number of common bean lines; y is the overall total; ε_{ij} is the experimental, medium error; and $V_{d_{ij}}$ is the regression deviation of the i cultivar in the j environment.

The coefficient of determination (R_i^2) was used instead of the regression deviations (V_{d_i}) because they provide essentially the same information and, as R^2 ranges from 0 to 100%, it is easier to make comparisons. The ecovalence in percentage W_i^2 % was estimated (Cruz & Carneiro, 2004). Ecovalence (W_i^2 %) is a measure of type II agronomic stability, (Becker, 1981); it estimates the contribution of each line to the interaction. Since line x environment interaction is of a fixed nature, the significance of the ecovalence estimates (H_0:W_i^2 = 0) was tested by the mean square error, using the following expression:

$$Fc = \frac{(gW_i^2/g\text{-}1)/a^{-1}}{MS_{error}} \sim F_{tab}\,(\alpha\%;a\text{-}1;DF_{error})$$

in which: g is number of common bean lines; and a is number of environments.

Pearson's correlation coefficient was estimated between mean grain yield, ecovalence, coefficient of determination (R^2), and regression coefficient (b_i).

With the estimates of mean grain yield, and R^2 and W_i^2 % obtained per year, analyses of variance were performed considering each year of the biennium as a replicate. Considering that the line has a fixed effect, repeatability ($r_{yy'}^2$) was estimated considering the year y and y' in each biennium, by the expression $r_{yy'}^2=(Q_1-Q_2)/Q_1=COV_{yy'}/V_F=V_P/[V_P+(V_E/2)]$, in which: Q_1 and Q_2 are the mean square of common bean line and error, respectively, by the analysis of variance of each biennium; $COV_{yy'}$ is the covariance between the performance of common bean lines in years y and y'; V_F is the variance among line means; V_P is the sum of square of genetic deviations between lines; and V_E is the environmental variance.

Results and Discussion

Pearson's correlation between ecovalence and coefficient of determination were high and significant (Table 2). The closer is R^2 to 100, more stable is the lineage. Thus, W_i^2 % and R^2 should provide similar results. Estimates of correlation between R^2 and b_i were mostly high and significant, except for the years 2003 and 2011, which shows that the greater b_i estimate, the better its adjustment to the regression line, and the higher was R^2. For W_i^2 % and b_i, all the estimates were low and nonsignificant, except for the years 2006 and

Table 2. Pearson's correlation coefficient between grain yield, ecovalence (W_i^2 %), coefficient of determination (R^2), and regression coefficient (b_i). Data obtained annually for the value for cultivation and use testing of common bean conducted in Minas Gerais state, Brazil, from 2003 to 2012.

Year	Estimates	Yield	b_i	R^2
2003	W_i^2 %	0.15^{ns}	0.12ns	-0.88**
	R^2	0.01^{ns}	0.21ns	-
	b_i	0.51*	-	-
2004	W_i^2 %	0.28^{ns}	-0.40ns	-0.89**
	R^2	-0.23^{ns}	0.74**	-
	b_i	-0.01^{ns}	-	-
2005	W_i^2 %	-0.32^{ns}	-0.26ns	-0.91**
	R^2	0.50**	0.54**	-
	b_i	0.53**	-	-
2006	W_i^2 %	0.10^{ns}	0.41*	-0.58**
	R^2	0.19^{ns}	0.46*	-
	b_i	0.24^{ns}	-	-
2008	W_i^2 %	-0.06^{ns}	-0.26ns	-0.79**
	R^2	0.17^{ns}	0.78**	-
	b_i	0.22^{ns}	-	-
2009	W_i^2 %	0.03^{ns}	-0.39*	-0.93**
	R^2	-0.02^{ns}	0.69**	-
	b_i	0.06^{ns}	-	-
2011	W_i^2 %	-0.33^{ns}	0.36^{ns}	-0.73**
	R^2	0.05^{ns}	0.31^{ns}	-
	b_i	-0.27^{ns}	-	-
2012	W_i^2 %	-0.37^{ns}	0.13^{ns}	-0.74**
	R^2	0.22^{ns}	0.53**	-
	b_i	-0.06^{ns}	-	-

^{ns}Nonsignificant. **, *Significant at 1 and 5% probability, respectively.

2009. Estimates of correlations between W_i^2 %, R^2 or b_i and grain yield were of small magnitude, and most of them were nonsignificant. Thus, in principle, it is possible to identify productive and stable common bean lines. Results similar to these were obtained under other conditions (Gonçalves et al., 2007; Silva Filho et al., 2008; Cargnelluti Filho et al., 2009; Rocha et al., 2010).

The existence of significant difference among the evaluated lines was shown by the fact that they grouped in more than one class by Scott-Knott test (Table 3). However, in each year, the four highest yielding lines always belonged to the same group by the aforementioned test. It is interesting to observe that coincidence in the lines classified as having better or worse performance, in the two years, varied according to the biennium. Coincidence was small in the two last biennia (2008/2009 and 2011/2012).

The four lines with W_i^2 % lowest estimate, in all cases, were nonsignificant, which means they did not differ from zero, and, therefore, contributed little to the interaction (Tabela 3). In contrast, the four common bean lines with the highest contribution to interaction showed W_i^2 % estimate different from zero. It was possible to identify common bean lines differing in agronomic stability, since ecovalence (W_i^2 %) is a measure of the type II agronomic stability, as already mentioned (Becker, 1981).

For mean grain yield, the effect of years did not vary between the biennia, except for the 2011/2012 biennium (Table 4). In principle, the VCU is carried out in two years, presuming that the behavior of each biennium represents the climatic conditions which the future cultivar – recommended to farmers – will confront (Gauch Júnior & Zobel, 1988).

Common bean line source of variation was significant for grain yield in all the biennia, except for the 2011/2012 (Table 4), showing that the mean performance of the lines was different in each biennium, which is desirable because breeders will be able to identify lines which may be recommended to farmers by means of this variable. Performance repeatability of common bean lines in the two years of each biennium was relatively high, except for the last biennium. This fact is particularly expressive, considering that year is an unpredictable environmental factor (Allard & Bradshaw, 1964).

As the ecovalence estimate was obtained in percentage within each year, the sum of squares of the year source of variation in the analysis of variance was null (Table 4). Similarly to b_i, as for each year the average of b_i was one, there was no variation between years. There was no significant difference among common bean lines for ecovalence. As a result, the repeatability estimate of stability parameters was practically null.

Table 3. Best and worst common bean lines selected by means of grain yield and estimates of ecovalence (W_i^2 %), per year, within each biennium.

Biennium	Yield[1]		W_i^2 %	
	Year 1	Year 2	Year 1	Year 2
2003/2004	11A	13A	1	16
	12A	11A	7	3
	10A	12A	11	2
	9A	10A	16	19
	...	...	...	...
	5C	15C	2**	9**
	17C	17C	12**	1**
	14C	16C	18**	13**
	20C	14C	15**	5**
2005/2006	19A	16A	3	23
	17A	18A	4	24
	3A	19A	19	22
	16A	2A	25	19
	...	...	...	...
	10B	12B	1**	4**
	11B	11B	10**	2**
	21C	9B	12**	20**
	12C	21B	17**	6**
2008/2009	9A	25A	23	23
	15A	20A	1	1
	18A	9A	17	24
	16A	12A	2	11
	...	...	...	...
	1C	13C	21**	15**
	4D	2C	7**	19**
	5D	5C	3**	7**
	2D	6C	6**	8**
2011/2012	18A	25A	24	11
	13A	2A	5	13
	7A	18A	13	2
	9A	1A	8	25
	...	...	...	...
	11B	14C	14**	8**
	23B	21C	11**	10**
	14B	15C	22**	21**
	10B	8D	23**	15**

[1]Means followed by equal letters, in the columns, belong to the same group by the Scott-Knott test, at 5% probability. **, *Significant at 1 and 5% probability, respectively. Hypothesis test for ecovalence ($H_0 : W_i^2 = 0$).

Information on genetic control of the estimates of stability parameters is scarce in the literature, mainly due to the difficulty of obtaining it. Pacheco et al. (1999) and Cruz & Carneiro (2004) proposed the use of diallel crosses evaluated in various environments to estimate the general and specific combination capacity of stability parameters. This strategy is very difficult to apply, due to the difficulty of performing all the crosses of the diallel and, moreover, evaluating them in a large number of environments.

The strategy used in this work can apply to any VCU experiment, since there is a coincidence of locations and sowing dates in both years. It should be emphasized that any study method of interaction can be applied. Repeatability estimates in the literature, as already mentioned, are overestimated because the numerator of the expression of $r^2_{yy'}$ contains not only genetic deviation, but also permanent environmental variations. The present study confirms the results found in literature for the estimates $r_{yy'}$, W^2_i %, and R^2 (Farias et al., 1998; Bruzi et al., 2007).

Grain yield proved to be a character more favorable for selection than the parameters of adaptability and stability, based on $r^2_{yy'}$ estimates, as already mentioned. However, for the parameters ecovalence (W^2_i %), coefficient of determination (R^2), and regression coefficient (b_i), breeders will rarely succeed in the selection, due to low repeatability from one year to another.

Table 4. P-value of the analysis of variance and estimates of repeatability (W^2_i %), means of grain yield (kg ha^{-1}), estimates of ecovalence , and regression coefficient (bi) by biennium. Data obtained for the value for cultivation and use (VCU) trials in Minas Gerais state, Brasil, for common bean, from 2003 to 2012.

Estimate	SV	Biennia			
	Years	2003/2004	2005/2006	2008/2009	2011/2012
Means of Yield	Lines	0.51	0.11	0.47	0.00
		0.02	0.00	0.00	0.26
	$r^2_{yy'}$	0.62	0.72	0.66	0.23
W^2_i %	Lines	0.59	0.46	0.26	0.53
	$r^2_{yy'}$	0.00	0.04	0.23	0.00
R^2	Years	0.03	0.00	0.01	0.00
	Lines	0.58	0.26	0.65	0.64
	$r^2_{yy'}$	0.00	0.23	0.00	0.00
b_i	Lines	0.18	0.46	0.27	0.53
	$r^2_{yy'}$	0.36	0.02	0.23	0.03

Conclusions

1. The estimate of repeatability for grain yield in most of the biennia is relatively high, whereas for ecovalence, coefficient of determination, and regression coefficient, it is null or of small magnitude.
2. Due to higher repeatability estimates, confidence in identification of common bean lines to be recommended is greater when based on yield instead of stability parameters.

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