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Stability and adaptability of carioca common bean genotypes in states of the central South Region of Brazil

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ABSTRACT - *The purpose of this study was to identify 'Carioca' common bean genotypes with high yield adaptability and stability in central South Brazil, based on different analysis methods. The value of cultivation and use (VCU) of 16 genotypes was evaluated in 26 trials in a randomized complete block design with three replications, in the states of Santa Catarina, São Paulo and Paraná, in 2003 and 2004. Grain yield data were subjected to analysis of variance, of stability and adaptability, using the methodologies of Lin and Binns, Annichiarico, Eberhart and Russell, Cruz et al. and AMMI. Several of the methodologies indicated the genotypes BRS Estilo and CNFC 9518 for high yield, high adaptability and high stability. The yield, stability and adaptability of cultivar Pérola, widely grown in the country, were lower than of the new elite genotypes obtained by the breeding programs.*

Key words: *Phaseolus vulgaris*, grain yield, genotype-environment interaction.

INTRODUCTION

Brazil is the world's largest producer and consumer of common bean, *Phaseolus vulgaris*, and has a number of commercial grain types, of which carioca, the most important, accounts for about 70% of the domestic market (Del Peloso and Melo 2005).

The common bean breeding programs in Brazil over the years have developed new higher-yielding cultivars that are less susceptible to biotic and abiotic stresses, with traits that meet the standards of the consumer market. These programs were responsible for the release of 145 varieties until the year 2008: 74 before and 71 after the enactment of the Law of Cultivar Protection (between 1998 and 2008); 30 of these new varieties are protected.

Since common bean is cultivated in almost all Brazilian states, the common bean breeding program of Embrapa Arroz e Feijão has standardized the evaluation of the value of cultivation and use (VCU) of the lines developed in a national network that includes the relevant regions of common bean production. One of these is the Center-South region with, among others, the states of Parana, Santa Catarina and São Paulo, which were responsible for 39% of the national production in 1997 and accounted for 45% of the production in 2006, with a mean yield of 1395 kg ha^{-1} (IBGE 2008).

Since common bean is being grown in most states of Brazil, the cultivation occurs under the most varied environmental conditions, with different sowing dates (rainy, dry and winter) distributed over the year, in

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different cropping systems and treated with different levels of technology, ranging from the lowest possible to the use of all recommended technology. In this situation, the effect of genotype-environment (GxE) interaction is great (Oliveira et al. 2006, Melo et al. 2007). However, the estimate of GxE interaction alone does not provide information on how environmental variation affects genotype performance. An alternative to minimize the interaction effect is to identify the genotypes with greatest adaptability and stability (Cruz and Regazzi 2001).

Stability and adaptability studies have been performed using different methodologies, based on several principles in varied species of economic importance, including common bean (Borges et al. 2000, Carbonell et al. 2004, Melo et al. 2007), resulting in greater safety for the indication of new cultivars. Among the most used methods are those based on regression (Eberhart and Russell 1966, Cruz et al. 1989) and the non-parametric (Lin and Binns 1988 modified by Carneiro 1998, Annichiarico 1992) and the multivariate (AMMI) analyses (Gauch and Zobel 1996).

The aim of this study was to identify Carioca genotypes in the common bean breeding program of Embrapa Arroz e Feijão, with high adaptability, yield and stability in states of the Center-South region of Brazil, using different approaches.

MATERIAL AND METHODS

The trials were installed in 2003 and 2004, in accordance with the rules of the Ministry of Agriculture and Livestock / National Cultivar Registry (MAPA/RNC 2006), in randomized blocks with three replications and plots of four rows (length 4 m), in 26 environments in the states of Paraná, Santa Catarina and São Paulo: Ponta Grossa (PR) and Abelardo Luz (SC) - Dry and Rainy in 2003 and 2004; Major Vieira (SC) - Dry/2004, Rainy 2003 and 2004; Prudentópolis (PR) - Dry 2003 and 2004; Roncador (PR) - Dry and Rainy, 2003; Campos Novos (PR) and Taquarituba (SP) - Rainy 2003 and 2004; Itapeva (SP), Capão Bonito (SP) and Concordia (SC) - Rainy/ 2003; Itaberá (SP), Paranapanema (SP), Laranjeiras do Sul (PR) and Londrina (PR) - Rainy/2004. Each test consisted of 16 genotypes, of which 12 were promising genotypes (CNFC's 9458, 9471, 9484, 9494, 9500, 9504, 9506, 9518, CNFE 8009, Carioca 11, BRS 9435 Cometa and BRS Estilo) and four were controls (Pérola, Iapar 81, Carioca Pitoco and Magnífico).

The grain yield (kg ha^{-1}) data were submitted to analysis of variance, considering the effect of treatments as fixed and the others as random. Combined analysis was performed and the percentage of simple and complex interactions was estimated for each pair of environments (Cruz and Castoldi 1991). Since the ratio between the highest and lowest residual mean square was greater than seven and the residual variances were therefore not homogeneous (Pimentel-Gomes 2000), the degrees of freedom of the mean error and the GE interaction were adjusted, based on the method of Cochran (1954).

The stability was analyzed by six methods: Eberhart and Russell (1966), Cruz et al. (1989), Lin and Binns (1988) modified by Carneiro (1998) (with decomposition of P_i), Lin and Binns (1988) modified by Carneiro (1998) (with weighting by the coefficient of variation), Annichiarico (1992) and AMMI. In the method of Eberhart and Russell (1966), the adaptability of the genotype is given by the parameter β_{1i} and the mean yield (β_{0i}) and the performance stability is attributed to the deviations of regression ($\sigma^2_{\delta i}$) and coefficient of determination ($R^2{}_i$), which is a complementary measure to assess stability when the $\sigma^2_{\delta i}$ are significant (Cruz and Regazzi 2001). In the bisegmented linear regression of Cruz et al. (1989) the response to unfavorable environments is given by the parameter, β_{1i} and the response to the favorable environments by $\beta_{1i} + \beta_{2i}$. The genotype stability is evaluated by the deviations from the regression ($\sigma^2_{\delta i}$) and the coefficient of determination ($R^2{}_i$).

Among the modifications proposed by Carneiro (1998) to the method of Lin and Binns (1988) the original approach was used with decomposition of P_i and of the weighted square trapezium by the coefficient of residual variation (CV). In the original method the decomposition of P_i was performed in parts due to the favorable and unfavorable environments and the environments were classified by environmental indices defined as the difference between the genotype means at each site and the overall mean. In the method weighted by the CV, the performance of each genotype is given by the P_i statistic, which is weighted by the coefficient of variation. Therefore, the performance lines with a lower P_i value is closer to the hypothetical ideal genotype, apart from taking the similarity of sites and the accuracy of each experiment into account.

The method of Annicchiarico (1992) is based on the so-called genotypic confidence index (W_i), derived from genotype means (in percentage) of the mean environmental values and then the estimation of the mean and standard deviation of each genotype in relation to the environment. The confidence coefficient was determined at 75% (α= 0.25).

The AMMI analysis (Zobel et al. 1988), which uses the additive model to examine the main effects and multiplicative model to study the interaction, was performed using the software Estabilidade (Ferreira 2000). The Gollob test was used to select the model and software Genes for the other methods (Cruz 2001).

RESULTS AND DISCUSSION

In 25 of the 26 trials the analysis of variance showed significant differences between genotypes and the CV values varied from 6% to 19%, indicating good experimental accuracy. The general yield mean in the tests ranged from 985 kg ha^{-1} to 4144 kg ha^{-1}, indicating rather divergent conditions for the genotypes, which had been expected, in view of the geographical differences between the sites of evaluation.

In the combined analysis, all effects were significant, indicating the presence of variability among genotypes, among environments and also a differential response of genotypes to environments (Table 1). Furthermore, it was found that the of the 325 possible combinations of pairwise environments, the simple part of interaction of only 24 (7.4%) was predominant against 301 (93.6%), in which the complex part was predominant, indicating changes in genotype ranking and reinforcing the need for stability analysis (Melo et al. 2007, Mendonça et al. 2007).

Table 1. Summary of the combined analysis of variance for grain yield (kg ha^{-1}) of 26 trials in the Center-South region of Brazil

Source of variation	Df	Mean square	F test
Replication/Environ-ment	52	405.004	-
Environments (E)	25	33.828.329	83.53**
Genotypes (G)	15	2.059.049	3.19**
G X E	(256)[1]	645.352	3.75**
Error	(526)[1]	171.762	-
Total	1.247	-	-
Mean	-	2.479	-
CV (%)	-	16.7	-

**: Significant at 1% error probability, by the F test
[1] DF adjusted according to Cochran (1954)

In terms of mean yield of genotypes, BRS Estilo and CNFC 9518 were the most productive, followed by CNFC 9458 and CNFC 9506 (Table 2). The genotypes Carioca 11 and BRS 9435 Cometa, with half-early cycle, performed worst.

According to the method of Eberhart and Russell (1966), CNFC 9458 was the only genotype adapted to favorable environments ($\hat{\beta}_{1i}$>1), with tolerable predictability (significant deviations and R^2 exceeding 80%) (Table 2). The genotypes Pérola, Carioca Pitoco and Carioca 11 were identified as adapted to unfavorable environments ($\hat{\beta}_{1i}$<1) and little predictable (significant deviations). The adaptation of the other genotypes was general ($\hat{\beta}_{1i}$=1) and among the most productive, CNFC 9518 should be highlighted, with high predictability (non-significant deviations) and BRS Estilo with acceptable predictability.

For the method of Cruz et al. (1989) the repeatedly reported limitations (Oliveira et al. 2006, Mendonça et al. 2007) were confirmed, e.g., the non-identification of genotypes with ideal performance, that is, with high mean, low sensitivity to unfavorable environments ($\hat{\beta}_{1i}$<1), responsiveness to environmental improvement ($\hat{\beta}_{1i} + \hat{\beta}_{2i}$>1) and high or tolerable predictability, apart from the difficulty of identifying genotypes adapted to specific environments, due to the large number of underlying parameters (Table 2).

The genotypes with highest yield, BRS Estilo and CNFC 9518, were sensitive to unfavorable environments ($\hat{\beta}_{1i}$=1) and not responsive to environmental improvement ($\hat{\beta}_{1i} + \hat{\beta}_{2i}$=1), whereas the predictability of BRS Estilo was acceptable and high for CNFC 9518. The genotypes CNFC 9458, little less productive than BRS Estilo and CNFC 9518, were sensitive to unfavorable environments ($\hat{\beta}_{1i}$=1), responsive to environmental improvement ($\hat{\beta}_{1i} + \hat{\beta}_{2i}$>1) and acceptably predictable. An advantage of this method is the possibility of greater detailing of the genotypes, e.g., the identification of responsiveness of BRS 9435 Cometa to environmental improvement ($\hat{\beta}_{1i} + \hat{\beta}_{2i}$>1).

The method of Lin and Binns (1988) modified by Carneiro (1998) has the great advantage of an immediate recommendation of more stable and adapted genotypes, due to the uniqueness of the parameter, the evaluation of genotype performance according to the environmental variation and the fact that the genotypes identified among the most stable and adapted are generally the most productive. According to this methodology, the most stable genotype is the one with least deviation from the maximum yield of each environment, i.e., with the lowest P_i value.

Table 2. Estimates of the parameters of adaptability and phenotypic stability by the methods of Eberhart and Russel (1966), Cruz et al. (1989) and AMMI, for 16 common bean genotypes evaluated in 26 environments in the Center South region

Genotype	Mean [1]	Eberhart and Russel			Cruz et al.				AMMI			
		$\hat{\beta}_{1i}$ [2]	$\hat{\sigma}_{di}$ [3]	R^2(%)	$\hat{\beta}_{1i}$ [2]	$\hat{\beta}_{1i}+\hat{\beta}_{2i}$ [4]	$\hat{\sigma}_{di}$ [3]	R^2(%)	CP 1 (33%) [5]	CP 2 (16%) [5]	WMAS [6]	C [7]
BRS Estilo	2.797 a	1.09^{ns}	65.974**	88	1.06^{ns}	1.29^{ns}	371.252**	88	-16.9	1.7	11.9	12
CNFC 9518	2.746 a	1.10^{ns}	24.197^{ns}	92	1.08^{ns}	1.22^{ns}	249.219^{ns}	92	1.3	-3.6	2.1	2
CNFC 9458	2.643 b	1.15**	50.769**	90	1.12^{ns}	1.33*	325.022**	90	-18.5	-14.4	17.1	13
CNFC 9506	2.567 b	1.07^{ns}	6.110^{ns}	93	1.05^{ns}	1.20^{ns}	192.257^{ns}	94	-7.9	10.2	8.6	9
CNFC 9484	2.513 c	1.02^{ns}	2.256^{ns}	93	1.01^{ns}	1.10^{ns}	183.864^{ns}	93	-8.5	-3.1	6.8	5
CNFC 9500	2.511 c	0.99^{ns}	16.920^{ns}	91	1.02^{ns}	0.78^{ns}	215.100^{ns}	91	-10.1	-2.5	7.6	7
CNFC 9471	2.501 c	1.08^{ns}	-1.124^{ns}	94	1.09^{ns}	1.02^{ns}	174.422^{ns}	94	-6.9	6.7	6.8	6
CNFC 9504	2.473 c	1.07^{ns}	29.331^{ns}	91	1.04^{ns}	1.23^{ns}	261.467^{ns}	91	-9.2	-12.0	10.1	10
Pérola	2.462 c	0.83**	190.732**	67	0.92^{ns}	0.30**	668.405**	72	38.6	-25.2	34.2	16
Iapar 81	2.457 c	1.01^{ns}	121.243**	81	0.99^{ns}	1.13^{ns}	553.640**	81	-1.4	7.4	3.4	3
CNFC 9494	2.444 c	1.00^{ns}	14.802^{ns}	91	1.02^{ns}	0.87^{ns}	219.274^{ns}	91	-10.6	1.5	7.6	8
Magnífico	2.389 c	1.02^{ns}	47.630**	88	1.05^{ns}	0.82^{ns}	313.815*	88	2.6	1.0	2.1	1
Carioca Pitoco	2.379 c	0.83**	231.455**	64	0.86*	0.67*	8.938.29**	64	34.5	-4.2	24.5	14
CNFE 8009	2.369 c	0.99^{ns}	75.755**	84	0.98^{ns}	1.06^{ns}	414.788**	84	6.4	2.5	5.1	4
BRS 9435 Cometa	2.243 d	0.99^{ns}	152.690**	77	0.90^{ns}	1.52**	548.586**	81	-12.8	-7.6	11.1	11
Carioca 11	2.166 d	0.75**	221495**	60	0.80**	0.46**	839.287**	61	19.4	41.8	26.8	15

(1) Means followed by the same letter are equal (Scott-Knott. α=0.10)
(2) H_0: $\hat{\beta}_{1i} = 1$
(3) H_0: $\sigma_{di} = 0$
(4) H_0: $\hat{\beta}_{1i} + \hat{\beta}_{2i1i} = 1$; ^{ns}, * and **, non-significant, significant at 5% and 1% error probability. by the t test, respectively
(5) Percentage of the variation explained by each principal component (CP) in the AMMI analysis
(6) Weighted mean of the absolute scores
(7) Classification

Table 3. Estimates of the parameters of adaptability and phenotypic stability of 16 common bean genotypes evaluated in 26 environments in the Center-South region, in 2003 and 2004, by the methods of Lin and Binns (1988) modified by Carneiro (1998), with decomposition of P_i (deviation in relation to the maximum yield) in favorable (P_{if}) and unfavorable (P_{id}) environments (mod L&B), square trapezium weighted by the CV (L&B mod CV) and Annichiarico (1992), with decomposition of W_i (confidence index) in favorable and unfavorable environments

Genotype	Mean[1]	mod L&B						mod L&B CV						Annichiarico					
		$P_i(x10^3)$	C[2]	$P_{if}(x10^3)$	C	$P_{id}(x10^3)$	C	$P_i(x10^6)$	C	$P_{if}(x10^6)$	C	$P_{id}(x10^6)$	C	W_i	C	W_{if}	C	W_{id}	C
BRS Estilo	2.797 a	150	2	144	2	154	2	959	1	485	1	473	1	110.0	1	111.3	1	108.1	1
CNFC 9518	2.746 a	130	1	129	1	131	1	1.032	2	528	2	503	2	108.1	2	108.2	2	107.9	2
CNFC 9458	2.643 b	208	3	163	3	241	5	1.091	3	543	3	548	4	101.8	3	99.5	3	105.0	3
CNFC 9506	2.567 b	209	4	252	4	178	3	1.128	4	574	4	554	5	100.0	4	99.4	4	100.7	4
CNFC 9484	2.513 c	268	6	299	8	246	6	1.172	5	605	5	566	7	98.0	6	97.5	5	98.9	7
CNFC 9500	2.511 c	271	7	286	6	260	7	1.195	6	632	9	562	6	98.2	5	97.3	6	99.4	5
CNFC 9471	2.501 c	241	5	273	5	218	4	1.217	8	622	8	594	11	96.3	7	94.3	10	99.1	6
CNFC 9504	2.473 c	320	10	296	7	337	13	1.207	7	615	6	593	10	95.2	9	92.8	12	98.7	9
Pérola	2.462 c	411	13	601	13	272	9	1.258	9	728	13	530	3	94.8	11	96.0	7	93.1	12
Iapar 81	2.457 c	304	9	308	9	273	10	1.261	11	658	10	603	13	95.1	10	94.8	8	95.2	11
CNFC 9494	2.444 c	293	8	324	10	270	8	1.266	12	674	11	592	9	95.3	8	94.6	9	96.0	10
Magnífico	2.389 c	368	11	347	11	413	15	1.260	10	621	7	639	15	92.3	12	87.9	14	98.8	8
Carioca Pitoco	2.379 c	473	14	686	14	317	12	1.317	14	746	15	572	8	91.8	13	93.9	11	89.0	14
CNFE 8009	2.369 c	403	12	483	12	345	14	1.310	13	708	12	601	12	90.3	14	88.7	13	92.7	13
BRS 9435 Cometa	2.243 d	561	15	729	15	437	16	1.397	15	745	14	652	16	84.3	15	84.7	16	83.7	15
Carioca 11	2.166 d	656	16	1.127	16	311	11	1.495	16	858	16	637	14	82.4	16	85.5	15	78.4	16

[1] Means followed by the same letter did not differ from each other (Scott-Knott. α=0.10)
[2] Genotype classification for stability by each method

The analyses by the method of Lin and Binns (1988) modified by Carneiro (1998), with decomposition of P_i showed CNFC 9518 as the most stable and adapted genotype when all environments were considered, followed by BRS Estilo (Table 3). The method of weighted square trapezium by CV identified the genotype BRS Estilo as the most adapted and stable followed by CNFC 9518, based on the three types of environments as well. Although the most stable and adapted genotypes (BRS Estilo and CNFC 9518) in the two methodologies were the same in the three types of environment, it was noted that for other genotypes, the performance varied considerably with the type of environment. An example was cultivar Pérola, the third most stable and adapted to unfavorable environments and only the 13th in favorable environments, according to the methodology of the weighted square trapezium by CV. Comparing the effect of the modifications in the methodology of Lin and Binns (1988), the classification of the two most stable and adapted lines was inverted, confirming that weighting by the CV results in an alteration of the genotype ranking.

The genotypes BRS Estilo and CNFC 9518 were also the most stable and adapted according to the methodology of Annichiarico (1992), in any environment (Table 3). Considering all environments, the confidence index (W_i) of BRS Estilo and CNFC 9518 exceeded 100%, indicating that, with 75% confidence, these genotypes exceeded the environmental mean by at least 10.0 and 8.1%, respectively. In the favorable environments, the genotypes outperformed the mean of the environments by 11.3 and 8.2%, respectively, and the yields in the unfavorable environments were by 8.1 and 7.9% higher.

By the AMMI analysis the first three axes and the residue were significant, at 1% probability, showing that these components together were insufficient to explain the effects of interaction. The first three principal components explained 33%, 16% and 11% of the sum of squares of the interaction, respectively, amounting to a total of 60% of the variation. This value was similar to that reported in other studies on common bean (Melo et al. 2007, Carbonell et al. 2004, Borges et al. 2000). Arias et al. (1996) and Borges et al. (2000) reported that for percentages below 70% to explain the variation in the interaction with the first components, results are unsatisfactory and conclusions therefrom are therefore not reliable. Gauch and Zobel (1996) argue that the first AMMI axes capture a greater percentage of the real "standard" performance and that with the accumulation of subsequent axes, there is a decrease in the "standard" percentage and an increase in inaccurate information ("noise"). Therefore, even if few components are selected that explained only a small proportion of the variation, the information would be of better quality, including that provided by the traditional methods.

To identify the most stable genotypes by AMMI, the mean of the absolute scores was obtained for the first two components, weighted by the percentage of explanation of each component (weighted mean of absolute scores – WMAS) for each genotype (Table 2). Thus, the lower the WMAS value, the lower the contribution of a genotype to the interaction and, consequently, the more stable is the genotype. The most stable and adapted genotypes can be identified by the graphic biplot (Figure 1), in which the genotypes Magnífico (G12) and CNFC 9518 (G2) can be identified as stable and adapted, because they are close to the origin, as well as Pérola (G9), as the least adapted and

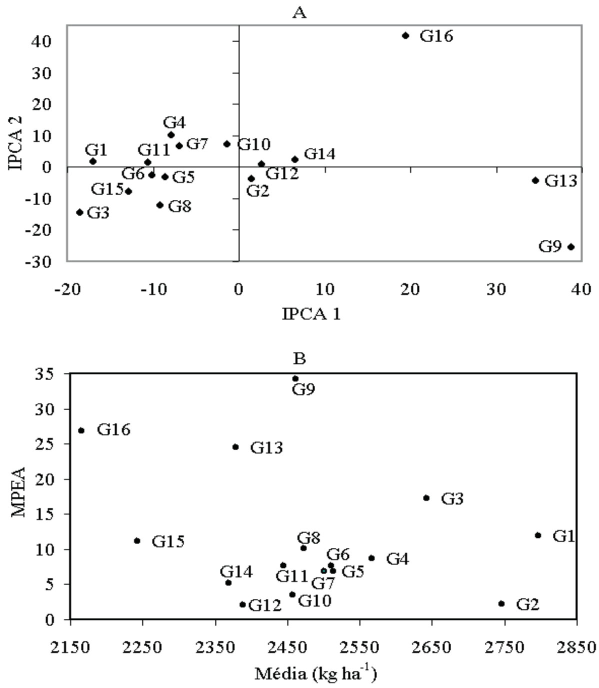

Figure 1. Graphical AMMI analysis for 16 common bean genotypes (G1-BRS Estilo; G2-CNFC 9518; G3-CNFC 9458; G4-CNFC 9506; G5-CNFC 9484; G6-CNFC 9500; G7-CNFC 9471; G8-CNFC 9504; G9-Pérola; G10-Iapar 81; G11-CNFC 9494; G12-Magnífico; G13-Carioca Pitoco; G14-CNFE 8009; G15-BRS 9435 Cometa; and G16-Carioca 11), evaluated in 26 environments in the Center-South region: **1A** - First principal component (IPCA1) x second principal component (IPCA2); **1B** - Weighted mean of absolute scores (WMAS) x yield means (kg ha^{-1})

stable (Figure 1A). Among the most productive, only CNFC 9518 (G2) was stable and adapted (Figure 1B).

CONCLUSIONS

The genotypes BRS Estilo and CNFC 9518 have high grain yield, adaptability and stability in the Center-South region of Brazil. The cultivar Pérola, widely planted in the Center-South region of the country, has a lower yield and is less adapted and stable than the new elite genotypes obtained by the breeding programs.

Estabilidade e adaptabilidade de genótipos de feijoeiro comum tipo carioca em estados da região Centro-Sul do Brasil

RESUMO - *O objetivo desse trabalho foi identificar genótipos de feijoeiro comum de tipo comercial carioca com alta adaptabilidade e estabilidade de produção na região Centro-Sul do Brasil, utilizando diferentes metodologias de análise. Foram conduzidos 26 ensaios para avaliação de valor de cultivo e uso (VCU), compostos por 16 genótipos, em blocos completos casualisados com três repetições, nos Estados de Santa Catarina, São Paulo e Paraná, em 2003 e 2004. Os dados de produtividade de grãos foram submetidos a análises de variância e de estabilidade e adaptabilidade pelas metodologias de Lin e Binns, Annichiarico, Eberhart e Russel, Cruz et al. e AMMI. Os genótipos BRS Estilo e CNFC 9518 destacaram-se por apresentar alta produtividade, alta adaptabilidade e alta estabilidade em várias das metodologias. A cultivar Pérola, amplamente plantada no país, apresenta menor produtividade, estabilidade e adaptabilidade do que novos genótipos elite obtidos pelos programas de melhoramento.*

Palavras chave: *Phaseolus vulgaris*, produção de grãos, interação genótipos x ambientes.

REFERENCES

Annichiarico P (1992) Cultivar adaption and recommendation from alfafa trials in Northern Italy. **Journal of Genetics and Plant Breeding 46**: 269-278.

Arias ERA, Ramalho MAP and Ferreira DF (1996) Adaptabilidade e estabilidade de cultivares de milho avaliados no Estado de Mato Grosso do Sul. **Ciência e Agrotecnologia 20**: 415-420.

Borges LC, Ferrreira DF, Abreu AFB and Ramalho MAP (2000) Emprego de metodologias de avaliação da estabilidade fenotípica na cultura do feijoeiro comum (*Phaseolus vulgaris* L.). **Revista Ceres 47**: 89-102.

Carbonell SAM, Azevedo Filho JA, Dias LA S, Garcia AAF and Morais LK (2004) Common bean cultivars and lines interactions with environments. **Scientia Agricola 61**: 169-177.

Carneiro PCS (1998) **Novas metodologias de análise da adaptabilidade e estabilidade de comportamento**. DS Thesis, Universidade Federal de Viçosa, Viçosa 168p.

Cochran WG (1954) The combination of estimates from different experiments. **Biometrics 10**: 101-129.

Cruz CD (2001) **Programa Genes**: aplicativo computacional em genética e estatística: versão Windows. Editora UFV, Viçosa, 648p.

Cruz CD and Carneiro PCS (2003) **Modelos biométricos aplicados ao melhoramento genético**. Editora UFV, Viçosa, 579p.

Cruz CD and Castoldi F (1991) Decomposição da interação genótipos x ambientes em partes simples e complexa. **Revista Ceres 38**: 422-430.

Cruz CD and Regazzi AJ (2001) **Modelos biométricos aplicados ao melhoramento genético**. Editora UFV, Viçosa, 390p.

Cruz CD, Torres RA and Vencovsky R (1989) An alternative approach to the stability analysis proposed by Silva and Barreto. **Revista Brasileira de Genética 12**: 567-580.

Del Peloso MJ and Melo LC (2005) **Potencial de rendimento da cultura do feijoeiro comum**. Embrapa Arroz e Feijão, Santo Antônio de Goiás, 131p.

Eberhart AS and Russel WA (1966) Stability parameters for comparing varieties. **Crop Science 6**: 36-40.

Ferreira DF (2000) **Aplicativo Estabilidade**. Universidade Federal de Lavras, Departamento de Ciências Exatas. / Available at www.ufla.br/dex. Accessed in May 2008.

Gauch HG and Zobel RW (1996) AMMI analysis of yield trials. In Kang MS and Gauch HG (Eds.) **Genotype by environment interaction**. CRC Press, Boca Raton, p. 85-122.

IBGE (2006) **Levantamento sistemático de produção agrícola.** IBGE, Rio de Janeiro, 18, p. 1-76.

Lin CS and Binns MR (1988) A superiority measure of cultivar performance for cultivar x location data. **Canadian Journal Plant Science 68**: 193-198.

MAPA/RNC – Ministério da agricultura e do abastecimento. Registro nacional de cultivares (2006) Anexo IV, **Requisitos mínimos para determinação do valor de cultivo e uso de feijão (*Phaseolus vulgaris*) para a inscrição no registro nacional de cultivares**, RNC.

Melo LC, Santos PG, Faria LC, Diaz JLC, Del Peloso MJ, Rava CA and Costa JGC (2007) Interação com ambientes e estabilidade de genótipos de feijoeiro-comum na Região Centro-Sul do Brasil. **Pesquisa Agropecuária Brasileira 42**: 715-723.

Mendonça O, Carpentieri-Pícolo V, Garbuglio DD and Fonseca Junior NF (2007). Análise de fatores e estratificação ambiental na avaliação da adaptabilidade e estabilidade em soja. **Pesquisa Agropecuária Brasileira 42**: 1567-1575.

Oliveira GV, Carneiro PCS, Carneiro JES and Cruz CD (2006) Adaptabilidade e estabilidade de linhagens de feijão comum em Minas Gerais. **Pesquisa Agropecuária Brasileira 41**: 257-265.

Pimentel-Gomes FP (2000) **Curso de estatística experimental**. Nobel, São Paulo, 466p.

Zobel RW, Wright MJ and Gauch HG (1988) Statistical analysis of a yield trial. **Agronomy Journal 80**: 388-393.