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Environmental stratification in Paraná and Santa Catarina to evaluate common bean genotypes

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ABSTRACT - *The purpose of this study was the environmental stratification of the states of Paraná and Santa Catarina for the evaluation of carioca common bean genotypes. The grain yield was evaluated in 20 trials, in a randomized block design with three replications testing 16 genotypes with carioca grain. The environments were stratified by five methodologies: traditional Lin; mean square of the interaction for paired locations, estimate of the percentage of the complex interaction; estimate of Pearson's correlation, and the Wricke method. Locations identified as uninformative by at least three of the methodologies were excluded. The locations considered uninformative in the respective growing seasons were Roncador (rainy/2003 and dry/2003) and Laranjeiras do Sul (rainy/2004) and no location in the growing season dry/2004. Only Roncador was identified as not very informative in at least two seasons and was therefore eliminated from the evaluation network of Carioca common bean genotypes.*

Key words: *Phaseolus vulgaris* L., genotype x environment interaction, common bean breeding.

INTRODUCTION

Common bean is subjected to different environmental conditions, since it is grown in several Brazilian states, in different growing seasons (rainy, dry and winter) and under different cropping systems, ranging from low-input subsistence farming to commercial high-technology agriculture. Under this condition a marked genotype-environment (GE) interaction is expected, which is not coincident with the performance of genotypes in the different environments, particularly for grain yield, as demonstrated in several studies of the crop conducted in Brazil (Carbonell et al. 2004, Melo et al. 2007, Pereira et al. 2009a, Pereira et al. 2009b).

The GE interaction consists of two parts. The first, called simple, represents the occurrence of differential responses of genotypes to environments, without modification of the classification of genotypes. The second, the complex part is given by the lack of correlation in the performance of genotypes in the environments and is caused by a change in the ranking of genotypes in these environments (Cruz and Regazzi 2001).

The GE interaction has a series of implications in breeding programs and its influence becomes even more evident in the test phase of lines for recommendation to farmers as new cultivars. Evaluations of common bean lines should be conducted under environmental conditions that best represent the prevailing growth conditions (Ramalho et al. 1998) and this requires the implementation of a network of assessment tests, including the major producing states. In the case of common bean in Brazil, the leading states are Santa Catarina and Paraná, which account for about 35% of the national production of common bean in 2007 (Feijão 2009).

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The implementation of this network is a rather labor and cost-intensive process. One of the major concerns for breeding programs is whether the assessment locations actually represent the environmental diversity of common bean cultivation in a particular region and whether the locations provide additional information, since any redundant locations should be eliminated, increasing the environmental diversity. Since the test locations change constantly, the environments should be stratified regularly.

Of the methods of environmental stratification, that of Lin (1982) seeks to form homogeneous subgroups, in which GE interaction is not significant (Lin 1982). When the GE interaction is significant between pairs of environments, the method of Cruz and Castoldi (1991) can be used, which identifies the percentage of interaction of the simple part, and also the correlation estimates of Pearson and Spearman. The method of Murakami and Cruz (2004) is based on the multivariate technique of factor analysis and combines environmental stratification and stability analysis. The estimate of ecovalence (Wricke 1965), initially used to measure the contribution of each genotype to the GE interaction may also be used to identify uninformative locations, measuring the contribution of each environment to the interaction, based on the decomposition of the sum of squares of interaction into fractions related to each environment.

For the safe exclusion of a location from the evaluation network, constant similarity patterns must be identified over time for the different growing seasons or for each sowing date.

Some studies about environmental stratification for common bean were conducted in the states of Minas Gerais (Ramalho et al. 1993, Oliveira et al. 2005) and Sao Paulo (Carbonell and Pompeu 1997), however, no such reports were found for Paraná and Santa Catarina. Other studies were performed in test networks in the states of Paraná and Santa Catarina, with corn (Garbuglio et al. 2007) and soybean (Mendonça et al. 2007). Since the crops respond differently to environmental variations, the objective of this study was to implement procedures of environmental stratification to identify uninformative locations in the evaluation of common bean genotypes in the states of Paraná and Santa Catarina.

MATERIAL AND METHODS

The experiments were set up and conducted in 2003 and 2004, in 20 environments in the states of Paraná and Santa Catarina, in rainy and dry growing seasons (nine locations, two sowing dates and two years), according to the norms defined by the Ministério da Agricultura e Pecuária/Registro Nacional de Cultivares (Brasil 2006), in a randomized block design with three replications, with plots consisting of four 4-m rows (Table 1). The yield data (kg ha^{-1}) were collected from the two central rows. Each combination of sowing date/year was considered one growing season. It is worth mentioning that not all locations were included in all growing seasons.

Each test consisted of 16 genotypes of the carioca group, with 12 promising genotypes (CNFCs 9458, 9471, 9484, 9494, 9500, 9504, 9506, 9518, CNFE 8009, Carioca 11, CNFC 9435 and CNFC 9461) and four controls (Pérola, Iapar 81, Carioca Pitoco and Magnífico). The yield data of each test were subjected to analysis of variance, considering the effect of treatments as fixed and locations as random. Thereafter, combined analyses of the tests were performed for each growing season. In the analyses in which the ratio between the highest and lowest residual mean square was greater than seven, indicating that the residual variances were not homogeneous (Pimentel Gomes 2000), the degrees of freedom of error and GE interaction were adjusted, by the method of Cochran (1954).

The environmental stratification was analyzed, using software Genes (Cruz 2001), by the following methods: traditional, as proposed by Lin (1982); the mean square of the GE interaction for pairs of locations; the method of Cruz and Castoldi (1991); estimate of Pearson's correlation, and method of ecovalence (Wricke 1965).

The method of Lin (1982) consists in the estimation of the sum of squares for the interaction between genotypes and pairs of environments, and subsequent clustering of the environments with non-significant interaction. In the following, the method estimated the sum of squares between genotypes and groups of three environments, using the F test to evaluate the possibility of creating a new group. Thus, groups of x environments are formed in which the interaction is not significant, which are therefore considered the most similar environments.

The estimate of the mean square of the GE interaction for location pairs was obtained in the combined analysis of variance for each pair of location and non-significance of the interaction was considered indication of similarity of locations.

The method of Cruz and Castoldi (1991) consisted in partitioning the GE interaction in two parts. The first, called simple, is determined by the difference in variability

Table 1. Geographical data of the locations and summaries of the individual analyses of variance of the 20 trials of carioca common bean in the rainy and dry growing seasons, in the states of Paraná and Santa Catarina

Location	State	Alt[1]	Lat[2]	Long[3]	MSE[4]	Mean[5]	CV[6]
Rainy/2003							
Campos Novos	SC	939	27º24’	51º13’	40,713	1,190	17
Abelardo Luz	SC	760	26º33’	52º19’	346,452	3,028	19
Major Vieira	SC	786	26º22’	50º19’	128,380	2,120	17
Concórdia	SC	569	27º14’	52º01’	120,830	2,440	14
Ponta Grossa	PR	969	25º05’	50º09’	100,214	3,688	9
Roncador	PR	762	24º36’	52º16’	35,767	985,000	19
Rainy/2004							
Abelardo Luz	SC	760	26º33’	52º19’	80,233	3,946	7
Major Vieira	SC	786	26º22’	50º19’	123,320	3,012	12
Campos Novos	SC	939	27º24’	51º13’	48,681	1,303	17
Ponta Grossa	PR	969	25º05’	50º09’	200,558	3,202	14
Laranjeiras do Sul	PR	840	25º24’	52º24’	56,942	2,160	11
Londrina	PR	585	23º18’	51º09’	33,368	1,399	13
Dry/2003							
Abelardo Luz	SC	760	26º33’	52º19’	52,618	1,919	12
Ponta Grossa	PR	969	25º05’	50º09’	144,728	2,182	17
Prudentópolis	PR	840	25º12’	50º58’	107,091	2,403	14
Roncador	PR	762	24º36’	52º16’	44,317	1,423	15
Dry/2004							
Abelardo Luz	SC	760	26º33’	52º19’	58,524	2,331	10
Major Vieira	SC	786	26º22’	50º19’	57,126	2,067	12
Ponta Grossa	PR	969	25º05’	50º09’	82,048	3,141	9
Prudentópolis	PR	840	25º12’	50º58’	136,114	2,403	15

[1] Altitude (meters); [2] Latitude South; [3] Longitude West; [4] Mean square of the error; [5] General mean of the experiment (kg ha^{-1}); [6] CV - Coefficient of variation (%).

between genotypes in the environments, and the second, called complex is given by the lack of correlation between genotypes and indicates the inconsistency of superiority of genotypes under environmental variation (Cruz and Regazzi 2001). The occurrence of most of the interaction due to the simple part indicates that the environments are similar. Locations with simple interaction percentage of more than 50% were considered similar.

Pearson’s correlations were estimated between the mean yields in different pairs of locations that were considered similar when the correlation was significant.

The ecovalence, used initially to measure the contribution of each genotype to the GE interaction (Wricke 1965), was used in this study to estimate the contribution of each location to the GE interaction. To estimate ecovalence, the sum of squares of the GE interaction was decomposed in the parts corresponding to each location, according to the following expression:

$$\omega_i = r \sum_j \left(Y_{ij} - \bar{Y}_{.j} - \bar{Y}_{i.} + \bar{Y}_{..} \right)^2$$

where: r: replictions; Y_{ij}: mean of genotype i in environment j; $\bar{Y}_i$: mean of genotype i; $\bar{Y}_j$: average environment j; $\bar{Y}_{..}$: overall mean.

To identify the least informative location in each growing seasons, we considered the results of the methods together, ie, locations or pairs of locations that were identified as uninformative by at least three of the methodologies, for each growing season.

To identify the locations that could be eliminated, we sought to identify sites that were repeatedly uninformative in at least two growing seasons.

RESULTS AND DISCUSSION

The mean grain yield of the tests ranged from 985 to 3946 kg ha^{-1}, showing the great variation in the test conditions (Table 1). This may be attributed in part to the diversity in the geographical distribution of sites used in the evaluation, where the altitude ranged from 585 to 969 m asl, lat from 23º 18’ to 27º 24’ S and long from 50º 09’ to 52º 24’ W, reflecting climate differences between the locations. Besides, regionally common and therefore quite variable cropping systems were used. The coefficient of variation ranged from 7 to 19%, indicating good experimental accuracy.

Significant differences between sites were detected in all combined analyses, demonstrating the feasibility of the analysis of environmental stratification (Table 2). No significant difference was observed for the source of genotypic variation, in the two growing seasons Rainy/2003 and Dry/2004. The GE interaction was significant in all analyses, reinforcing the possibility of environmental stratification.

For the growing season rainy/2003, the stratification analysis by Lin (1982) grouped the locations Campos Novos, Major Vieira and Roncador together, indicating similarity (Table 3). By this method, Roncador formed yet another group with Ponta Grossa, which indicates similarity of the former with some of the others. Comparing the locations by pairs, for Major Vieira and Roncador, as well as Ponta Grossa and Abelardo Luz, the GE interaction was not significant, indicating that the locations are similar in genotype performance (Table 4). Between the pairs of locations for which the interaction was significant, the pair Campos Novos and Concórdia had a high percentage of interaction related to the simple part (68%), confirming the similarity in genotype ranking at these two locations. The results of the Pearson's correlation also indicated similarity between Ponta Grossa and Abelardo Luz (0.54). The ecovalence analysis showed that the locations that contributed least to interaction were Campos Novos and Roncador (Table 5). Considering the combined methods, the location Roncador was grouped in two clusters by Lin (1982), the interaction was not significant when considered together with Major Vieira, and the ecovalence estimate was also low. In this growing season, Roncador was therefore considered the least informative location.

In the growing season rainy/2004 the sites Abelardo Luz and Laranjeiras do Sul were grouped as similar by Lin (1982) (Table 3). Analyzing the locations by pairs, once more the GE interaction of the pair Abelardo Luz and Laranjeiras do Sul was not significant. The simple interaction of this pair of environments was 46.8% and the estimate of Pearson's correlation high (0.72) (Table 4). The pair of locations Ponta Grossa and Laranjeiras do Sul was also identified as similar by the high Pearson's correlation (0.75). The ecovalence estimates for Laranjeiras do Sul (7%) and Abelardo Luz (8%) indicate these sites as the least informative by his methodology (Table 5). A comparison of the results of various methods showed that in this season the least informative location was Laranjeiras do Sul, because aside from being grouped with Abelardo Luz by Lin (1982), and a lower ecovalence estimate, the site was also identified as similar to Ponta Grossa by another methodology.

Table 2. Summary of the combined analyses of variance per growing season/year, for grain yield (kg ha^{-1}), in the rainy and dry growing seasons, in the States do Paraná and Santa Catarina.

Sources of variation	df	Rainy		df	Dry	
		Mean squares			Mean squares	
		2003	2004		2003	2004
Replic./Location	12	21,719	428,460	8	578,341	396,328
Locations (E)	5	52298,987**	53814,527**	3	8531,817**	10161,486**
Genotypes (G)	15	629,230ns	1274,849**	15	747,385**	335,201ns
E X G	75 (49)[1]	739,920**	325,919**	45	293,166**	346,554**
Error	180 (109)[1]	212,574	90,516	120	87,188	83,452
Total	287	-	-	191	-	-
Mean	-	2,242	2,503	-	1,981	2,485
CV (%)	-	16.0	12.0	-	14.9	12.6

[1] Degrees of freedom of the interaction and of the adjusted error according to Cochan (1954), for the growing seasons rainy/2003; ** Significant at 1% probability by the F test.

Table 3. Clusters of the locations with non-significant GE interaction, according to Lin (1982), and their respective mean squares of the GE interaction (MS_{GxL}), calculated F and tabled F at 5% probability, per growing season

Group	Locations	MS_{GxL}	F cal	F tab
Rainy/2003				
I	Campos Novos, Major Vieira and Roncador	25,005	1.12	1.52
II	Ponta Grossa and Roncador	0,822	1.41	1.72
Rainy/2004				
I	Abelardo Luz and Laranjeiras do Sul	38,424	1.27	1.72
Dry/2003				
I	Prudentópolis and Roncador	47,300	1.63	1.72

Table 4. Summary of the analyses of environmental stratification of environment pairs for the trials conducted in the States of Paraná and Santa Catarina, in the rainy and dry growing seasons

MSGE[1]			% SGE[2]			Pearson's correlation		
E_1	E_2	MS	E_1	E_2	%	E_1	E_2	r_p
Rainy/2003								
2	6	25,006	2	5	68.0	1	3	0.54*
4	6	46,926^{ns}	2	3	49.4	2	5	0.43
1	6	60,822	3	6	47.4	4	6	0.40
2	4	72,141	1	3	40.3	1	6	0.39
1	2	83,613	1	6	40.0	2	6	0.38
1	3	102,752^{ns}	4	6	34.3	2	3	0.26
2	3	132,059	5	6	32.1	3	6	0.24
3	6	134,171	2	6	21.4	1	4	0.13
1	4	106,594	1	2	21.1	1	2	0.07
2	5	170,235	3	4	13.3	3	4	0.04
3	4	184,711	2	4	10.7	2	4	0.00
5	6	252,501	1	4	7.5	3	5	-0.14
4	5	306,379	4	5	7.3	5	6	-0.20
1	5	345,620	1	5	0.0	4	5	-0.23
3	5	393,515	3	5	0.0	1	5	-0.30
Rainy/2004								
3	7	38,424^{ns}	1	7	69.9	1	7	0.75**
2	3	63,329	3	7	46.8	3	7	0.72**
2	4	65,720	1	3	46.0	1	3	0.51*
3	8	70,016	1	2	42.7	3	8	0.49*
2	7	72,803	2	3	41.2	3	2	0.34
2	8	82,178	1	4	36.4	3	4	0.34
3	4	86,121	3	8	28.9	7	8	0.34
7	8	88,302	2	4	28.2	1	4	0.34
4	7	91,423	1	8	27.8	4	7	0.28
1	7	94,752	2	7	26.7	1	8	0.25
4	8	100,726	2	8	22.8	4	8	0.22
1	3	150,231	3	4	19.2	4	2	0.20
1	4	187,759	7	8	18.8	7	2	0.15
1	8	211,354	4	7	14.9	8	2	0.06
1	2	226,315	4	8	12.1	1	2	-0.06
Dry/2003								
6	9	47,300	1	6	44.4	1	6	0.65**
1	6	63,741	6	9	38.9	6	9	0.62**
3	9	108,558	1	3	23.9	1	3	0.25
1	3	114,371	1	9	18.0	1	9	0.24
1	9	124,586	3	9	0.0	3	9	-0.10
3	6	127,802	3	6	0.0	3	6	-0.18
Dry/2004								
3	4	70,620	1	4	20.5	3	4	0.34
1	4	84,708	3	4	19.0	1	4	0.33
4	9	112,041	1	3	5.1	1	3	0.08
1	3	121,622	1	9	0.0	1	9	-0.08
1	9	132,203	4	9	0.0	4	9	-0.16
3	9	172,070	3	9	0.0	3	9	-0.65**

[1] MSGE: Mean square of the GE interaction; [2] %SGE: Simple percentage of the GE interaction; E_1 and E_2 – Environments, 1-Ponta Grossa, 2-Campos Novos, 3-Abelardo Luz, 4-Major Vieira, 5-Concórdia, 6-Roncador, 7-Laranjeiras do Sul, 8-Londrina, 9-Prudentópolis; ^{ns} non-significant GE interaction by the F test; * and **: Significant correlation at 5% and 1%, respectively.

In the growing season dry/2003 the method of Lin (1982) clustered Prudentópolis and Roncador as similar (Table 3). The GE interaction of the pairs of sites was always significant, showing that the genotype performance at these sites was not coincidental. None of the pairs had a high percentage of simple GE interaction, confirming that the genotype ranking of these pairs of locations is different (Table 4). However, Ponta Grossa and Roncador were identified as similar by Pearson´s correlation estimate (0.65). Ecovalence estimates for Roncador (15%) were lower than for the others (Table 5). Based on the combined methods, it was therefore inferred that the least informative site is Roncador, since aside from being grouped together with Prudentópolis by Lin (1982), and having a lower ecovalence estimate, Pearson´s correlation estimate also indicated the site as similar to Ponta Grossa.

By Lin (1982), in the growing seasons dry/2004 no groups of locations with significant interaction were

Table 5. Estimates of Ecovalence (W) for the locations of the common bean trials, in the rainy and dry growing seasons, in the states of Paraná and Santa Catarina

Location	Rainy				Dry			
	2003		2004		2003		2004	
	W[1]	%	W	%	W	%	W	%
Ponta Grossa	4,448	12	8,982	36	3,512	27	3,717	24
Campos Novos	1,203	3	3,581	16	-	-	-	-
Abelardo Luz	8,165	23	2,048	8	4,593	35	4,297	27
Major Vieira	4,708	13	3,902	16	-	-	2,116	14
Concórdia	15,981	44	-	-	-	-	-	-
Roncador	1,748	5	-	-	2,075	15	-	-
Laranjeiras do Sul	-	-	1,711	7	-	-	-	-
Londrina	-	-	4,215	17	-	-	-	-
Prudentópolis	-	-	-	-	3,011	23	5,467	35
Total	36,255	100	24,441	100	13,193	100	15,598	100

[1] ($x10^3$).

formed (Table 3) and none of the methods of environmental stratification analysis comparing the sites in pairs detected similar locations (Table 4). Ecovalence analysis identified Major Vieira as the location with lowest contribution to the GE interaction (Table 5). Because only this methodology identified the site as little informative, it was considered that in this growing season no uninformative site had been identified.

Considering paired sites for each growing seasons, the GE interaction was significant in 93%, the percentage of interaction due to the complex part high in 96% and the correlation coefficient low in 86% of the combinations (Table 4), confirming the strong influence of GE interaction. Other authors observed a strong GE interaction for grain yield when performing environmental stratification, but these authors considered data of several growing seasons in a single analysis. For maize, in environments in the States of Paraná and Santa Catarina, Garbuglio et al. (2007) found predominance of the complex part in 87% of the environment pairs and 56% with a low Pearson correlation coefficient. For soybean, in the states of Paraná and Santa Catarina, Mendonça et al. (2007) found predominance of the complex part in 92% of the pairs and 90% with a low correlation coefficient.

Since environments change over the years, it would be over-hasty to eliminate a location because it is identified as uninformative in one growing season only. Such sites should be identified in different growing seasons over time, or also for each sowing date, since the indication of common bean cultivars is based on sowing dates (Brasil 2006).

In the growing seasons evaluated, the locations identified as uninformative were Roncador (rainy/2003), Laranjeiras do Sul (rainy/2004), Roncador (dry/2003) and none in the growing season dry/2004. This indicates that Roncador should be eliminated from the network of evaluation sites for Carioca common bean in the states of Paraná and Santa Catarina. It is however noteworthy that not all sites were repeated in each growing season, which reduces the chance of identifying less informative sites. This variation in the sites used for evaluation from one growing season to another is a result of the difficulty in maintaining durable partnerships for common bean evaluation and also because the crop can be grown in only one growing season at some locations. For example in the case of Londrina, cultivation in the dry season would be extremely risky for an attack of the bean golden mosaic virus.

Underlying the elimination of a location from the test network, aside from the fact of being little informative, other factors are important, e.g., the support at each location with infrastructure and trained staff for the installation and performance of trials. Accordingly, in Ponta Grossa tests are installed in an area of the Embrapa Transferência de Tecnologia (SNT Ponta Grossa), where the infrastructure required for such tests is given. The same site is also important for disease resistance evaluation, due to its climatic conditions favorable to the expression of several of the major diseases of the crop. For these reasons, this site is also used for the initial stages of breeding programs of Embrapa Arroz e Feijão. These features make Ponta Grossa indispensable from the assessment network, and if locations similar to Ponta Grossa were identified, any others should be eliminated first.

The sites constant in the different growing seasons, Ponta Grossa and Abelardo Luz, were always informative, confirming that they must remain in the evaluation network. In Major Vieira tests were performed in three of the four growing seasons and this location was not always identified as informative either. The conclusion may therefore be drawn that the main locations of the test network, where assessments are constantly carried out, are informative. The location Roncador was identified as not very informative for the evaluation of carioca common bean genotypes and will henceforth be eliminated from the evaluation network.

Estratificação ambiental no Paraná e em Santa Catarina para avaliação de genótipos de feijoeiro comum

RESUMO – *O objetivo deste trabalho foi realizar a estratificação ambiental nos Estados do Paraná e Santa Catarina para a avaliação de genótipos de feijoeiro comum tipo carioca. Foram utilizadas avaliações de produtividade de grãos em 20 ensaios conduzidos em blocos ao acaso, com três repetições, compostos por 16 genótipos com grãos tipo carioca. A estratificação ambiental foi realizada por cinco metodologias: tradicional de Lin; quadrado médio da interação para os locais dois a dois; estimativa da porcentagem complexa da interação; estimativa de correlação de Pearson; e método de Wricke. Foram considerados pouco informativos, locais identificados em pelo menos três das metodologias. Os locais pouco informativos foram Roncador (águas/2003 e seca/2003) e Laranjeiras do Sul (águas/2004) e nenhum local na safra da seca/2004. Somente Roncador foi identificado como pouco informativo em pelo menos duas safras e, portanto, será eliminado da rede de avaliação de genótipos de feijoeiro comum tipo carioca.*

Palavras-chave: *Phaseolus vulgaris* L., interação genótipos x ambientes, melhoramento de feijoeiro comum.

REFERENCES

Brasil (2006) Instrução Normativa nº 25, de 23 de maio de 2006. Anexo I. Requisitos mínimos para determinação do valor de cultivo e uso de feijão (*Phaseolus vulgaris*) para a inscrição no registro nacional de cultivares - RNC. **Diário Oficial [da] República Federativa do Brasil**, Brasília. Available at <http://extranet.agricultura.gov.br/sislegisconsulta/servlet/VisualizarAnexo?id=11376>. Accessed on November 10, 2008.

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

Carbonell SAM and Pompeu AS (1997) Estratificação de ambientes em experimentos de feijoeiro no Estado de São Paulo. **Bragantia 56**: 207-218.

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

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

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.

Feijão (2009) **Dados conjunturais do feijão (área, produção e rendimento) - Brazil - 1985 to 2007**. Available at <http://www.cnpaf.embrapa.br/apps/socioeconomia/index.htm>. Accessed on November 25, 2009.

Garbuglio DD, Gerage AC, Araújo PM, Fonseca Júnior NS and Shioga OS (2007) Análise de fatores e regressão bissegmentada em estudos de estratificação ambiental e adaptabilidade em milho. **Pesquisa Agropecuária Brasileira 42**: 1567-1575.

Lin CS (1982) Grouping genotypes by a cluster method directly related to genotype-environment interaction mean-square. **Theoretical and Applied Genetics 62**: 277-280.

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.

Murakami DM and Cruz CD (2004) Proposal of methodologies for environment stratification and analysis of genotype adaptability. **Crop Breeding and Applied Biotechnology 4**: 7-11.

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.

Pereira HS, Melo LC, Faria LC, Del Peloso MJ, Costa JGC, Rava CA and Wendland A (2009a) Adaptabilidade e estabilidade de genótipos de feijoeiro-comum com grãos tipo carioca na região Central do Brasil. **Pesquisa Agropecuária Brasileira 44**: 29-37.

Pereira HS, Melo LC, Faria LC, Díaz JLC, Del Peloso MJ, Costa JGC and Wendland A (2009b) Stability and adaptability of carioca common bean genotypes in states of the Central South region of Brazil. **Crop Breeding and Applied Biotechnology 9**: 181-188.

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

Ramalho MAP, Abreu AFB and Righetto GU (1993) Interação de cultivares de feijão por épocas de semeadura em diferentes localidades do Estado de Minas Gerais. **Pesquisa Agropecuária Brasileira 28**: 1183-1189.

Ramalho MAP, Abreu AFB and Santos PSJ (1998) Interações genótipos x épocas de semeadura, anos e locais na avaliação de cultivares de feijão nas Regiões sul e Alto Paranaíba em Minas Gerais. **Ciência e Agrotecnologia 22**: 176-181.

Wricke G (1965) Zur berechnnung der ökovalenz bei sommerweizen und hafer. **Pflanzenzüchtung 52**: 127-138.