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Factor analysis in the environment stratification for the evaluation of common bean cultivars

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ABSTRACT - *Two trials evaluating the value of cultivation and use (VCU) for common bean were conducted in six counties of the state of Minas Gerais in 2002 and 2003 for the three traditional crop seasons. Objective was to investigate the efficiency of different methods of environmental stratification. The subgroups formed by the traditional environmental stratification presented, for the most part, environments corresponding to the winter cultivation period, indicating in this case a small effect of the site on the performance of the lines in this cultivation period. The splitting of the interaction in simple and complex fractions did not enhance the clustering based on the traditional method of stratification. The factor analysis was however more effective at clarifying the similarity between the environments than the analysis based on the principle of insignificant interaction genotypes x environments, indicating its potential for this kind of studies.*

Key words: *Phaseolus vulgaris*, interaction genotype x environment, ecological zoning, factor analysis.

INTRODUCTION

Common bean is a crop with broad edapho-climatic adaptation which allows its cultivation all year round in nearly all Brazilian states and which makes the constant supply of the product on the market possible. Breeders in tropical conditions however face greater challenges than those of the temperate regions. The climatic instability and heterogeneity of the soils are greater under tropical conditions, and require that the cultivars recommended for farmers include a high grain yield and greater stability (Paterniani 1986).

The indication of cultivars in generalized form, in other words, without taking into consideration that there are favorable or unfavorable environments for common bean cultivation, may result in the recommendation of cultivars with higher yields in the favorable, but with low productivity in the unfavorable environments. Besides, it is possible that a cultivar performs outstandingly on certain sites, while at other locations it is outperformed by another cultivar. This difference of performance of the cultivars in the distinct environments is explained by the interaction genotypes x environments (interaction G x E) (Cruz and Regazzi 2001).

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The interaction is composed of two fractions. The first, denominated simple, is expressed in the difference of variability between genotypes in the environments. In other words, this interaction fraction represents the occurrence of differential responses of the genotypes to the different environments, without altering the relative position of the genotypes. The second, designated complex, is given by the lack of correlation in the performance of the genotypes in the environments. It is caused by the alteration of the classification order of the genotypes in the evaluated environments (Cruz and Regazzi 2001).

Studies with common bean have however evidenced that among the environmental components (location, year and crop season) the latter contributed most to the interaction genotypes x environments. For this reason future evaluations of common bean cultivars should be realized in the various crop seasons in detriment of sites (Ramalho et al. 1993, Carbonell and Pompeu 1997, Ramalho et al. 1998, Ramalho et al. 2002).

Agronomical zoning, based on the diverse methods of environmental stratification, is one of the moderating strategies of the interaction. Environment stratification consists in the subdivision of the heterogeneous area in more uniform sub-regions, excluding any significant interaction of the cultivars with the environments in the sub-regions. However, this methodology is only consistent for the interaction of genotypes x locations, and not for genotypes x years and/or genotypes x locations x years (Eberhart and Russel 1966), which also applies to the interaction genotypes x crop seasons.

Carbonell and Pompeu (1997) proposed the environmental stratification within each crop season where the interaction is significant. According to these authors, the proposal serves to identify specific environments for the selection and evaluation of genotypes that are resistant or tolerant to the factors of this interaction (disease, temperature, drought, etc).

Depending on the referential there are two forms of environmental stratification. The first (traditional), based on the algorithm of Lin (1982), clusters similarly performing genotypes and, consequently, the interaction is not significant. The second is based on the expression proposed by Cruz and Castoldi (1991), where pairs of environments that present a G x E interaction of predominantly simple nature are clustered.

A joint analysis of environment stratification and adaptability by means of the factor analysis was suggested by Murakami and Cruz (2004). The factor analysis is a multivariate technique which allows a reduction from the high number of originally observed variables to a small number of abstract variables, the factors. The original variables are grouped by means of their correlations and those that characterize a particular factor are strongly correlated with each other but weakly correlated with other factors. The methodology, according to the author, proved effective to unite locations for their similarities in genotypic performance, besides presenting a great potential for exploring the adaptability of genotypes in a more effective way than the traditional methods, presenting results according to the environmental stratification. The proposed methodology also proved effective for an evaluation of the representative capacity of locations, with the advantage of making the interpretation and execution easier. This methodology also indicates which environment is most able to substitute the location of best general capacity of representativity if this should present an unexpected problem. Although interesting, there are still no reports on the use of the factor analysis in studies on the genotype x environments interaction in common bean. Our study had the objective to investigate the efficiency of the factor analysis in the environmental stratification for common bean in the state of Minas Gerais.

MATERIAL AND METHODS

Data of two trials of value of cultivation and use (VCU) of common bean were used, one of the black and the other of the carioca group. The experiments were conducted in Viçosa (rainy/2002, dry/2002 and winter/2002 and 2003), Ponte Nova (dry/2002 and winter/2002 and 2003) and Coimbra (rainy/2002, dry2002 and winter/2002 and 2003), regions of the Zona da Mata in Minas Gerais. Besides, data of experiments in Leopoldina (winter/2002), Florestal (dry/2003) and Capinópolis (winter/ 2003) were used, amounting to a total of 14 environments.

The experiments were installed in randomized blocks with three replications, according to the minimal requirement established for the VCU trial of common bean, (governmental order nr. 294, October 14 of 1998 by the Ministry of Agriculture). The yield data were obtained in kg ha^{-1} skipping the two border rows. Each experiment was composed of 20 lines of the carioca and black groups, including two controls (cultivars recommended for the state of Minas Gerais) per group. No disease control was applied, but pests were controlled whenever necessary.

The data of each experiment were subjected to the analysis of individual variance and later, the joint analysis of the experiments was realized involving those with a coefficient of residual variation below 20%, according to the VCU trial norms for common bean. The genotype effect was considered fixed and the others (replication, experiment and interaction genotypes x experiments) random. The environments were clustered based on the traditional method of Lin (1982), on the partition of the interaction in simple and complex parts (Cruz and Regazzi 2001) and on the factor analysis proposed by Murakami and Cruz (2004).

According to Cruz and Carneiro (2003), the number of factors to be retained corresponds to the number the eigenvalues from the matrix of phenotypic correlations of the standardized variables higher than the unit and/or when an adequate proportion of absorbed variability, generally more than 80% of the total variation, had been obtained.

The clustering of environments was based on the final factor loadings as described by Johnson and Wichern (1992). Factor loadings higher than or equal to 0.70 and of the same signal indicate environments with a high similarity pattern. These are clustered within each factor. The factor loadings were extracted by the method of the principal components and the factors established by varimax rotation, with 50 rotations at the most. The analyses were processed on software Genes (Cruz 2001).

RESULTS AND DISCUSSION

In the VCU trials of the black as well as carioca common bean, the genotypic effect (lines) was highly significant in the evaluated environments, except in Capinópolis in the winter crop season/2003 and in Ponte Nova in the dry period/2003 (Table 1).

The experiments generally presented good experimental precision with coefficients of variation (CV) below 20%. The CV was over 20% for the three experiments in the wet period (Table 1) Viçosa and Coimbra (black VCU) and Viçosa (carioca VCU). The other experiments of this crop season did not provide sufficient data for an analysis. These results demonstrate the enormous difficulty of conducting experiments with common bean during the rainy season. The incidence of weeds is higher and, above all, rainfall concentrates at the moment of the harvest, leading to the germination of the seeds in the pods before they are harvested. This results in the loss of most of these experiments or a reduced experimental precision. The rainy season was therefore not included in the study of environmental stratification.

The ratio of the highest by the lowest mean square of the residue was lower than seven, which allows the

Table 1. Summary of the individual analyses of variance corresponding to the VCU trials of the black and carioca bean groups, conducted in Minas Gerais state, in different crop seasons and years

Environments		black VCU trial			carioca VCU trial		
Crop season	Location	MS Genotypes	Yield kg ha^{-1}	CV %	MS Genotypes	Yield kg ha^{-1}	CV %
Rainy	Viçosa	330996.78**	880	31.55	167853.25**	1057	25.18
(2002)	Coimbra	171378.34**	991	26.55	-	-	-
Winter(2002)	Viçosa[1▲]	236474.58**	1647 (-)	11.57	308592.25**	2034 (-)	14.51
	Coimbra[2]	358596.73**	2578 (+)	7.95	566173.96**	2552 (+)	10.87
	Ponte Nova[3]	232520.89**	2520 (+)	12.25	350526.66**	2246 (-)	9.92
	Leopoldina[4]	162334.56**	2004 (-)	9.73	318741.68**	1926 (-)	16.81
Dry(2003)	Viçosa[5]	237500.55**	3098 (+)	9.72	420589.90**	2846 (+)	11.19
	Coimbra[6]	327314.57**	2145 (-)	13.96	406117.70**	2327 (-)	16.77
	Ponte Nova[7]	193303.13	2767 (+)	14.26	305689.58	3130 (+)	15.42
	Florestal[8]	665533.63**	1607 (-)	17.03	277756.50**	1711 (-)	17.83
Winter(2003)	Viçosa[9]	395164.82**	1436 (-)	19.83	591615.57**	1487 (-)	18.99
	Coimbra[10]	302560.14**	3665 (+)	6.34	281418.85**	3824 (+)	7.83
	Ponte Nova[11]	241482.12**	2599 (+)	11.10	203427.73**	3168 (+)	10.42
	Capinópolis[12]	204997.77*	2602 (+)	11.33	102109.57	2989 (+)	8.72
Overall mean			2389			2520	

▲- codification of the environments
**; * P < 0.01 and P < 0.05, respectively
(+) and (-) indicate favorable and unfavorable environments, respectively, above and below the mean

joint analysis of the data, according to Pimentel Gomes (1985) (Table 2). In this analysis, all sources of variation presented significant effects. A significant genotypic effect in the presence of a significant G x E interaction evidences high variability among the evaluated lines since the variance component of the interaction G x E (σ^2_{ga}) tends to reduce or eliminate the estimated variability among the lines (Cruz and Regazzi 2001). The significant effect of environments evidences that the experiments were conducted in contrasting environments (in this case locations and crop seasons). Lastly, the significant effect of the interaction G x E indicates that the different evaluated genotypes presented a differential performance across the environments, in other words, there were changes of the relative position of the lines or difference in the magnitude of response of the grain yield to the environmental variation.

By the traditional clustering method of environments it was verified that the 12 environments of the VCU trial of for black common bean were distributed in six groups (Table 3). Environments 1, 2, 3, 4, (Viçosa, Ponte Nova, Coimbra and Leopoldina – winter/2002) clustered with environments 10 and 11 (Coimbra and Ponte Nova – winter/2003), forming the first group, whose interaction G x E was not significant. Note that all environments in group I belonged to the winter crop season, indicating that this crop season represented a factor of greater influence on the genotypes than the effect of locations and years.

Some authors have suggested disease incidence as the principal cause for the interaction genotypes x crop seasons, which in turn is quite influenced by the climatic conditions of each season (Miranda et al.1993, Ramalho et al. 1998, Carbonell and Pompeu 1997, 2000, Carbonell et al. 2001). However, the clustering of environments including different crop seasons, as observed for group II (Viçosa - dry/2003 and Capinópolis -winter/2003), shows that other factors such as the factor location contribute to the interaction genotypes x environments. In the carioca bean trial, the 13 environments were distributed among eight groups (Table 4). Once again, there was a tendency to cluster environments corresponding to the winter crop season, as can be verified by the environments that are components of groups I and II.

It should be mentioned that the clustering method based on the algorithm of Lin (1982) forms mutually exclusive groups, in other words, other environment combinations where the interaction G x E is not significant could exist, however one of these environments was clustered in another group. Comparing the clustering of the environments based on the black bean trial (Table 3) with that of the carioca bean trial (Table 4) we observed a higher number of environments included in the groups in the first case. This result indicates a greater interaction of the carioca type lines with these environments than of those of the black group.

When the interaction G x E is significant and there is no relevant alteration in the relative position of the evaluated genotypes its nature is predominantly simple. Some authors such as Cruz and Regazzi (2001) have suggested an enhancement of the environment stratification in order to form subgroups where the pairs would present a G x E interaction of predominantly simple

Table 2. Summary of the joint analysis of variance of the 20 genotypes of the VCU trials for black and carioca bean evaluated in 12 environments in the state of Minas Gerais state

Sources of variation	df	MS black VCU	MS carioca VCU
Block/Environment	24	427258.22	582015.06
Environments (E)	11	25596941.77*	28596474.80*
Genotypes (G)	19	1019567.41*	1052309.12*
G x E	209	230746.91**	280040.99**
mean error	456	77373.15	103726.12
Mean		2389.46	2520.57
CV (%)		11.64	12.78

**; * P < 0.01 and P < 0.05, respectively

Table 3. Groups of environments with insignificant G x E interaction and their respective mean squares (MS G x E), calculated F (F cal), probability (P) at the level of 5% based on the yield of 20 black common bean lines of the VCU trial

Group	Environments	MS G x E	F cal	P %
I	1. 3. 11. 4. 2 and 10	32770.39	1.27	5.83
II	5 and 12	38017.42	1.47	9.13
III	6			
IV	7			
V	8			
VI	9			

Table 4. Environment groups with insignificant G x E interaction and their respective mean squares of the interaction (MS G x E), calculated F (F cal) and probability (P) at the level of 5%, based on the yield of carioca common bean lines in the VCU trial

Group	Environments	MS G x E	F cal	P %
I	11, 12, 1, and 3	44325.78	1.28	9.15
II	2 and 4	45377.75	1.31	17.13
III	5			
IV	6			
V	7			
VI	8			
VII	9			
VIII	10			

nature. In this case, the interaction does not affect the recommendation of cultivars since the relative position of the cultivars is the same across the environments.

The pairs of environments that presented interaction of predominantly simple nature by the method of Cruz and Castoldi (1991) were only 1 x 2, 1 x 3, 2 x 11 in the trial of common black bean and 1 x 2, 1 x 9, 2 x 4, 3 x 12, 5 x 12 and 9 x 12 in the trial of carioca bean (Table 5). It is noteworthy that the environments that were not clustered by the traditional method did not present a fraction of G x E interaction of predominantly simple nature either, in analogy with the already clustered environments. Particularly in this study, it was therefore not possible to add environments to the groups formed by the traditional method.

We underscore that in our study most environment pairs presented a G x E interaction of complex nature. Regarding the correlation between the environment pairs on the other hand, we observed that, with exception of pair 4 x 10, all environment pairs of group I, black common

Table 5. Environment pairs, their correlations (r) and percentage of the simple part (PS) of the GxA interaction according to Cruz and Castoldi (1991) in the VCU trials of black and carioca common bean evaluated in Minas Gerais state

Environment	black VCU		carioca VCU		Environment	black VCU		carioca VCU	
pairs	r	PS %	r	PS %	pairs	r	PS %	r	PS %
1 x 2	0.72	50.42	0.74	56.33	1 x 3	0.76	51.20	0.62	38.32
1 x 4	0.53	34.08	0.47	27.47	1 x 5	-0.23	-10.84	0.32	18.83
1 x 6	-0.21	-8.85	0.21	12.26	1 x 7	0.18	9.74	-0.19	-9.15
1 x 8	-0.04	9.65	-0.10	-4.56	1 x 9	0.68	48.71	0.71	54.86
1 x 10	0.62	39.73	0.28	15.34	1 x 11	0.70	45.36	0.57	37.82
1 x 12	0.47	27.51	0.30	31.58	2 x 3	0.55	36.46	0.51	34.18
2 x 4	0.58	45.87	0.72	54.03	2 x 5	0.14	9.69	0.09	5.50
2 x 6	-0.12	-5.83	-0.13	-5.21	2 x 7	0.10	9.88	-0.04	2.70
2 x 8	-0.24	-7.06	-0.36	-11.44	2 x 9	0.28	15.53	0.75	49.99
2 x 10	0.70	45.60	0.37	27.68	2 x 11	0.77	56.36	0.43	38.50
2 x 12	0.40	27.38	0.15	36.83	3 x 4	0.59	38.12	0.44	25.09
3 x 5	0.02	0.98	0.50	29.79	3 x 6	-0.34	-14.46	-0.09	-4.00
3 x 7	0.44	25.95	-0.09	-4.31	3 x 8	0.00	12.30	-0.28	-12.52
3 x 9	0.56	38.44	0.59	40.55	3 x 10	0.56	35.05	0.07	4.22
3 x 11	0.63	39.50	0.35	23.89	3 x 12	0.50	29.52	0.53	51.53
4 x 5	0.17	10.67	-0.20	-8.88	4 x 6	-0.15	-1.56	-0.46	-20.16
4 x 7	0.27	15.01	0.00	0.27	4 x 8	0.02	21.68	-0.48	-21.63
4 x 9	0.33	29.04	0.50	35.36	4 x 10	0.41	29.33	0.41	23.59
4 x 11	0.69	47.94	0.17	11.63	4 x 12	0.42	24.91	0.40	39.12
5 x 6	0.14	8.64	0.41	23.25	5 x 7	0.09	5.28	-0.01	0.77
5 x 8	-0.08	7.89	0.10	7.36	5 x 9	-0.56	-22.24	0.27	16.05
5 x 10	0.19	10.67	-0.21	-8.19	5 x 11	0.02	1.24	0.54	41.14
5 x 12	0.49	28.67	0.46	50.20	6 x 7	-0.01	2.66	-0.03	-0.47
6 x 8	0.37	27.74	0.48	30.24	6 x 9	-0.16	-7.33	-0.08	-2.21
6 x 10	0.16	8.61	-0.04	-0.51	6 x 11	-0.33	-14.41	0.07	9.28
6 x 12	0.06	5.83	-0.16	11.43	7 x 8	0.47	46.57	0.00	-0.13
7 x 9	0.29	22.64	-0.20	-4.76	7 x 10	0.31	19.61	0.24	12.67
7 x 11	0.38	21.80	-0.15	-5.41	7 x 12	0.19	10.06	-0.09	8.43
8 x 9	0.07	6.85	-0.03	5.28	8 x 10	-0.01	6.66	0.15	7.80
8 x 11	0.19	22.33	-0.06	-1.83	8 x 12	0.12	22.29	-0.13	4.33
9 x 10	0.20	11.52	0.21	18.57	9 x 11	0.44	29.12	0.49	44.08
9 x 12	0.11	10.89	0.38	52.77	10 x 11	0.50	30.16	0.35	21.04
10 x 12	0.46	28.94	0.19	22.83	11 x 12	0.41	23.89	0.39	28.78

bean trial based on the traditional method, presented a correlation of over 0.5. This fact was also verified for groups I and II in the carioca bean trial, except for the environment pairs 11 x 12, 1 x 12 and 3 x 11, which presented correlation values below 0.5. This contradiction may be due to the fact that environment 12 did not provide a significant difference between the studied lines of the carioca group (Table 1). Despite significant, the probability associated to environment 11 was 4.99%, indicating a low genotypic variability in this environment. These results indicate the importance of environment clustering methods that prioritize the correlation.

In the factor analysis proposed by Murakami and Cruz (2004) the four eigenvalues absorbed 79.75 and 76.40% of the total variation for the VCU trial of black and carioca bean, respectively (Table 6). Thus, four factors were fixed to obtain the final factor loadings after the rotations.

Different from the methods that classify the environments in only two subgroups, favorable or unfavorable (Table 1), the number of environment subgroups established by the factor analysis can be higher. The reason is that this analysis considers the similarity of the environments by the performance of the evaluated genotypes instead of the mean yield of each environment.

The communalities (sums of squares of the factor loadings of the i^{th} environment for the four considered factors) that correspond to the portion of the variance of the i^{th} explained environment by the factors presented relatively high values, indicating a good quality of factorization with a small specific variance. Only the environments Ponte Nova, in the dry crop season/2003, and Capinópolis in winter/2003, presented communalities below 0.8 in the trial of the black as well as the carioca type bean (Tables 6 and 7).

Analyzing the final factor loadings of the factors in the black common bean trial (Table 6), it was verified that factor 1 clustered nearly all locations of the winter crop seasons of 2002 as well as 2003, except for the environment Viçosa/winter/2003. In factor 3 it was possible to unite the locations Ponte Nova and Florestal, both in the dry crop season/2003 and finally, the location Coimbra in the dry crop season/2003 remained isolated in factor 4. Although factor 2 had presented two environments with factor loadings over 0.70, these were not clustered since the loadings presented opposite signals. The composition of factor 4 with only one environment had already been expected. The experiment presented incidence of white mold *(Sclerotinia sclerotiorum)*, a disease that practically decimates the entire plant and leads to a differential classification of the genotypes from those in the other environments.

Based on the final factor loadings of the factors in the trial of carioca bean (Table 7) it was verified that factor 1 grouped the locations Viçosa and Coimbra in the winter crop season/2002, and Viçosa/winter/2003. Factor 2 grouped the locations Coimbra and Florestal/dry/2003. Factor 3 clustered the location Viçosa/dry/2003 and Capinópolis/winter/2003. Factor 4 finally grouped the location Ponte Nova/dry/2003 and Coimbra/winter/2003. The location Ponte Nova (winter/2002 and 2003) and Leopoldina (winter/2002) could not be associated to any of the four factors owing to their factorial loading with a value below 0.7.

The environment clustering of the lines of the black were better than those of the carioca type group, since not all environments of the carioca bean trial were included in the four factors which explain around 80% of the total variation (Tables 6 and 7). These results ratify the stronger interaction of the carioca type lines with the environments in evaluation. We point out that, based on this method, a similarity pattern occurred between the locations within the crop season, in other words, the locations clustered within the respective crop seasons. This indicates the factor crop season as one of the principal determinants of the interaction genotypes x environments. The similarity pattern of the locations was more expressive in the VCU trial of black than of carioca bean, evidencing a stronger interaction of the black than of the carioca type group with the crop season.

In general, it was verified that the environment stratification of the black and carioca common bean trials, based on the factor analysis (Tables 6 and 7), grouped a larger number of environments than the stratification based on the principle of the non-significant G x E interaction (Tables 3 and 4) and was therefore more effective to show the similarity between the environments.

CONCLUSIONS

The component lines of the VCU trials of black and carioca common bean presented genetic variability. Furthermore, the environments used for their evaluations presented sufficient variation to discriminate the potential of the lines under study, which presented differentiated performance across the environments, in function of the occurrence of the interaction genotypes x environments.

The subgroups formed by the environmental stratification based on the algorithm of Lin (1982), presented, for the most part, environments corresponding to the winter crop season indicating, in this case, a small effect of locations on the performance of the lines in this

Table 6. Environment stratification by the factor analysis and evaluation of 20 lines of black common bean in 12 environments in the state of Minas Gerais

Eigenvalue estimates		Factor loadings after rotation					Communalities
Eigen-value	Accumulated variation (%)	Environments	Factor1	Factor2	Factor3	Factor4	
4.94	41.14	1	**0.8608**	-0.4018	-0.0124	-0.0547	0.9055
1.92	57.18	2	**0.8872**	0.0126	-0.2150	-0.0170	0.8338
1.65	70.92	3	**0.7820**	-0.1429	0.2406	-0.3056	0.7833
1.06	79.75	4	**0.7184**	0.0772	0.1760	-0.2219	0.6022
0.67	85.33	5	0.1693	**0.9451**	0.0349	0.0321	0.9241
0.64	90.67	6	-0.1000	0.1030	0.1336	**0.9420**	0.9258
0.47	94.56	7	0.2554	0.0102	**0.8205**	-0.1213	0.7533
0.27	96.82	8	-0.0904	-0.0726	**0.8466**	0.3192	0.8320
0.17	98.22	9	0.4462	**-0.7575**	0.1992	-0.1182	0.8265
0.11	99.13	10	**0.8080**	0.0656	0.0120	0.3264	0.7637
0.08	99.79	11	**0.7919**	-0.0923	0.2664	-0.2836	0.7869
0.02	100.00	12	**0.6479**	0.4091	0.1890	0.0995	0.6328

Environments: 1. Viçosa, winter/2002; 2. Coimbra, winter/2002; 3. Ponte Nova, winter/2002; 4. Leopoldina/winter/2002; 5. Viçosa/dry; 6. Coimbra/dry; 7. Ponte Nova/dry; 8. Florestal/dry; 9. Viçosa/winter 2003; 10. Coimbra/winter 2003; 11. Ponte Nova/winter 2003; 12. Capinópolis/winter 2003

Table 7. Environment stratification by the factor analysis and evaluation of 20 lines of carioca bean in 12 environments in the state of Minas Gerais

Eigenvalue estimates		Factor loadings after rotation					Communalities
Eigen-value	Accumulated variation (%)	Environments	Factor1	Factor2	Factor3	Factor4	
4.37	36.42	1	**0.8688**	0.0981	-0.2809	-0.0768	0.8492
2.22	54.89	2	**0.8811**	-0.2637	-0.0555	0.0634	0.8530
1.44	66.89	3	0.4852	-0.2549	-0.6421	-0.1107	0.7250
1.14	76.40	4	0.6286	-0.6433	-0.0157	0.2289	0.8616
0.90	83.91	5	0.0546	0.3444	**-0.8792**	-0.1533	0.9181
0.68	89.56	6	0.0360	**0.8435**	-0.1038	-0.1012	0.7338
0.50	93.74	7	-0.2767	-0.0508	-0.0742	**0.7599**	0.6621
0.32	96.36	8	-0.0810	**0.8039**	0.1141	0.1610	0.6918
0.19	97.94	9	**0.8190**	-0.0605	-0.2726	-0.0876	0.7563
0.15	99.19	10	0.4799	0.0669	0.1135	**0.7679**	0.8373
0.07	99.82	11	0.5328	0.1741	-0.5194	0.1002	0.5940
0.02	100.00	12	0.1785	-0.2533	**-0.7526**	0.1530	0.6857

Environments: 1. Viçosa, winter/2002; 2. Coimbra, winter/2002; 3. Ponte Nova, winter/2002; 4. Leopoldina/winter/2002; 5. Viçosa/dry; 6. Coimbra/dry; 7. Ponte Nova/dry; 8. Florestal/dry; 9. Viçosa/winter 2003; 10. Coimbra/winter 2003; 11. Ponte Nova/winter 2003; 12. Capinópolis/winter 2003

crop season. The splitting of the interaction in its simple and complex fractions did not improve the clustering based on the traditional method of stratification.

The methodology of environmental stratification by the factor analysis was more effective at showing the similarity between the environments than the earlier methodologies, indicating its potential for this type of study.

Análise de fator na estratificação ambiental para avaliação de cultivares de feijão

RESUMO - *Dois ensaios de valor de cultivo e uso (VCU) foram conduzidos nas três safras tradicionais, em seis municípios do estado de Minas Gerais, nos anos de 2002 e 2003. O objetivo foi investigar a eficiência de diferentes métodos de estratificação ambiental. Os subgrupos formados pela estratificação ambiental tradicional apresentaram, em sua maioria, ambientes referentes à safra de inverno, indicando, neste caso, pequeno efeito de locais sobre o comportamento das linhagens nesta safra. A decomposição da interação nas suas frações simples e complexa não contribuiu para aprimorar o agrupamento com base no método tradicional de estratificação. Já a análise de fator foi mais eficiente em apontar a similaridade entre os ambientes do que aquela baseada no princípio de interação genótipos x ambientes não significativa, indicando seu potencial para este tipo de estudo.*

Palavras-chave: *Phaseolus vulgaris*, interação genótipo por ambiente, zoneamento ecológico, análise de fatores.

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