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CROP BREEDING AND
APPLIED BIOTECHNOLOGY

Stratification of the state of Santa Catarina in macro-environments for bean cultivation

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ABSTRACT - *The purpose of this study was to suggest a division of the State of Santa Catarina in macro-environments for experimentation and bean production. Data of the traits grain yield and plant cycle were evaluated in 10 common bean genotypes grown in nine environments. The data were submitted to the Student-Newman Keuls test, to detect differences between environments, and the Best Linear Unbiased Prediction, to predict the environmental values. The results showed: (a) differences between the regions of Santa Catarina for the traits grain yield and plant cycle, which had a significant positive correlation of 0.26 (b) Based on the genotypes and environments studied the state can be divided in two macro-environments (MA1 and MA2) and four micro-environments (MI1, MI2, MI3 and MI4). The state of Santa Catarina may be roughly divided in at least two macro-environments for the recommendation of new cultivars.*

Key words: *Phaseolus vulgaris* L., subdivision, environmental effect.

INTRODUCTION

Common bean is a widely cultivated species in Brazil and is grown in all seasons and regions of the country. Despite its role in the Brazilian economy and culture, the productivity of common bean in São Paulo is still low, regardless of the breeding techniques used for the crop. On the other hand, over the years there has been a nation-wide, gradual decline in common bean consumption and production (Berthold et al. 2008). A yield of 3696 tons of beans in Brazil was predicted for the harvest 2008/09, representing a small increase compared to the previous harvest (CONAB 2008).

Common bean is a crop grown by different categories of farmers - on family farms, where little or no technology is applied, to large industrial farms, with the most modern production technology (Melo et al. 2007) - and in different climate regions of the country, so the availability of specific varieties for each of the categories is crucial, particularly for small farmers, to obtain higher productivity at lower costs. For Backes et al. (2005), one way to minimize the influence of the genotype x environment (GE) interaction would be the development of specific regional cultivars. Still, the influence of the interaction between a given genotype and environment on some traits, such as yield, can make the recommendation of a cultivar for large geographic areas difficult (Araújo et al. 2003). In this situation, the use of landraces, apart from the use of commercial varieties with stable and wide adaptability, would be an alternative.

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The state of Santa Catarina is divided into eight regions: i) West ii) Midwest iii) the Northern Plateau iv) Mountain Plains v) Itajai valley vi) Northeast vii) Coastline and viii) South (Government of Santa Catarina 2008). Common bean is grown in a variety of environments under rather heterogeneous conditions. These differences influence the harvest, and differences in grain yield are observed between the regions where common bean is grown. For example, the air temperature affects bean yields, despite the wide geographic distribution (Silva et al. 2007). Some varieties may therefore be better adapted to certain temperatures and a given region, producing more in one than in another region. In the state of Paraná, in the specific case of maize, seed companies divided the state into two macro-environments (Andrade et al. 1996), demonstrating that this practice can be used in other states and for other crops. This possibility may allow breeders to use the information of GE interaction in the bean breeding programs in Santa Catarina state in favor of common bean production. In the Plains, for example, cultivation in the second growing season is not recommended because of the possibility of low temperatures at the end of the crop cycle, which may limit the yield (Bisognin et al. 1997), so late-maturity varieties could be chosen, specific to environmental conditions of the Mountain Plains, if planted in the appropriate growing season.

This study proposes a division of the State of Santa Catarina in macro-environments, using 10 genotypes grown at nine sites in the growing seasons from 2004/05 to 2006/07.

MATERIAL AND METHODS

Data of the harvest of common bean, Carioca commercial, in the 2004/05, 2005/06 and 2006/07 growing seasons, in tests of Value for Cultivation and Use (VCU), performed and coordinated in network by the Agricultural Research and Rural Extension Corporation of the State of Santa Catarina of Santa Catarina (EPAGRI) - Research Center for Family Farming of Chapecó, conducted at nine locations in Santa Catarina (Table 1). A randomized block design with four replications was used in all VCU tests; rows were spaced 0.50 m apart 15 seeds were planted per meter (250,000 plants per hectare). To avoid competition, pests and weeds were controlled chemically and by hand-weeding, as needed. Base fertilization and side-dressing was applied according to soil analysis and recommendations for common bean.

Five common bean lines were used: EPAGRI - CHC 9715, CHC 9729, CHC 9851, CHC 9861, LP 9979 - and five commercial varieties recommended for Santa Catarina - Carioca, FT Bonito, FT Magnífico, SC 202 Guará and Pérola.

The statistical model used in the experiment was the random model, as proposed by Littell et al. (2006) $Y_{ijk} = \mu + g_i + a_j + ga_{ij} + b_k + e_{ijk}$
where μ: mean; g_i: random genotype effect; a_j: random environmental effect; ga_{aij}: random effect of GE interaction; b_k: block effect; e_{ijk}: error;

The data were first subjected to preliminary analysis of variance (F test) and the means analyzed by the SNK test, to verify the difference between environments for the traits grain yield and plant cycle, for the genotypes used. The correlation between the traits grain yield and plant cycle was also analyzed by Pearson's correlation. By the PROC MIXED (Littell et al. 2006) the contribution of each environment to the 10 genotypes was estimated, as well as the magnitude and significance of the interaction of each genotype with

Table 1. Characteristics of nine environments of common bean cultivation in the state of Santa Catarina[*]

Location	Region	Mean annual temp. (ºC)	Altitude (m asl)	Growing season
Águas de Chapecó	West	20	291	Second
Campos Novos	Mid West	20	946	Main
Canoinhas	Northern Plateau	20	839	Main
Chapecó	West	20	670	Main
Ituporanga	Itajaí valley	17	370	Second
Lages	Mountain plains	16	904	Main
Ponte Serrada	West	16	1.067	Main
Urussanga	South	20	49	Second
Xanxerê	West	20	800	Main

[*]Source: Government of Santa Catarina, 2009

each environment (sensitivity). Moreover, the yield and plant cycle data, as well as estimates of the environmental contribution were analyzed by the procedure PROC CANDISC (Khattree and Naik 1999) for the establishment and verification of the significance of the matrix of Mahalanobis´ distance and also by PROC CLUSTER (Statistical Analysis System 2002) for the construction of an environment clustering dendrogram, based on the similarity degree from the cited distance matrix.

RESULTS AND DISCUSSION

The significant differences by the SNK test at 5% error probability between the mean values for the traits grain yield and plant cycle of the nine locations evaluated corroborated the hypothesis of heterogeneous environments in Santa Catarina (Table 2). The environments with highest and lowest mean grain yield were Ponte Serrada (4,500 kg ha^{-1}) and Ituporanga (1,890 kg ha^{-1}), respectively. The significant difference between the means showed the wide diversity between the environments in this study for common bean cultivation, which can be verified, for example, in the contrasting environments Ponte Serrada and Ituporanga, where the difference between the mean grain yield was 2,610 kg ha^{-1}. The contrasting differences between the

environments can be verified based on individual scores, estimated as the differences between the means of each individual environment compared to the overall mean (Table 2). Based on the scores of each environment, both for the trait grain yield and plant cycle, the difference between the nine locations was evident. For example, the highest score for the trait grain yield was of the environment of Ponte Serrada (1,607), estimated by the difference between the environment mean and the general mean of environments (4,500 to 2,893 = 1,607 kg ha^{-1}).

For the trait plant cycle, the highest mean was found in the environment Ponte Serrada (98.56 days) and the lowest in Chapecó (81.45), a difference of 17 days in the cycle. It is noteworthy that some genotypes differ in the plant cycle; they are early in some regions and late in others, such as in the environments of Ponte Serrada and Chapecó, a fact that further intensifies the difference between the regions of the state Santa Catarina. Similarly, the score of the nine environments, based on the differences between the means for the traits under study indicated a significant contrast between the environments.

The coefficients of variation (14.31% and 2.04%) and determination (0.89 and 0.96), for the traits grain yield and plant cycle, respectively, indicated good experimental accuracy. The data analysis showed that

Table 2. Means of the nine environments and Pearson correlation for the traits grain yield and plant cycle using 10 common bean genotypes of the group carioca in the growing season 2006/07

Location	Yield (kg ha^{-1})				Cycle (days)			
	^1X_m [*]	$^2X_{ma}$	$^3X_{mi}$	^4Sc	^1X_m [*]	$^2X_{ma}$	$^3X_{mi}$	^4Sc
Águas de Chapecó	2.035f	2.320	1.789	-858	89.18e	92	69	-2.04
Campos Novos	2.553d	3.151	2.281	-340	93.50c	93	92	2.27
Canoinhas	3.961b	4.141	3.752	1.068	90.79d	91	89	-0.45
Chapecó	2.538d	2.924	2.168	-355	81.45g	82	80	-9.80
Ituporanga	1.890f	2.120	1.304	-1.003	93.50c	96	89	2.24
Lages	2.383e	2.688	2.147	-510	98.50a	99	97	7.23
Ponte Serrada	4.500a	4.707	4.269	1.607	98.56a	99	97	7.28
Urussanga	2.299e	2.539	2.139	-594	82.36f	96	89	-8.93
Xanxerê	3.757c	3.911	3.512	864	95.85b	98	92	4.55
Mean Geral	2.893				91.22			
CV (%)		14.31				2.04		
R^2		0.89				0.96		
Correlation				0.26[**]				

^1X_m general mean; $^2X_{ma}$ maximum value; $^3X_{mi}$ minimum value; ^4Sc score based on the differences between the individual means of the environments and the general mean
[*] Equal letters did not differ by the SNK test at 5% error probability
[**] significant by the F test at 5% error probability

Ponte Serrada was the most productive environment, with an intermediate-late cycle (98 days). On the other hand, the environments of Águas de Chapecó and Ituporanga, with a cycle considered intermediate-early (89 and 93 days) produced the lowest grain yield. Therefore, the analysis of correlation between the two variables under study (0.26) showed a positive correlation, i.e., part of the variation is common to the two variables. Despite the low correlation value found, this may indicate that environments where the varieties have a longer plant cycle can produce more.

Since there is a wide divergence between the regions of Santa Catarina, it is essential that the recommendation of new varieties should take these differences into account and that these varieties are adapted to the specific environmental conditions, aiming to increase the grain yield and productivity. Plant breeders usually develop varieties with wide adaptability for a region, however, if the region is agroecologically diverse, it may be necessary to stratify the region into more homogeneous sub-regions (Piepho and Mohring 2006). According to Atlin et al. (2000), the division can be performed either in small areas, exploring the local adaptation, or in large regions, although these would result in loss of accuracy when estimating the mean number of genotypes due to environmental heterogeneity. In other words, breeding could be carried out in specific regions, e.g., in breeding programs to improve common bean specifically for the Mountain Plains, because this region has typical characteristics.

To assess the contribution of the nine environments to the traits grain yield and plant cycle, the environmental values were predicted by Best Linear Unbiased Predictor (BLUP) (Figure 1) as a basis for environment clustering.

The environments contributed differently to the 10 genotypes, because some genotypes were more sensitive and responsive in a particular environment than in another. Therefore, a disagreement between the sites can be observed for both grain yield (Figure 1) and for plant cycle (Figure 2). Since the presence of environmental effects and of GE interaction is inevitable, the ideal genotype, to be widely grown, could be the most insensitive to the environment, in other words, the most stable in different environments, with above-mean yields. On the other hand, when the effect of environment and GE interaction is very strong, the ideal would be an environment that induces an intensified response of the genotype in the traits of interest, e.g., increased productivity. In this way, specific varieties could be recommended for each macro-environment.

The results showed that the grain yield values of all genotypes exceeded the mean in the environments of Ponte Serrada, Canoinhas and Xanxerê. On the other hand, the grain yield was below the mean for all genotypes in the other environments, with the exception of CHC 9729 and CHC 9861 in Campos Novos (Figure 1c and 1e, respectively) and LP 9979 in Chapecó (Figure 1i). This result may indicate a possible formation of groups of different environments, that is, of environments where the genotypes have higher and lower yields. Furthermore, the genotypes CHC 9729 and CHC 9861 may have been significantly influenced by interaction in the environment Campos Novos and genotype LP 9979 in Chapecó, since all other genotypes had lower grain yield values than the mean of these environments.

As demonstrated in numerous studies, the environment influences grain yields strongly (Ramalho et al. 1993, Falconer and Mackay 1996, Allard 1999), which was also demonstrated in this study. The yield oscillated mainly due to the environment; in the environments with positive contribution, the grain yield of the genotypes exceeded the mean (Figure 1). This, once again, reinforces the importance of establishing and recommending specific genotypes for each region. The primary concern when starting a breeding program should therefore be to determine whether the goal is the development of productive varieties in a wide range of environments or of a variety highly adapted to specific environments. In the first case, situations of low GE interaction should be preferred and in the second, a high GE interaction (Borém and Miranda 2009).

For the trait plant cycle, results were similar to those for the trait grain yield, since the strong environmental influence induced the genotypes to be early in some regions and have an intermediate cycle in others (Figure 2). Thus, for genotype Carioca in the most contrasting environments, which were Lages (cycle close to 98 days) and Águas de Chapecó (cycle close to 80 days), the difference in the cycle was 18 days (Figure 2a). This difference may be related mainly to the environment, and the contribution of the environment of Lages was 3.777, and in the environment of Águas de Chapecó -5.636 (Figure 2a). A genotype

classified as early in one environment may therefore not have the same performance in another. In addition, the plant cycle of all genotypes exceeded the mean in the environments of Ponte Serrada, Lages, Joinville, Ituporanga and Campos Novos (Figure 2). However, some genotypes were more sensitive to other environments, besides the above-cited, e.g., genotype FT Bonito (Figure 2f), since the value of plant cycle exceeded the mean in Canoinhas and Águas de Chapecó. Chapecó and Urussanga were the only environments where the plant cycle was below the mean and the predictions negative for all genotypes.
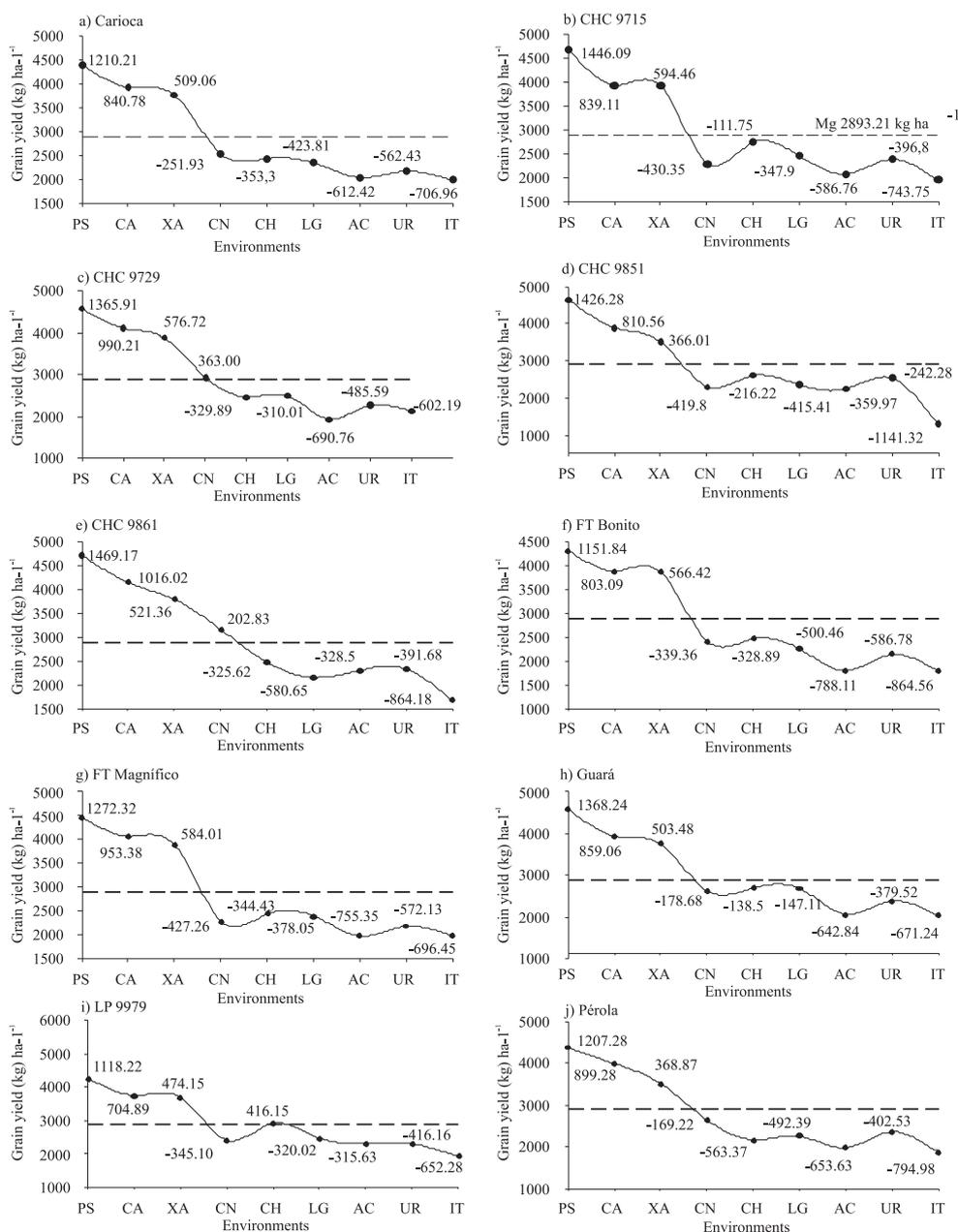
Figure 1. Values of the trait grain yield and prediction of the environmental values by the BLUP method for 10 genotypes grown in nine environments ((Águas de Chapecó (AC), Campos Novos (CN), Canoinhas (CA), Chapecó (CH), Ituporanga (IT), Lages (LG), Ponte Serrada (PS), Urussanga (UR) and Xanxerê (XA)) in the state of Santa Catarina in the growing season of 2004/05, 2005/06 and 2006/07
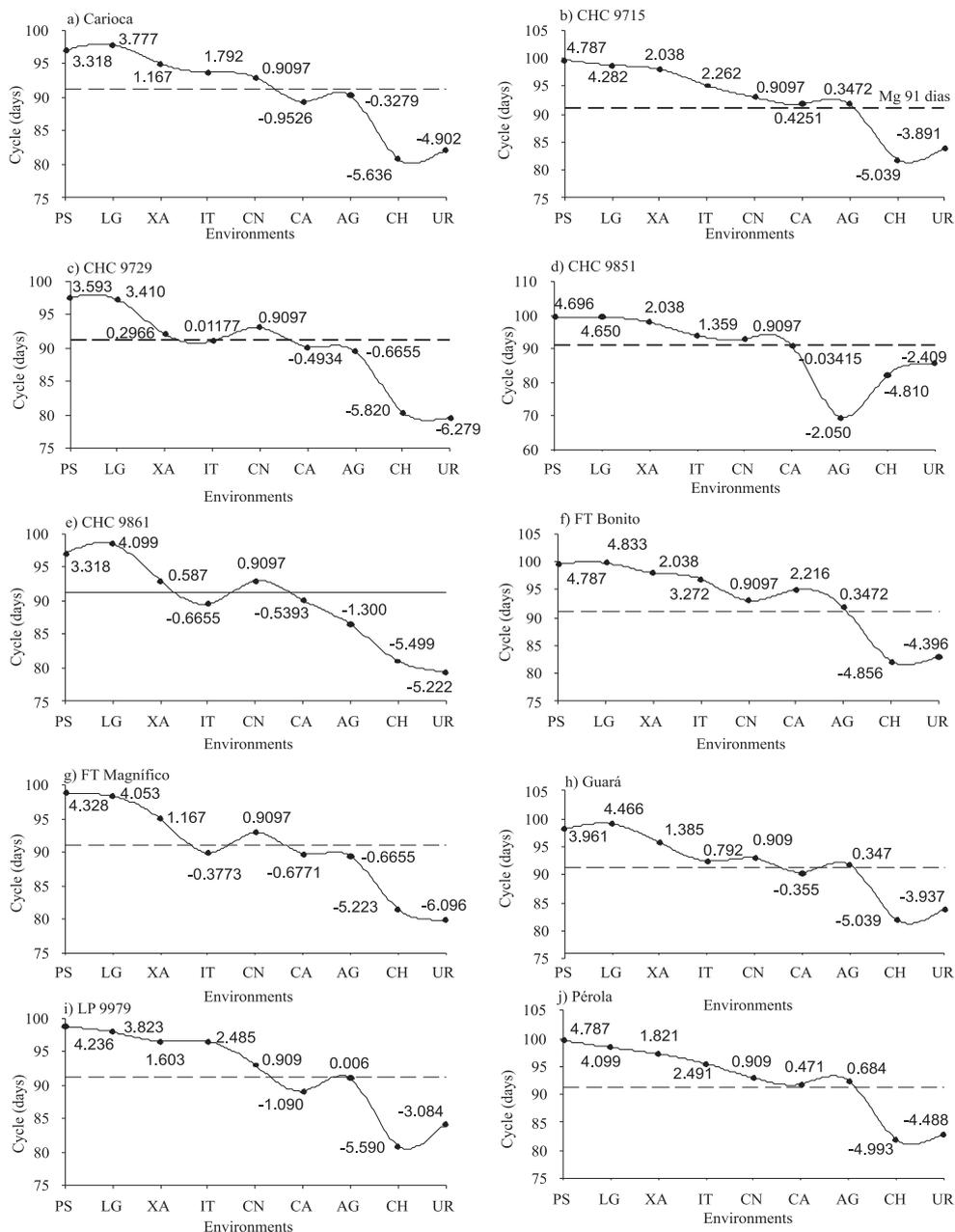
Figure 2. Values of the trait plant cycle and prediction of the environmental values by the BLUP method for 10 genotypes grown in nine environments ((Águas de Chapecó (AC), Campos Novos (CN), Canoinhas (CA), Chapecó (CH), Ituporanga (IT), Lages (LG), Ponte Serrada (PS), Urussanga (UR) and Xanxerê (XA)) of the state of Santa Catarina in the growing seasons of 2004/05, 2005/06 and 2006/07

Based on these results, the nine environments were grouped into 2 macro-environments (MA1 and MA2) and four micro-environments (Figure 3). Therefore the environments Águas de Chapecó (AC), Ituporanga (IT), Campos Novos (CN), Lages (LG), Chapecó (CH) and Urussanga (UR) represent MA1, and the environments of Ponte Serrada (PS), Xanxerê (XA) and Canoinhas (CA) MA2. Moreover, the environments Águas de Chapecó (AC) and Ituporanga were grouped in the first micro-environment (MI1); micro-environment (MI2) comprised the environments Campos Novos (CN) and Lages (LG); Chapecó (CH) and Urussanga (UR)

represent the third micro-environment (MI3) and; the environments Canoinhas (CA), Ponte Serrada (PS) and Xanxerê (XA) constitute the fourth micro-environment (MI4) (Figure 4).

In addition to the results of the mean test and of BLUP, the results generated by the environment clustering, based on the variables grain yield and plant cycle, also reinforced the possibility of dividing the state
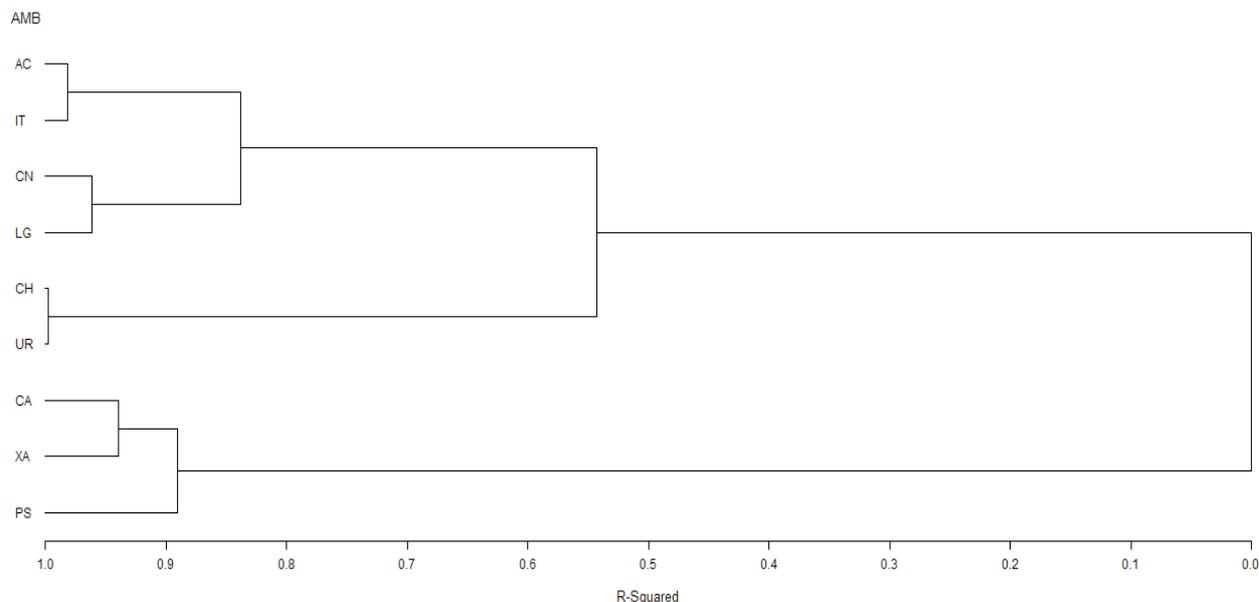
Figure 3. Dendogram based on nine environments of the state of Santa Catarina ((Águas de Chapecó (AC), Campos Novos (CN), Canoinhas (CA), Chapecó (CH), Ituporanga (IT), Lages (LG), Ponte Serrada (PS), Urussanga (UR) and Xanxerê (XA)) for the traits grain yield and plant cycle in Carioca common bean genotypes
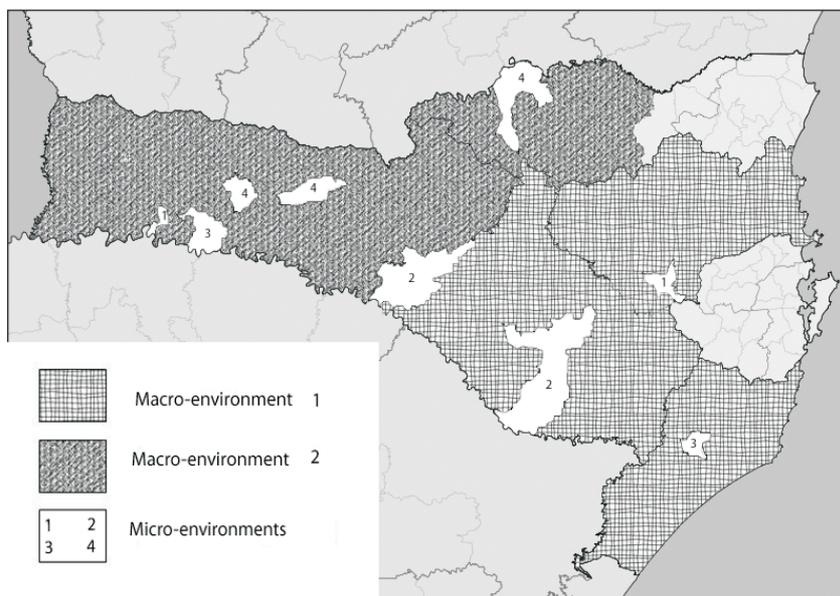
Figure 4. Division of the state of Santa Catarina in two macro-environments (MA1, comprising the municipalities in the regions Mid West, Mountain Plains, Itajaí valley and South and MA2 comprising the municipalities in the regions West and Northern Plateau) and four micro-environments (MI1: Águas de Chapecó and Ituporanga; MI2: Campos Novos and Lages; MI3: Chapecó and Urussanga and; MI4 Canoinhas, Ponte Serrada and Xanxerê) for recommendations of research and/or seed production of Carioca common bean, based on the traits grain yield and plant cycle

into regions for experimentation and bean cultivation, since they corroborated the other analyses of this study.

The state of Santa Catarina can therefore be divided into two macro-environment for common bean cultivation: i) MA1, comprising two municipalities in the West (Águas de Chapecó and Chapecó) and the municipalities of the Mountain Plains, Midwest, Itajaí Valley and South and ii) MA2, consisting of two municipalities in the West (Ponte Serrada and Xanxerê) and Northern Plateau. Similarly, the results allow the subdivision of the macro into four micro-environments.

In this respect, the recommendations of research and seed production, in view of the need to attend all regions in a specific way and consider the peculiarities of each municipality could be better adapted if the State of SC was divided into at least two macro-environments (MA1 and MA2). Subsequently, the new cultivars could be recommended for the municipalities in regions Midwest, Mountain Plains, Itajaí Valley and South (MA1) or for the municipalities of the regions West and Northern Plateau (MA2). It is also noteworthy that further studies are needed in future to validate these findings. However, this is the first step towards a better exploitation of the environmental conditions of the State of Santa Catarina and of the availability of genotypes adapted to these conditions, always with a view to higher yields increase yields.

From the foregoing, it can be concluded that: i) the traits grain yield and plant cycle had a significant positive correlation of 26%, ii) it is possible to divide the State of Santa Catarina, on the basis of genotypes and environments, in two macro-environments (MA1 and MA2) and four micro-environments (MI1, MI2, MI3 and MI4) and iii) the state of Santa Catarina can be generalized in at least two macro-environments (MAG1 and MAG2) for the recommendation of new cultivars.

ACKNOWLEDGEMENTS

Estratificação do estado de Santa Catarina em macro-ambientes para o cultivo do feijão

RESUMO - *Este trabalho teve como objetivo sugerir uma divisão do Estado de Santa Catarina em macro-ambientes para experimentação e produção de feijão. Foram avaliados dados dos caracteres rendimento de grãos e ciclo de planta de dez genótipos de feijão carioca cultivados em nove ambientes. Os dados foram submetidos ao Teste SNK, no intuito de verificar a existência de diferenças entre os ambientes, e ao método do Blup, para a predição dos valores de ambiente. Os resultados evidenciaram: (a) divergências entre as regiões de Santa Catarina para os caracteres rendimento de grãos e ciclo de planta, que apresentaram uma correlação positiva e significativa de 0,26; (b) Que é possível dividir o Estado, a partir dos genótipos e ambientes estudados, em dois macro-ambientes (MA1 e MA2) e quatro micro-ambientes (MI1, MI2, MI3 e MI4). O Estado de Santa Catarina pode ser generalizado em no mínimo dois macro-ambientes para a recomendação de novos cultivares.*

Palavras-chave: *Phaseolus vulgaris* L., subdivisão, efeito de ambiente.

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