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Agronomic performance and stability of andean common bean lines with white grains in Brazil

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Abstract

This work evaluated the effect of genotype by environment interaction in Andean common bean lines with white grains, in Central Southern Brazil, to identify lines with high agronomic performance, stability and adaptability, aiming to meet domestic demand and to increase the Brazilian participation in the foreign market of common bean. Nineteen trials with twelve Andean lines were conducted in 2007, 2008 and 2009, in Central Southern Brazil. Grain yield and other agronomic traits were evaluated. Data were subjected to analysis of variance and of adaptability/stability using Annicchiarico and modified AMMI methods. Significant differences were found between lines for all traits evaluated. Genotype by environment interaction was important for lines with Andean origin and white seed. The utilization of weighted mean of absolute scores and yield with the AMMI results enabled the identification of the most stable and adapted lines. Lines Poroto Alubia, CNFB 16211, Ouro Branco and WAF 160 were stable and adapted, using both methods. CNFB 16211 line presented high agronomic performance, stability and adaptability and therefore this line may be a new cultivar. USWA 70 and WAF 75 lines presented grain size similar to that required by the foreign market and superior to the Brazilian cultivars, besides favorable agronomic traits, and thus these lines may be indicated as new cultivars.

Key words: *Phaseolus vulgaris*, special grains, adaptability, genotype by environment interaction, AMMI.

Potencial agronômico e estabilidade de linhagens de feijoeiro-comum de origem andina com grãos brancos no Brasil

Resumo

Os objetivos deste trabalho foram avaliar o efeito da interação genótipos x ambientes em linhagens de feijoeiro-comum de origem andina com grãos brancos na Região Centro-Sul do Brasil e identificar linhagens com alto potencial agronômico, estabilidade e adaptabilidade, visando atender a demanda interna e possibilitar a participação brasileira no mercado externo. Dezenove ensaios constituídos por 12 linhagens foram conduzidos em campo na Região Centro-Sul do Brasil nos anos 2007, 2008 e 2009. Avaliaram-se a produtividade de grãos e outros caracteres de importância agronômica. Os dados foram submetidos a análises de variância e de adaptabilidade/estabilidade pelos métodos de Annicchiarico e AMMI com modificações. Houve diferenças entre as linhagens para todos os caracteres avaliados. A interação genótipos x ambientes foi importante na avaliação de linhagens de origem andina com grãos brancos. A utilização da média ponderada pelos escores absolutos e da produtividade com os resultados da análise AMMI facilitou a identificação de linhagens mais estáveis e adaptadas. As linhagens Poroto Alubia, CNFB 16211, Ouro Branco e WAF 160 são estáveis e adaptadas utilizando-se as duas metodologias. A linhagem CNFB 16211 apresenta alto potencial agronômico, alta estabilidade e adaptabilidade sendo, portanto, possível a sua indicação como nova cultivar. As linhagens USWA 70 e WAF 75 apresentam tamanho de grão semelhante ao exigido pelo mercado externo e superior ao das cultivares brasileiras, além de apresentarem caracteres agronômicos favoráveis, sendo portanto possível a sua indicação como novas cultivares.

Palavras-chave: *Phaseolus vulgaris*, grãos especiais, adaptabilidade, interação genótipos x ambientes, AMMI.

1. INTRODUCTION

Common bean was domesticated independently in two centers of diversity, giving rise to two gene groups: Mesoamerican and Andean (Beebe et al., 2000). Differences between these groups can be checked in the morphology of the plant, seed size and type of phaseolin (reserve protein), among others. Andean lines have larger seed (100 seed weight above 30 grams) while Mesoamerican lines have smaller seed size (100 seed weight under 30 grams) (Gonzales et al., 2009).

Brazil is one of the largest producers and consumers of beans, which is the main source of vegetable protein for direct consumption of Brazilians. Carioca and black beans have Mesoamerican origin and represent 85% of Brazilian production. However there is increasing demand for production of other types of grains with higher added value and export possibilities (Del Peloso and Melo 2005). Among the commercial groups with higher international interest is the white group of Andean origin, with 55 to 59 grams per 100 seeds, consumed and marketed in Europe, Asia and the United States (Gonzales et al., 2009). Historically, breeding programs in Brazil have given low priority to Andean beans, including the white type, and as a result, few cultivars are available, which leads to low production and high import of this type of grain in Brazil. Currently, some breeding programs have focused on this type of grain, seeking to obtain and identify lines showing better adaptation to the soil and climatic conditions of the country (Gonçalves et al., 2010).

When breeding new cultivars, one of the main obstacles is the presence of the genotype by environment interaction (G x E). For the cultivation of common bean, numerous studies have shown the presence of such interaction, mainly for grain yield and with Mesoamerican lines (Melo et al., 2007; Pereira et al., 2011; 2012; Oliveira et al., 2006). Thus, one should seek alternatives to mitigate and/or take advantage from the interaction effects, including the use of methods for analysis of stability and adaptability, which provide detailed information about the behavior of cultivars, such as predictability and responsiveness to environmental variation (Cruz et al., 2004). Among the methods for studying stability, stands out the genotype recommendation index (Annicchiarico, 1992), for combining concepts of adaptability and stability into a single parameter (Pereira et al., 2009). Another methodology used in stability studies is the AMMI method (Additive Main Effects and Multiplicative Interactions) (Zobel et al., 1988), which allows a more detailed analysis of the G x E interaction.

These two methods are poorly correlated with each other and therefore can be used simultaneously (Melo et al., 2007; Pereira et al., 2009; Silva and Duarte, 2006). Among the few studies of this nature with Andean common bean (Gonçalves et al., 2010), none was performed with white grains. In this context and considering the above, the present study aimed to evaluate the importance of the genotype by environment interaction for Andean common bean lines with white grains in Brazil, identifying lines with high adaptability, stability and agronomic performance, aiming to meet domestic demand and to expand the Brazilian participation in the foreign market of this grain.

2. MATERIAL AND METHODS

Trials were performed in 2007, 2008 and 2009, in 19 environments, conducted in the winter sowing season in the states of Goiás and Minas Gerais (ten trials) and in the rainy and dry sowing season in the Paraná State (nine trials) (Table 1). Trials were installed according to procedures proposed by Melo (2009). The design was completely randomized blocks with three replications and plots consisted of four rows of four meters long. Each trial was formed by 12 common bean lines, 10 promising lines with white grains and two controls: Ouro Branco, a cultivar registered in Brazil with white grains and BRS Radiante, a cultivar of 'rajado' grains (cream with red stripes) , of Andean origin, with excellent agronomic performance.

To assess agronomic performance, field evaluations were conducted in 19 trials for grain yield. For the other traits, the trials were evaluated whenever possible: lodging resistance (nine trials); plant architecture (eight trials); resistance to common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*) (eight trials); reaction to angular leaf spot (*Pseudocercospora griseola*) (three trials); reaction to powdery mildew (*Erysiphe polygoni*) (seven trials); reaction to anthracnose (*Colletotrichum lindemutianum*) (three trials); and reaction to rust (*Uromyces appendiculatus*) (seven trials). These assessments were performed by means of rating scales described by Melo (2009), ranging from 1 (totally favorable phenotype) to 9 (totally unfavorable phenotype). It was also evaluated the weight of 100 seeds in three trials.

Data were subjected to analyses of variance considering the effect of mean and lines as fixed factors, and the others as random. In the combined analysis, the maximum F test was run to check for homoscedasticity, given by the ratio between the highest and the lowest mean square residual (Pimentel-Gomes, 1990). Once detected heteroscedasticity, it was adjusted the degrees of freedom of the GxE interaction and of average error according to Cochran (1954). For evaluation of experimental precision, selective accuracy (SA) was estimated (Resende and Duarte, 2007), using the equation $SA = (1 - (1/Fc))^{0.5}$, wherein: Fc = F-test value for the genotype, in which to $Fc<1$, SA = 0. To compare means, the Scott-knot Test at 10% was used.

Adaptability and stability analysis were performed by the methods of Annicchiarico (1992) and AMMI (Zobel et al., 1988). The first considers the genotype recommendation index that estimates the risk of adopting a particular line.

Table 1. Geographical information of sites and summary of individual analysis of variance for grain yield of 19 trials of common beans conducted in the states of Minas Gerais (MG), Goiás (GO) and Paraná (PR) in different sowing times

Site/State [1]	Alt [2]	Lat. [3]	Long. [4]	QM_L [5]	QM_E [6]	P [7]	Média [8]	CV [9]	F (Genot)	SA
Winter/2007										
Senador Canedo-GO	801	16° 42’	49° 06’	189804	27915	0.0001	1708	9.8	6.80	0.92
Santo Antônio de Goiás-GO	823	16° 29’	49° 17’	144063	129802	0.3989	1997	18.0	1.11	0.31
Urutaí-GO	900	17° 27’	48° 12’	337886	156392	0.0598	3107	12.7	2.16	0.73
Rainy/2007										
Ponta Grossa-PR	969	25° 05’	50° 09’	833343	56018	0.0000	2132	11.1	14.88	0.97
Guarapuava-PR	1098	25° 23’	51° 27’	98188	19393	0.0006	757	18.4	5.06	0.90
Araucária-PR	897	25° 35’	49° 24’	590592	85477	0.0001	2045	14.3	6.91	0.92
Dry/2008										
Araucária-PR	897	25° 35’	49° 24’	446497	61124	0.0000	1915	12.9	7.30	0.93
Ponta Grossa-PR	969	25° 05’	50° 09’	343795	111905	0.0120	2592	12.9	3.07	0.82
Winter /2008										
Senador Canedo-GO	801	16° 42’	49° 06’	216163	99949	0.0595	1698	18.6	2.16	0.73
Itumbiara-GO	448	18° 25’	49° 12’	191586	100162	0.0941	1578	20.1	1.91	0.69
Anápolis-GO	1018	16° 19’	48° 57’	681207	287748	0.0411	3034	17.7	2.37	0.76
Uberlândia-MG	863	18° 55’	48° 16’	464628	137826	0.0074	1667	22.3	3.37	0.84
Patos de Minas-MG	832	18° 34’	46° 31’	49079	64600	1.0000	989	25.7	0.76	0.00
Lavras-MG	919	21° 14’	44° 59’	696778	136305	0.0006	1866	19.8	5.11	0.90
Sete Lagoas-MG	761	19° 27’	44° 14’	76776	24174	0.0101	1023	15.2	3.18	0.83
Rainy /2008										
Ponta Grossa-PR	969	25° 05’	50° 09’	154229	20448	0.0000	1120	12.8	7.54	0.93
Araucária-PR	897	25° 35’	49° 24’	199925	26089	0.0000	1250	12.9	7.66	0.93
Dry /2009										
Ponta Grossa-PR	969	25° 05’	50° 09’	270703	96079	0.0186	1818	17.1	2.82	0.80
Araucária-PR	897	25° 35’	49° 24’	121396	10740	0.0000	725	14.3	11.30	0.95

(1)Municipality; (2)Altitude (meters); (3)South Latitude; (4)West Longitude; (5)Mean squared linhagens; (6) Mean squared error; (7) Probability associated with the source of variation lines; (8)Overall mean of the trial (kg ha^{-1}); (9)Coefficient of variation (%); F(Genot) –F-test for the effect of lines; SA – Selective Accuracy

The stability is measured by the superiority of the lines in relation to the average of environments, associated with a given probability (Cruz et al., 2004). For AMMI (*Additive Main Effects and Multiplicative Interactions*), significance level was set at 5% according to the F_r test criterion of Cornelius et al. (1992). Some studies have suggested adjustments to the AMMI method like the inclusion of additional genotype (AG), to increase the precision of identifying superior lines (Pacheco et al., 2005). Pereira et al. (2009) suggested obtaining an index that considers the average of the absolute scores of each line in each significant component, weighted by the percentage of explanation of each significant component (AWAS), to facilitate the interpretation of results and identification of lines with high stability. Based on the AWAS index, the AWASY index wasproposed, which uses the weighted average of the absolute scores associated with the weighting of average yield of lines. This index allows the simultaneous evaluation of adaptability and stability associated with grain yield.

The identification of the most stable lines was based on the AWAS index of each line. Thus, the line with lower AWAS values is the most stable. The stability interpretation was also carried out through the graphical analysis, with the average of genotypes and AWAS. Lines closer to zero on the ordinate lines are the most stable, while those further away are those that contribute most to the interaction.

To combine stability with adaptability, we estimated the weighted average of the absolute scores associated with the weighting of average yield (AWASY) of lines, with weights equal to two and three, respectively. To obtain the AWASY, data of yield and AWAS were transformed to the same scale. The highest yield was considered 100% and the other values were obtained in relation to this. In the case of AWAS, all values were subtracted from 100 to reverse the rating scale, and then obtained the percentage relative to the highest value, for each line.

Analysis of variance and Annicchiarico were run in the application Genes (Cruz, 2001), and AMMI was performed in the SAS.

3. RESULTS AND DISCUSSION

There was a wide variation between mean values and between precision measurements for grain yield, evidencing the different conditions of the trials (Table 1). Average yields ranged from 725 kg ha^{-1} to 3107 kg ha^{-1}, with coefficients of variation (CV) equal to or lower than 26%, and SA (selective accuracy) indicated high or very high accuracy in 85% of cases (Cargnelutti Filho and Storck, 2009).

The joint analysis detected significant differences (p<0.01) for environments and lines, which confirm the variation between the studied environments and genetic variability between lines (Table 2), as also reported by Gonçalves et al. (2010). For the other traits, significant differences were also verified between lines. There was great geographic variation between environments, once the altitude of the sites varied from 448 m to 1098 m, besides differences of more than 9 degrees of latitude and more than 7 degrees of longitude (Table 1). Moreover, it was examined different years (2007, 2008 and 2009) and sowing times (rainy, dry and winter). The lines x environments interaction was significant and points out that, as usually found for Mesoamerican lines (Melo et al., 2007; Oliveira et al., 2006; Pereira et al., 2011; 2012), the performance of Andean lines in Central Southern Brazil is also influenced by the different response of lines to these environments, and therefore it is necessary to evaluate lines in several environments.

Average yields were lower (Table 3) than registered with Mesoamerican lines, in studies developed in the same regions (Melo et al., 2007; Oliveira et al., 2006; Pereira et al., 2011; 2012), validating the observation that Andean lines are less productive than Mesoamerican ones (Gonzales et al., 2009). The BRS Radiante control, which has 'rajado' grains, was the most productive line (2082 kg ha^{-1}), statistically different from other genotypes (Table 3). This was expected, since the breeding of 'rajado' beans in Brazil has already been done for a long time, and therefore there are available lines with good adaptation and higher performance than for white beans. The second group was formed by Poroto Alúbia and CNFB 16211, which surpassed the control Ouro Branco, being promising for grain yield. Between these two lines, the CNFB 16211 is among the most resistant to angular leaf spot, anthracnose and rust. Besides that, this line has erect plant architecture and good resistance to lodging, which results in lower grain loss at harvest and better quality grains. In relation to grain size, CNFB 16211 had size similar to that of Ouro Branco, thus being commercially acceptable.

The other lines were not different in grain yield from the control Ouro Branco, indicating that these lines have other favorable agronomic traits to justify their indication as new cultivars (Table 3). Regarding the resistance to diseases, most lines were resistant to anthracnose, angular leaf spot and rust, as well as Ouro Branco. However, few lines presented resistance to powdery mildew and common bacterial blight, highlighting the control BRS Radiante. In general, the lines WAF 170 and WAF 141 showed greater resistance to the diseases evaluated, but both had smaller grain size than the control Ouro Branco.

As for grain size, an essential trait for acceptance of cultivars of this grain (Gonzales et al., 2009), the line USWA 70 stood out for presenting the highest 100 seed weight among the lines evaluated and above that of the Ouro Branco. Additionally, this line has erect architecture and good resistance to lodging, angular leaf spot, anthracnose and rust. Another promising line in relation to grain size is the WAF 75 (57.7g/100 seeds), which also has agronomic traits similar to that of USWA 70. It is noteworthy that the international market prefers grains slightly larger than that of Ouro Branco, and then lines USWA70 and WAF 75 have potential to meet this requirement. Recently, a new cultivar of white beans, named IPR Garça, was released, though it also has grain size similar to that of Ouro Branco.

The different responses of lines to environmental variation (Table 2) justify the need for stability and adaptability analysis. Using the method of Annicchiarico (1992) were identified the lines BRS Radiante, Poroto Alúbia and CNFB 16211 with recommendation index values (Wi) above 100%,

Table 2. Combined analysis for grain yield (kg ha^{-1}) of 19 VCU trials of common beans, in 2007, 2008 and 2009, with breakdown of the interaction genotypes x environments into three axes of the interaction principal component analysis (IPCA), according to AMMI method

SV	DF	SQ	MS	F	Pr>F
BLOCKS/ENV	38	12526135	329635	-	0.000
Lines (L)	11	13128287	1193481	8.77	0.001
Environments (E)	18	301437716	16746540	123.02	0.000
L X A	129 (1)	49471397	383499	2.82	0.000
IPCA 1	28	16113236	575473	4.23	0.000
Residual 1	101	33358761	330285	2.43	0.000
IPCA 2	26	11381332	437744	3.22	0.000
Residual 2	75	21977429	293032	2.15	0.000
IPCA 3	24	5739341	239139	1.76	0.018
Residual 3	51	16238087	318394	2.34	0.000
Error	267 (1)	36347252	136132	-	-
TOTAL	683	412934229	-	-	-
Mean: 1742 kg ha^{-1} CV: 21.2 %					

SV: Source of variation; DF: Degrees of freedom; SQ: Sum of Squares; MS: Mean Square; F: F-test of Cornelius et al. (1992); Pr: P-value; (1)The degrees of freedom of the error and of the interaction genotype x environment, including its breakdown, were adjusted by the method of Cochran (1954).

Table 3. Average yield (AY) (kg ha^{-1}), mean and maximum scores for resistance to lodging (RL), plant architecture (PA), reaction to common bacterial blight (CBC), angular leaf spot (ALS), powdery mildew (PM), anthracnose (AN), rust (RU) and 100 seed weight (100W) of 12 lines of common beans evaluated in 19 sites in the states of Goiás, Minas Gerais and Paraná (Brazil), in 2007, 2008 and 2009

Genotype	AY		PA		RL		CBC		ALS		PM		AN		RU		100W
			M	Max	M	Max	M	Max	M	Max	M	Max	M	Max	M	Max	
BRS RADIANTE	2083	a	3.8 b	5	3.7 b	5	3.4 a	6	3.7 b	6	1.5 a	3	1.0 a	1	1.2 a	2	39.7 f
POROTO ALUBIA	1912	b	4.4 b	7	4.6 c	8	5.0 b	9	4.0 b	7	5.3 c	9	1.7 a	3	2.6 b	5	51.8 c
CNFB 16211	1872	b	3.4 a	5	3.2 b	5	3.9 b	7	2.4 a	5	5.4 c	8	1.0 a	1	2.2 b	8	49.0 d
OURO BRANCO	1789	c	3.0 a	4	3.3 b	6	4.1 b	7	2.4 a	3	5.5 c	8	2.0 a	4	1.2 a	3	49.3 d
ALUBIA ARGENTINA	1717	c	6.5 c	7	6.1 d	9	6.0 b	9	6.3 c	9	6.0 d	9	9.0 b	9	6.2 c	9	43.2 e
WAF 160	1693	c	4.1 b	5	3.5 b	8	4.9 b	8	2.7 a	4	7.0 d	9	1.0 a	1	1.2 a	3	47.8 d
WAF 170	1666	c	4.5 b	6	3.8 b	5	2.6 a	4	2.7 a	6	2.7 b	5	1.0 a	1	1.4 a	3	45.9 e
WAF 130	1654	c	3.8 b	5	3.5 b	6	5.0 b	9	2.7 a	4	5.9 d	9	1.0 a	1	1.0 a	1	46.8 d
USWA 70	1648	c	3.2 a	5	2.8 a	4	4.3 b	8	1.0 a	1	6.3 d	9	1.0 a	1	1.0 a	1	64.5 a
WAF 75	1627	c	3.3 a	6	2.3 a	4	4.1 b	9	2.7 a	6	4.5 c	8	2.3 a	5	1.2 a	3	57.7 b
WAF 157	1624	c	4.3 b	7	3.2 b	6	4.1 b	7	2.0 a	3	4.7 c	7	1.0 a	1	1.0 a	1	43.7 e
WAF 141	1623	c	3.6 a	5	2.9 a	5	2.6 a	4	1.4 a	2	3.7 b	7	1.0 a	1	1.0 a	1	45.0 e

indicating that these lines exceed the mean of environments in at least 15.6%, 7.2% and 1.8%, respectively (Table 4). In favorable environments, lines BRS Radiante and CNFB 16211 continue to stand out, with 18.6% and 11.6% superiority, respectively.

In unfavorable environments, lines BRS Radiante, Poroto Alúbia and Alúbia Argentina exhibited the highest indices of stability/adaptability (112.8%, 111.2% and 107.2%, respectively) (Table 4). The classification of environment into favorable and unfavorable is based on the environments and generally, the reduction in grain yield reflects the sensitivity of lines to the effects of biotic (pests and diseases) and abiotic factors (water deficit, temperature stress, low soil fertility). Meanwhile, the line Alubia Argentina in spite of having good adaptability/stability to unfavorable environments, also showed the highest indices of susceptibility to diseases (Table 3). Importantly, the lines WAF 75 and WAF 170 also presented higher stability/adaptability in unfavorable environments compared to the control Ouro Branco. In general, lines Poroto Alubia and CNFB 16211 were also superior to the control Ouro Branco (Table 4).

Considering the AMMI analysis, the first three components were significant ($p<0.05$). According to Chaves (2001) the appropriate model is the one that associates significance to the axes and non-significance to the residuals, but it was found in this work the continued significance to the residuals, even after axes are no longer significant. In this way, as a model selection criterion, it was used the last axis with significance for the main component. In agreement with Arias et al. (1996) the use of models with more than three components, from the biological point of view, is unsatisfactory, besides being difficult to handle, in relation to the possible benefits. The first three axes together explained 67.2% of the variation (PC1 = 32.6%; PC2 = 23.0% and PC3 = 11.6%), similarly to values found by Carbonell et al. (2004), Melo et al. (2007) and Pereira et al. (2009), in common beans.

Furthermore, with the significance level of 5%, we selected the AMMI3 model (Table 2). Besides the possibility to reduce the occurrence of type II error (accepting a AMMI model with fewer axes when this is more parameterized), the adoption of this level resulted in higher approximation of the satisfactory percentage to the explanation of the variation of the interaction in the first axes. Thus the identification of the most stable axes was achieved with information of the first three components, using the weighted average of the absolute scores of each line (AWAS) (Table 4). The use of this parameter as stability measurement allows to present the mean stability and yield of the lines in a single graph, facilitating the combined analysis of the two parameters. By applying this parameter, the most stable lines were those with lower AWAS values. The most stable lines were WAF 160, WAF 170 and USWA 70, WAF 130, WAF 141 and WAF 75, (Table 4 and Figure 1). However, none of these are among the most productive, but all were more stable than the control Ouro Branco. The line of lowest stability was the BRS Radiante, which showed a higher average yield.

The AWASY index was used with the purpose to associate stability and average yield. With this, it was identified the control BRS Radiante as the one with higher stability and adaptability. Among the white grain lines, CNFB 16211, Poroto Alubia, WAF 160 and Ouro Branco were slightly superior to the others (Table 4). The line with the worst performance was the Alubia Argentina, a cultivar used in Argentina, which was very susceptible to diseases occurring in Brazil. This indicates the potential of these lines to be indicated as new and more adapted cultivars.

The application of the AWASY index enables aggregate methodological advantages of the AMMI analysis with information about average grain yield. Thus, it was possible

Table 4. Estimates of parameters of adaptability and phenotypic stability by the Annicchiarico method (1992) (W_i- recommendation index), breakdown into favorable (W_{if}) and unfavorable (W_{id}) environments, and by the AMMI method, with values of the significant principal components (IPCA), indices AWAS (average weighted by the absolute scores) and AWASY (average weighted by the absolute scores and yield) and ratings of 12 lines of common beans evaluated in Central Southern Brazil, from 2007 to 2009

Genotype			Annicchiarico (1992)						AMMI					
	Y(1)		W_i	C(2)	W_{if}	C	W_{id}	C	IPCA1	IPCA2	IPCA3	AWAS	AWASY	C
BRS RADIANTE	2083	a	115.6	1	118.5	1	112.8	1	23.10	6.92	−2.15	13.94	95.92	1
POROTO ALUBIA	1912	b	107.2	2	102.8	4	111.2	2	−15.33	−9.07	22.37	14.40	90.81	3
CNFB 16211	1872	b	101.7	3	111.5	2	94.2	6	13.62	3.79	12.40	10.04	91.49	2
OURO BRANCO	1789	c	96.0	4	103.2	3	90.2	8	16.15	8.90	3.61	11.50	88.49	5
WAF 160	1717	c	94.9	5	96.2	5	93.7	7	−0.97	−7.75	6.07	4.17	89.48	4
ALUBIA ARGENTINA	1693	c	94.0	6	80.8	12	107.6	3	−25.90	24.67	−10.32	22.79	81.01	12
WAF 170	1666	c	91.8	7	87.4	10	95.9	5	−5.27	−10.15	−10.53	7.85	86.45	6
WAF 130	1654	c	89.8	9	94.5	6	85.8	11	5.40	14.33	6.06	8.57	85.80	7
WAF 157	1648	c	89.7	10	90.0	8	89.3	9	2.98	−23.96	−7.52	10.95	84.64	11
USWA 70	1627	c	87.5	12	94.3	7	81.9	12	8.39	3.34	−16.13	7.97	85.30	8
WAF 75	1624	c	91.3	8	85.9	11	96.7	4	−16.12	1.60	5.00	9.22	84.69	10
WAF 141	1623	c	88.9	11	88.6	9	89.1	10	−6.00	−12.61	−8.87	8.76	84.89	9

(1)Means followed by the same letter are not significantly different by Scott-Knott test at 10% probability. (2) Rating of genotypes as for stability, by the method of Annicchiarico (1992).

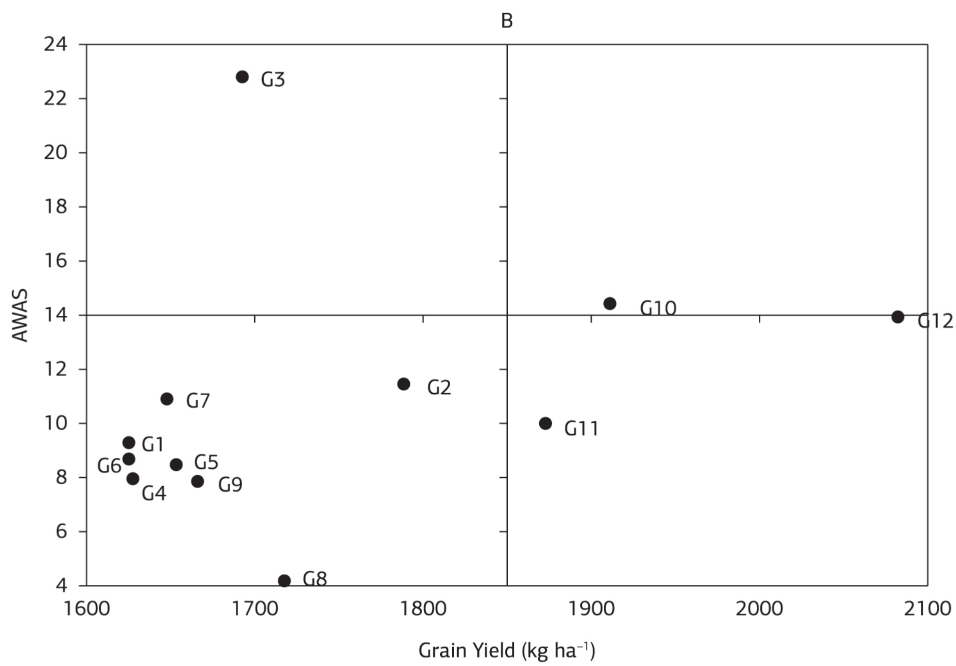

Figure 1. Graphical analysis of the AMMI of common bean lines (G1: WAF 75, G2: Ouro Branco, G3: Alubia Argentina, G4: USWA 70, G5: WAF 130, G6: WAF 141, G7: WAF 157, G8: WAF 160, G9: WAF 170, G10: Poroto Alubia, G11: CNFB 16211, G12: BRS Radiante) evaluated in 19 environments in Central Southern Brazil. Average yield (kg ha−1) x average weighted by the absolute scores (AWAS).

to identify lines with improved performance, considering the stability and adaptability together. Greater similarity was also found between results of the Annicchiarico method and AWASY index, which strongly considers the average yield to obtain estimates of the stability/adaptability parameter.

Taking into account the stability analysis by the two methods, the lines Poroto Alubia, CNFB 16211, Ouro Branco and WAF 160 stand out (Table 4). When considering agronomic traits, the lines CNFB 16211, USWA 70, WAF 75 and WAF 141 stand out, since they show similar or better performance than the control Ouro Branco for eight out of nine traits evaluated (Table 3). Among them, it is worth highlighting USWA 70 and WAF 75, because they have grain size greater than that of Ouro Branco, which represents a great advantage for this commercial grain. The line CNFB 16211 is also noteworthy, since it shows grains and agronomic traits similar to those of Ouro Branco, and is among the most stable and adapted, and is more productive than the Ouro Branco.

4. CONCLUSION

The genotypes by environments interaction is important in assessing lines of Andean common beans with white grains in Central Southern Brazil.

The use of AWASY combined with AMMI analysis facilitates the identification of more stable and adapted lines of common beans.

Lines Poroto Alubia, CNFB 16211, Ouro Branco and WAF 160 are the most stable and adapted, using the methods of Annichiaricco and AMMI.

The line CNFB 16211 has high stability and adaptability, grain and agronomic traits similar to those of Ouro Branco, and higher yield. Thus, it may be used as a new cultivar in the domestic market. The lines USWA 70 and WAF 75 have favorable agronomic traits and grain size similar to that required by the foreign market, superior to that of Ouro Branco, and may be indicated as new cultivars for export.

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