Euphytica (2018) 214:12
https://doi.org/10.1007/s10681-017-2093-z

Genotype by environment interaction for disease resistance and other important agronomic traits supporting the indication of common bean cultivars

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Received: 8 July 2016 / Accepted: 12 December 2017 / Published online: 16 December 2017

Abstract The present work aimed to study the genotype by environment interaction for nine important agronomic traits as a support for the indication of common bean cultivars for the Southern region of Brazil, identifying cultivars that possess high adaptability/stability. We carried out 25 field trials, in the rainy and dry sowing seasons, at different locals in the states of Paraná and Santa Catarina, from 2008 to 2010. The trials included 17 cultivars. Data were obtained for agronomic traits and subjected to variance analyses, and to adaptability and stability analyses according to the Nunes method. The genotype by environment interaction is important for different agronomic traits. There is genetic variation among cultivars and it was identified a different number of superior cultivars for each trait. Considering the means and adaptability and stability scores, 88% of the cultivars were superior for rust, 53% for anthracnose, 41% for grain yield, plant architecture and cycle, 30% for fusarium wilt and lodging, and 18% for angular leaf spot and common bacterial blight. For some of these traits, like angular leaf spot, common bacterial blight, fusarium wilt and lodging, it is necessary to intensify the efforts to provide more cultivars with high resistance or tolerance level, adaptability and stability. BRS Esplendor, a black-seeded cultivar, CNFC 10431 and BRS Sublime, both carioca-seeded cultivars, presented superiority for six of nine traits, being indicated to be used in the Southern region of Brazil. Other cultivars presented advantages for fewer traits and must be used in environments which these traits present greater importance.

Keywords *Phaseolus vulgaris* L. · Grain yield · Stability · Plant architecture

Abbreviations

G × E	Genotype by environment interaction
Z_i	Adaptability parameter for each cultivar
CV_i	Stability parameter for each cultivar
SA	Selective accuracy

Introduction

Brazil is one of the largest producers and consumers of common bean (*Phaseolus vulgaris* L.) in the world, producing about 2.6 million tons of grain in 2013 (Feijão 2014). Common bean is part of the staple diet of the Brazilian population, especially of the lower income populations. The Southern region of the country was responsible for the production 921,085 tons in 2013, in 637,992 ha, with average grain yield

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of 1444 kg ha^{-1}. In this region, the states of Paraná and Santa Catarina are the largest producers of grains and the production is concentrated during the rainy season (sowing between August and November) and the dry season (sowing between January and February), both in small and large production areas with great variation of technology inputs. These two states together represent 32.2% of the Brazilian production of common bean grains.

Common bean in the Southern region of Brazil is grown in different cropping systems and, consequently, the genotype by environment interaction (G × E) is relevant, as reported in various studies, especially concerning grain yield (Pereira et al. 2009a; Gonçalves et al. 2009; Torga et al. 2013). Thus, the search for alternatives must be done to mitigate the effect of the G × E interaction. The identification of adapted/stable lines using adaptability/stability methods of analyses can be highlighted as an efficient strategy. Adaptability/stability studies, especially for grain yield, have been helping the indication of common bean cultivars for different Brazilian regions (Gonçalves et al. 2009; Pereira et al. 2009b, 2012, 2013). However, only few studies have been conducted for other agronomic important traits in addition to grain yield, such as plant architecture, lodging tolerance, and reaction to diseases.

In the Southern Brazil, the occurrence of diseases is especially important due to temperature and humidity favorable conditions to the development of many pathogens that attack this crop, such as anthracnose (*Coletotrichum lindemuthianum*), angular leaf spot (*Pseudocercospora griseola*), common bacterial blight (*Xantomonas axonoposis* pv. *phaseoli* and *Xanthomonas fuscans* subsp. *fuscans*), rust (*Uromyces appendiculatus*), and fusarium wilt (*Fusarium oxysporum* fsp. *phaseoli*).

In the case of disease resistance, the genotype by environment interaction has also great importance, because in addition to the different environmental conditions that occur in each environment (temperature, humidity, type of soil, etc.), which may be more or less favorable to the development of a particular disease, there is still another factor that is the pathogenic variability of causal agents. In the case of pathogens with high variability, such as the *C. lindemuthianum* and *P. griseola*, the identification of cultivars with high stability in the field may mean that these cultivars are resistant to the most common physiological races of a particular region and/or resistant to a greater number of races of the pathogens. Only for anthracnose, 71 different races of *C. lindemuthianum* were already described in the country (Damasceno e Silva et al. 2007; Ribeiro et al. 2016). Considering only Paraná and Santa Catarina, these states present a great number of different races (29 and 16, respectively) (Alzate-Marin and Sartorato 2004).

Among the adaptability and stability methodologies of analysis, the method developed by Nunes et al. (2005) assess adaptability and stability with the standardization of different genotype averages, using adaptability parameter (Z_i) for each cultivar and stability by the variation coefficient for each cultivar, based on the values of z_{ij} (CV_{ij}). This method still allows graphical representation, using the values of z_{ij} for each cultivar in each environment, which facilitates the interpretation of the results. This method has been used recently in the common bean crop.

Based on the exposed information, the objectives of this work were to study the G × E interaction for several important agronomic traits as a support for the indication of new cultivars in Southern Brazil and to identify common bean cultivars with high adaptability/stability for grain yield, plant architecture, lodging tolerance, cycle, reaction to anthracnose, angular leaf spot, common bacterial blight, rust, and fusarium wilt.

Materials and methods

Each field trial included four pre-commercial common bean lines with carioca grains type (CNFC 10431, CNFC 10432, CNFC 10467 and VC6), 10 carioca seeded cultivars (BRS Horizonte, BRS Cometa, Pérola, BRS Ametista, BRSMG Madrepérola, BRS Pontal, BRS Sublime, BRSMG Majestoso and BRS Notável) and three black seeded cultivars (BRS Esplendor, BRS Valente and BRS Supremo). The trials were conducted in the years of 2008, 2009 and 2010, at 22 environments in the States of Santa Catarina and Paraná, during the rainy (sowing between September and November) and dry (sowing between January and February) sowing seasons, in addition to three specific environments to evaluate the genotypes for fusarium wilt reaction (Santo Antônio de Goiás/winter of 2009, 2010 and 2011) in a naturally infested area. All experiments were installed in random blocks, with three repetitions and plots with four lines 4.0 m long, spacing by 0.5 m.

Evaluations were performed in all experiments for grain yield (kg ha^{-1}), and for agronomic traits, such as plant architecture, lodging tolerance, reaction to anthracnose, angular leaf spot, common bacterial blight, rust, and fusarium wilt, and cycle, evaluations were performed whenever possible. Except for grain yield, evaluations for other traits were carried out in only one repetition by each environment.

For the evaluations of plant architecture, lodging tolerance and disease reaction, a scale with grades ranging from 1 to 9 was used. Architecture evaluation takes into consideration three traits: length of plant guides, height of the end of pods in relation to the ground, and the angle of insertion of primary branches. Grade 1 refers to the ideal genotype for mechanical harvesting, showing short guides (smaller than 20 cm), pods (end of the pod of more than 15 cm in relation to the ground), very closed branches (angle of insertion of primary branches smaller than 10°), while grade 9 was attributed to genotypes unable to be mechanically harvested (climber) (Melo 2009). The scale used to evaluate lodging tolerance considers the percentage of lodged plants in the plot. Grade 1 referred to the percentage of 0% of lodged plants and so on until the note 9, which the plot presented 91–100% of lodged plants.

For the assessment of disease reaction, a scale of 1–9 grades was used, based on the disease severity in each plot. Grade 1 refers to the absence of disease; grade 2–1% of leaf infection or infected plants; grade 3–5%; grade 4–10%; grade 5–20%; grade 6–40%; grade 7–60%; grade 8–80%; and grade 9–100% of plants with symptoms (Melo 2009). While for the evaluation of cycle, the scale used ranged from 1 to 5 grades: 1-super early (< 65 days); 2-early (65 ≥ cycle ≥ 74); 3-semi-early (75 ≥ cycle ≥ 84); 4-normal (85 ≥ cycle ≥ 94); and 5-late (≥ 95 days) (Del Peloso et al. 2009).

Data from each trial were submitted to the analysis of variance, considering the effect of treatments as fix. For agronomic traits, data from each environment have been considered as a repetition and variance analyses were performed considering the complete design of random blocks. The means of traits from the evaluated cultivars were grouped by the Scott-Knott method at a probability of 10%. This level of significance was used to decrease the probability of absence of discrimination between genotypes because of the type II error. According to Zimmerman (2004), this procedure is recommended when small differences are expected between treatments, as in the case of tests with elite cultivars. In addition, to evaluate the experimental precision, selective accuracy was estimated by the expression (Resende and Duarte 2007):

$$SA = \left(1 - \frac{1}{F_c}\right)^{0,5},$$

for $F_c < 1$, in which F_c is the value of the F tests for cultivars.

The joint analysis of the trials was performed for grain yield considering the environments effect as randon. As the ratio between the biggest and the smallest mean square of the residue was superior to seven, indicating that the residue variances were not homogeneous (Pimentel-Gimes 2000), the degrees of freedom of the average error and of the interaction were adjusted according to the method by Cochran (1954). Statistical analyses were carried out using the Programs Genes and SAS (Cruz 2013).

Stability and adaptability parameters of the cultivars were estimated for traits evaluated in at least six environments, using the method proposed by Nunes et al. (2005). Initially, the averages of the cultivars in diverse environments were standardized for each environment (experiment), using the expression: $z_{ij} = \frac{(\bar{y}_{ij} - \bar{y}_{\cdot j})}{s_{\cdot j}}$, in which z_{ij} is the value of the standardized variable corresponding to the genotype i in the environment j; $\bar{y}_{ij}$ is the average of the genotype i in the environment j; $\bar{y}_{\cdot j}$ is the average j of the environment; $s_{\cdot j}$ is the phenotypic standard deviation between the averages of genotypes in the environment j, given by:

$$s_{\cdot j} = \sqrt{\sum_{i-1}^{t} \frac{(\bar{y}_{ij} - \bar{y}_{\cdot j})^2}{t - 1}}$$

The method proposed by Nunes et al. (2005) provides information on the adaptability to a line by the statistics z_{ij}, and stability is measured by the coefficient of variation of z_{ij} (CVZ_i). The z_{ij} values were used for the construction of graphics for each cultivar, for each trait, being the dimensions of the axes (environments) equivalent to the values of each cultivar i in the environment j. As the variable z_{ij} can take negative values, the constant 4 was added to always turn values into positive values, facilitating the graphical view.

To carry out stability analyses, it was performed the inversion of the treatment means for the traits evaluated by a scale of grade, since, in these scales, the smallest value is desired.

Results and discussion

Values of the coefficient of variation for grain yield ranged from 7.9 to 25.5%, showing good experimental accuracy (Table 1), which was confirmed by selective accuracy estimates, considered high or very high (above 0.7) (Cargnelutti Filho et al. 2009) for 13 of the 22 trials. The mean of grain yield in the trials ranged from 965 to 3247 kg ha^{-1}, indicating great environmental variation. This result can be confirmed by observing the geographic data of the evaluation sites that show altitude ranging from 509 to 969 m, latitude ranging from 23°18′S to 27°24′S, and longitude from 49°24′W to 53°03′W.

The joint analysis for grain yield showed differences between cultivars, between environments and also the presence of the G × E interaction, which means that there are differential responses of genotypes to environments (Table 2). Two groups of means were formed, with eight cultivars among the most productive, being seven from the carioca group and only one with black grains (Table 3).

As found that the G × E interaction is important (Table 2) and, therefore, that cultivars do not have the same responses in different environments, it is important to identify cultivars that besides presenting high grain yield, are also stable and adapted. The method of Nunes et al. (2005) provides information on adaptability by statistics z_i and stability using CV_i. Observing the values of z_i for grain yield, highly adapted cultivars were the same eight of highest means, showing that the relationship between means and z_i is high. Estimates of CV_i varied a lot (18.0–45.8%), showing great difference in the stability of cultivars (Table 4). BRSMG Majestoso, BRS Notável, BRS Esplendor, BRS Estilo, VC6, CNFC 10431 and BRS Sublime were the most stable,

Table 1 Geographical information of locations (altitude, latitude and west longitude), sowing seasons (dry and rainy), years, and summary of individual analysis of variance for grain yield of 22 common bean field trials conducted in the states of Santa Catarina and Paraná, from 2008 to 2010

Location	Altitude	Latitude	Longitude	Season	Year	P[1]	Mean[2]	CV[3]	AS[4]
Ponta Grossa-PR	969	25°05′	50°09′	D	08	0.016	1926	16.4	0.77
Araucária-PR	897	25°35′	49°24′	D	08	0.000	1822	13.8	0.88
Prudentópolis-PR	840	25°12′	50°58′	D	08	0.000	1518	14.6	0.89
Ponta Grossa-PR	969	25°05′	50°09′	R	08	0.003	1874	8.6	0.82
Araucária-PR	897	25°35′	49°24′	R	08	0.002	1386	24.9	0.84
Prudentópolis-PR	840	25°12′	50°58′	R	08	0.065	2163	19.4	0.68
Canoinhas-SC	839	26°10′	50°23′	R	08	1.000	1796	19.1	0.00
Dois vizinhos-PR	509	25°44′	53°03′	R	08	0.000	1408	12.5	0.89
Color. Vivida-PR	700	25°58′	52°34′	R	08	0.209	1069	19.5	0.53
Ouro Verde-SC	758	26°41′	52°18′	R	08	0.041	1078	20.6	0.72
Ponta Grossa-PR	969	25°05′	50°09′	D	09	1.000	1853	20.1	0.00
Araucária-PR	897	25°35′	49°24′	D	09	0.004	965	21.1	0.82
Prudentópolis-PR	840	25°12′	50°58′	D	09	0.042	2351	12.9	0.72
Ponta Grossa-PR	969	25°05′	50°09′	R	09	0.000	2311	10.9	0.88
Ponta Grossa-PR	969	25°05′	50°09′	R	09	0.263	3135	19.2	0.47
Araucária-PR	897	25°35′	49°24′	R	09	0.002	2736	7.9	0.84
Prudentópolis-PR	840	25°12′	50°58′	R	09	0.000	1310	13.5	0.98
Canoinhas-SC	839	26°10′	50°23′	R	09	0.337	3247	15.4	0.39
Londrina-PR	585	23°18′	51°09′	R	09	1.000	1145	24.1	0.00
Xanxerê-SC	800	26°52′	52°24′	R	09	0.057	1582	25.5	0.69
Camp. Novos-SC	939	27°24′	51°13′	R	09	1.000	2773	20.7	0.00
Ponta Grossa-PR	969	25°05′	50°09′	D	10	0.000	2286	9.7	0.93

[1] p value for lines

[2] General mean of the trial (kg ha^{-1})

[3] Coefficient of variation (%)

[4] Selective accuracy

Table 2 Summary of the joint analysis of variance for grain yield of 17 common bean cultivars evaluated in 22 environments of Paraná and Santa Catarina, from 2008 to 2010

Source of variation	DF	MS	p value
Blocks/environments	44	243,551	–
Cultivars (C)	16	823,275	0.0041
Environments (E)	21	22,640,721	0.0000
C × E	200[a]	357,995	0.0000
Residue	412[a]	187,728	–
Average	1897		
CV (%)	22.8		

DF degrees of freedom, *MS* mean square

[a]Degrees of freedom set according to Cochran (1954)

showing CV_i below 25% (Fig. 1). Among these, it is worth highlighting the BRS Notável, which presented the smallest CV_i (18.0%), and, therefore, the cultivar with greater stability, as well as high adaptability and high grain yield. Some of these cultivars were already identified with high stability for grain yield in other common bean growth regions, such as: BRS Esplendor in Mato Grosso and Pernambuco (Pereira et al. 2012, 2013); BRS Estilo in Mato Grosso, Paraná/Santa Catarina and Goiás/Federal District/Mato Grosso/Mato Grosso do Sul/Tocantins (Pereira et al. 2009a, b, 2012); and BRS Sublime, CNFC 10431 and BRS Notável in Goiás/Distrito Federal (Pontes Junior et al. 2012).

In addition to the grain yield, other traits are important in the acceptance of a cultivar in a region. The upright plant architecture and lodging tolerance have great importance because they reduce losses during the mechanical harvest and prevent pods to be in touch with the ground, which causes the deterioration of the commercial quality of the grains. The cycle of cultures is also important, since early cultivars allow the obtaining of the product before the peak marketing, which directly affects the price of the product, besides increasing planning flexibility of the crop rotation system, and ensuring water and electricity saving in irrigated crops. The resistance to the major crop diseases, such as anthracnose, angular leaf spot, common bacterial blight, fusarium wilt, and rust,

Table 3 Means (M), adaptability (Z_i) and stability (CV_i) parameters for grain yield, plant architecture, lodging tolerance, and earliness, evaluated in 17 common bean cultivars in 22 environments of Paraná and Santa Catarina, from 2008 to 2010, according to the method of Nunes et al. (2005)

Cultivars	Grain yield			Architecture			Lodging			Earliness		
	M	Z_i	CV_i	M	Z_i	CV_i	M	Z_i	CV_i	M	Z_i	CV_i
BRSMG Majestoso	2077a	4.7	21.4	5.0c	3.6	17.8	5.2c	3.4	20.1	3.9b	4.1	22.0
BRS Notável	2032a	4.6	18.0	5.0c	3.6	27.6	3.7b	4.2	28.7	3.1a	5.6	29.9
BRS Esplendor	2029a	4.5	24.7	3.0a	5.0	10.6	2.7a	4.7	17.1	4.0b	3.8	10.6
BRS Estilo	2002a	4.4	23.8	4.2b	4.1	11.8	4.5b	3.8	25.7	4.0b	3.8	10.6
VC6	1984a	4.3	23.1	4.2b	4.1	11.9	4.3b	3.9	17.2	4.0b	3.8	10.6
CNFC 10431	1961a	4.2	23.8	3.5a	4.7	14.2	2.8a	4.7	9.3	4.1b	3.3	38.1
BRS Sublime	1952a	4.1	20.9	3.3a	4.7	11.1	3.0a	4.6	10.3	4.1b	3.5	33.8
BRS Pontal	1928a	4.1	33.5	6.5d	2.4	17.3	6.3d	2.8	75.3	4.1b	3.5	26.8
CNFC 10467	1886b	4.0	31.2	4.5b	3.8	23.5	4.3b	3.8	22.8	3.7b	4.2	35.1
BRS Valente	1882b	3.9	29.8	3.7a	4.6	12.9	2.5a	4.9	4.6	4.0b	3.8	10.6
BRSMG Madrepérola	1855b	3.8	27.0	5.7d	3.1	47.9	7.0d	2.5	27.6	3.4a	4.8	33.0
BRS Ametista	1834b	3.8	43.3	5.8d	2.9	60.6	5.2c	3.4	49.7	4.0b	3.8	10.6
Pérola	1828b	3.8	34.7	6.0d	2.7	21.3	6.3d	2.9	26.4	4.0b	3.8	10.6
BRS Supremo	1789b	3.6	35.4	3.0a	5.1	6.3	2.8a	4.8	22.2	4.0b	3.8	10.6
CNFC 10432	1779b	3.5	44.8	3.3a	4.8	13.9	2.8a	4.7	11.9	4.1b	3.3	38.1
BRS Cometa	1756b	3.4	40.6	3.7a	4.6	12.9	3.3a	4.4	21.3	3.4a	5.2	35.1
BRS Horizonte	1677b	3.3	45.8	3.8b	4.4	8.7	3.2a	4.5	13.5	3.9b	4.1	22.0

Means followed the same letter, in the columns, not differer among them (Scott-Knott-10%)

Table 4 Summary of the analysis of variance for agronomic important traits in 17 common bean cultivars evaluated in 22 environments in Paraná and Santa Catarina, from 2008 to 2010

FV	Architecture			Lodging			Cycle			Anthracnose		
	DF	MS	P	DF	MS	P	DF	MS	P	DF	MS	P
Blocks	5	1.3		5	6.7		6	0.31		7	8.18	
Cutlivars	16	7.4	0.000	16	12.4	0.000	16	0.59	0.000	16	15.85	0.000
Res	80	0.7		80	2.1		96	0.16		112	2.42	
Mean		4.4			4.1			3.9			2.2	
CV (%)		18.9			34.8			10.2			70.0	
SA		0.95			0.91			0.86			0.92	
FV	ALS			CBB			Fusarium wilt			Rust		
	DF	MS	P	DF	MS	P	DF	MS	P	DF	MS	P
Blocks	9	15.5		6	12.1		2	2.4		3	3.2	
Cultivars	16	29.8	0.000	16	3.8	0.002	16	12.1	0.000	16	3.0	0.020
Res.	144	1.5		96	1.5		32	1.8		48	1.4	
Mean		3.9			3.2			6.0			1.9	
CV (%)		30.9			37.7			18.0			61.0	
SA		0.98			0.79			0.95			0.73	

ALS angular leaf spot, *CBB* common bacterial blight

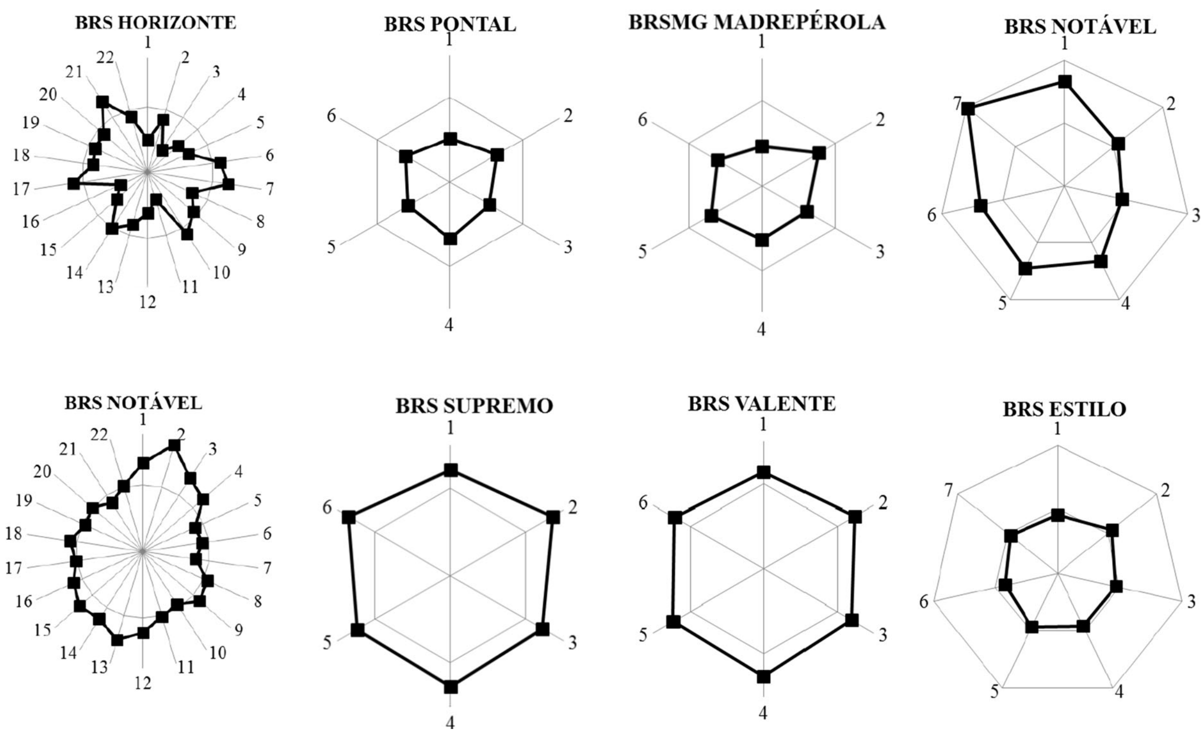

Fig. 1 Graphical representation of the performance of inferior and superior genotypes for grain yield, plant architecture, lodging tolerance and cycle, in columns 1, 2, 3 and 4, respectively, according to the methodology of Nunes et al. (2005). The circle represents the average environment (constant value associated with the variable Z), and the axes represent each of the evaluated environments

is also of great importance, since the common bean crop is attacked by many diseases that cause heavy losses.

For all these traits, significant differences were detected among cultivars (Table 4), confirming the existence of genetic variability among cultivar for various agronomic important traits. CV estimates were reasonable for most traits, except for resistance to anthracnose and rust, which can be explained by the fact that evaluations were carried out in the field depending of the natural occurrence of the disease. However, selective accuracy estimates were always high or very high (AS > 0.7), showing that it was possible to differentiate cultivars.

For plant architecture, seven cultivars were grouped as the most upright, presenting the best means (Table 3) and the best estimates of z_i. Estimates for CV_i ranged from 8.3 to 60.6%, showing great difference concerning the stability of different cultivars. The same seven cultivars (BRS Esplendor, BRS Supremo, CNFC 10432, BRS Sublime, CNFC 10431, BRS Cometa and BRS Valente) showed satisfactory stability estimates ($CV_i < 15\%$). It is worth noting the BRS Supremo (black grains), ($CV_i = 6.3\%$) and the BRS Sublime ($CV_i = 11.1\%$), with carioca grains, bringing together good averages, adaptability and the best stabilities for plant architecture (Fig. 1). These two cultivars presented means inferior to general means in all six environments, confirming its good stability. Pereira et al. (2013) also found good plant architecture for BRS Esplendor, BRS Supremo, and BRS Valente, in the state of Pernambuco. However, these authors identified BRS Estilo and BRS Horizonte among the most upright cultivars, which differs from the present study and confirms the great environmental effect and the importance of the G × E interaction in the expression of plant architecture. Cultivars with inferior plant architectures were BRS Pontal (6.5 d), Pérola (6.0 d), BRS Ametista (5.8 d), and BRSMG Madrepérola (5.7 d). For this reason, they are not recommended for direct mechanical harvest, as they may loose a large amount of grains during this process.

For lodging tolerance, eight cultivars were grouped as the most tolerant, presenting the best means (Table 3) and also the best estimates of z_i. Estimates for CV_i ranged from 4.6 to 75.3%, showing great difference in the stability of cultivars. Five of these eight cultivars (BRS Valente, CNFC 10431, BRS Sublime, CNFC 10432, and BRS Horizonte) showed high stability ($CV_i < 15\%$). It is worth noting that the BRS Valente (black grains, $CV_i = 4.6\%$), and the CNFC 10431 (carioca grains, $CV_i = 9.3\%$), showed good means, adaptability, and the best stabilities for lodging resistance, presenting means inferior to the general mean in the six environments (Fig. 1). Cultivars with inferior tolerance to lodging were BRS Pontal (6.3 d), Pérola (6.3 d), and BRSMG Madrepérola (7.0 d).

Only three cultivars (BRS Notável, BRSMG Madrepérola, and BRS Cometa) showed semi-early cycles (75–84 days) (Table 3), presenting low stability, with CV_i above 30%, which indicates that, depending on the environment, the cycle of such cultivars may vary almost reaching what is considered normal in absolute values (85–94). In most of the times, they show to be inferior to the other genotypes (Fig. 1). Among the other cultivars, seven showed high stability, with CV_i below 15% (BRS Esplendor, BRS Estilo, VC6, BRS Valente, BRS Ametista, Pérola, and BRS Supremo).

Regarding to disease resistance, stability is especially important in the case of diseases with high variability of pathogen, such as anthracnose and angular leaf spot (Damasceno e Silva et al. 2007; Sartorato 2002). A greater stability may indicate resistance to a greater number of races of a particular pathogen, which means fewer risks of losses in production. Even with this importance, there are few studies approaching stability for disease resistance in the field for the common bean crop.

Anthracnose is one of the diseases with great importance for the common bean production in Brazil, because it is widely distributed throughout the country, causing up to 100% of losses. This disease is especially important in Paraná and Santa Catarina, states that bring favorable environmental conditions for its occurrence. About 71 different races for *C. lindemuthianum* were already described in the country (Damasceno e Silva et al. 2007; Ribeiro et al. 2016). Paraná and Santa Catarina present a great number of different races (29 and 16, respectively) (Alzate-Marin and Sartorato 2004).

Eleven cultivars showed reduced means and high estimates of z_i for reaction to anthracnose, indicating, respectively, high resistance and adaptability to reaction to anthracnose (Table 5). Estimates for CV_i ranged from 6.3 to 120.4%. Nine of these cultivars (BRS Esplendor, BRS Notável, CNFC 10431, BRS

Table 5 Means (M), adaptability (Zi) and stability (CVi) parameters for reaction to anthracnose, angular leaf spot, common bacterial blight (CBB), fusarium wilt (FW), and rust (RU), of 17 common bean cultivars evaluated in 22 environments of Paraná and Santa Catarina, from 2008 to 2010, according to the method of Nunes et al. (2005)

Cultivars	Anthracnose			Angular leaf spot			CBB			FW	RU
	M	Z_i	CV_i	M	Z_i	CV_i	M	Z_i	CV_i	M	M
BRSMG Majestoso	1.6a	4.3	11.3	2.9b	4.5	12.0	3.3a	3.9	19.9	4.0a	2.0a
BRS Notável	1.0a	4.6	6.4	4.5c	3.7	28.3	2.7a	4.3	36.1	3.3a	3.0b
BRS Esplendor	1.3a	4.5	6.3	4.1c	3.9	16.5	2.0a	4.9	10.1	2.0a	2.0a
BRS Estilo	1.9a	4.2	21.8	4.0c	3.9	19.0	3.6a	3.7	28.5	7.3b	1.5a
VC6	3.0b	3.7	26.0	3.2b	4.3	8.8	3.3a	3.9	33.4	6.7b	2.3a
CNFC 10431	1.1a	4.5	6.5	2.1a	4.9	9.0	2.6a	4.7	24.7	8.0b	1.5a
BRS Sublime	2.6b	3.6	48.6	1.6a	5.2	9.6	2.7a	4.4	11.9	7.3b	1.3a
BRS Pontal	1.4a	4.4	10.8	2.8b	4.5	17.1	2.6a	4.5	11.3	6.0b	1.0a
CNFC 10467	1.3a	4.4	11.1	2.6b	4.6	11.2	3.1a	4.1	31.6	6.7b	1.5a
BRS Valente	6.0c	2.2	120.4	3.3b	4.2	17.6	4.0a	3.5	55.6	7.3b	4.8c
BRSMG Madrepérola	2.8b	3.9	30.0	4.4c	3.9	27.6	3.1a	3.8	43.2	7.3b	2.3a
BRS Ametista	2.0a	4.2	16.2	6.6e	2.7	30.7	3.1a	4.0	25.2	2.7a	1.5a
Pérola	5.0c	2.4	75.4	4.2c	3.9	18.7	3.1a	4.2	20.5	4.0a	1.8a
BRS Supremo	2.9b	3.7	42.7	4.2c	3.8	16.1	5.4b	2.3	76.3	8.0b	1.5a
CNFC 10432	1.3a	4.4	11.1	1.9a	5.0	12.7	3.4a	3.9	22.0	6.7b	1.8a
BRS Cometa	1.3a	4.4	11.1	5.6d	3.2	19.0	3.4a	3.7	38.1	7.3b	1.8a
BRS Horizonte	1.5a	4.4	10.1	8.3f	1.8	81.8	2.9a	4.2	13.5	8.0b	1.5a

Means followed by the same letter, in the columns, not differ among them (Scott-Knott-10%)

Horizonte, BRS Pontal, BRS Cometa, CNFC 10432, CNFC 10467 and BRSMG Majestoso) showed high stability ($CV_i < 15\%$). It is relevant to highlight that BRS Esplendor, BRS Notável and CNFC 10432, the most stable for anthracnose reaction ($CV_i = 6.3$, 6.4, and 6.5%, respectively) (Fig. 2). It is important to mention the performance of the carioca seeded cultivar Pérola, that is still the most grown in the country. Pérola was in the worst group of means (5.0 c) and presented low stability ($CV_i = 75.4\%$), showing to be highly susceptible to anthracnose, as reported in other works (Pereira et al. 2013). The results obtained indicate the presence of a higher level of anthracnose resistance of newer cultivars, since the evaluations for this disease were held in eight different environments and, therefore, with probable occurrence of different races of the pathogen, which ensures the consistency and representativeness of the evaluation.

The angular leaf spot is another disease widely distributed in the country that also presents great variability of this pathogen (Sartorato 2002; Damasceno e Silva et al. 2008). Only three cultivars showed a good level of resistance, high adaptability and high stability for angular leaf spot reaction (BRS Sublime, CNFC 10431, CNFC 10432) (Table 5). It confirms the existence of a small number of cultivars showing satisfactory resistance to this pathogen (Del Peloso et al. 2009) and reinforces the importance of obtaining new resistant cultivars. These cultivars also showed good resistance to the angular leaf spot disease in the Central region of Brazil (Pontes Júnior et al. 2012). It is also important to mention the existence of cultivars very susceptible to this disease, such as BRS Horizonte with the worst average (8.3 f), low adaptability and stability ($CV_i = 81.8\%$) (Fig. 2). This cultivar had already shown great susceptibility to angular leaf spot in Southern Brazil (Melo et al. 2007), in addition to the State of Mato Grosso (Pereira et al. 2012).

For common bacterial blight reaction, the superior cultivars were the BRS Esplendor, BRS Sublime, and BRS Pontal, with low means and high adaptability and stability (Table 5; Fig. 2). Observing the reaction means of the cultivars, it is possible to see that the reviews did not allow a good discrimination between them, which can be explained by the low means for most cultivars, indicating the severity of the disease was low, even having occurred in seven environments. As an example, the cultivars BRS Cometa (3.4 a) and BRS Estilo (3.6 a), which are highly susceptible to common bacterial blight (Del Peloso et al. 2009) and were classified in the most resistant group. Among the three cultivars that stood out, BRS Pontal and BRS Esplendor have been indicated in other studies as

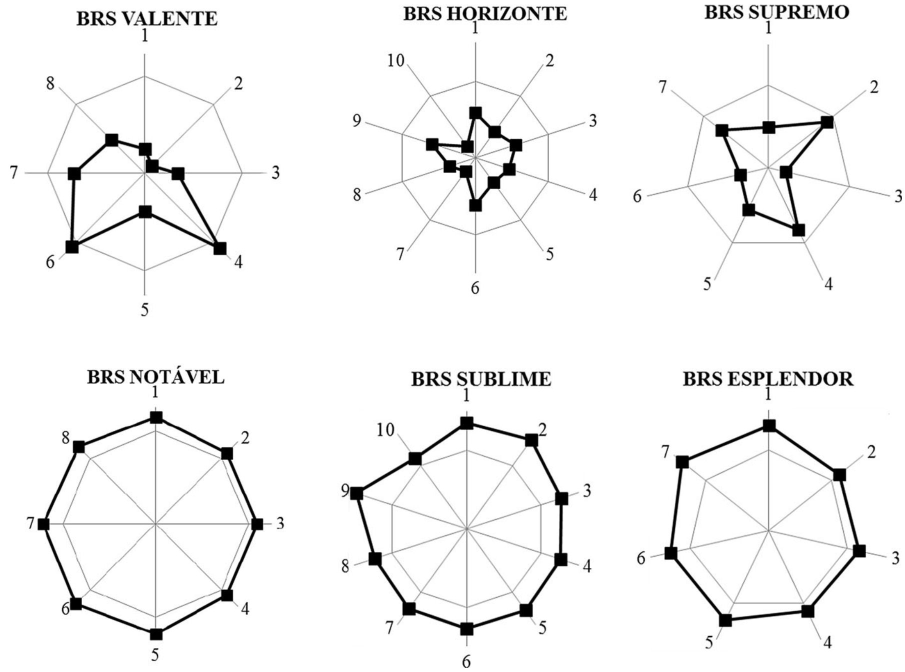

Fig. 2 Graphical representation of inferior and superior genotypes for reaction to anthracnose, angular leaf spot and common bacterial blight, in columns 1, 2 and 3, respectively, according to the method of Nunes et al. (2005). The circle represents the average of environments (constant value associated with the variable Z), and the axes represent each of the environments evaluated

resistant to common bacterial blight (Melo et al. 2007; Del Peloso et al. 2009; Pontes Júnior et al. 2012).

For reaction to fusarium wilt and rust, the number of evaluations was insufficient to perform stability analysis, therefore, it was only considered the averages. Five cultivars showed resistance to fusarium wilt, staying in the same mean group (BRS Esplendor, BRS Notável, BRS Ametista, Pérola, and BRSMG Majestoso), with means between 2.0 and 4.0 (Table 5). The other 12 cultivars were very susceptible to this disease, with means between 6.0 and 8.0, which indicates the need for greater efforts to obtain resistant cultivars to fusarium wilt. For rust resistance, we observed an inverse behavior. Most cultivars (15) showed to be highly resistant, even though the causal pathogen of this disease is a fungus that shows great variability (Souza et al. 2007). This result is consistent to the recent literature, confirming that new common bean cultivars, mainly those with black and carioca grains, present high level of resistance to rust, a disease currently not occurring anymore (Melo et al. 2007).

Considering the means and adaptability and stability scores for traits evaluated, 88% of the cultivars were superior for rust, 53% for anthracnose, 41% para grain yield, plant architecture and cycle, 30% for fusarium wilt and lodging, and only 18% for angular leaf spot and common bacterial blight. This indicate that to some of these traits, like rust and anthracnose, the breeding programs have provided several cultivars that meet the demands of farmers. For other traits like angular leaf spot, common bacterial blight, fusarium wilt and lodging, it is necessary to intensify the efforts to provide more cultivars with high resistance or tolerance level, adaptability and stability.

The farmer needs cultivars that add a greater number of desirable traits, and with high adaptability and stability to ensure greater security in return of the investments made in the process of implantation and conduction of farming. Thus, it is important to identify cultivars that are as complete as possible, in terms of desirable traits. By considering the 17 cultivars and the nine traits evaluated, we can highlight some cultivars that contain the maximum number of desirable phenotypes for these traits. Cultivars BRS Esplendor, of black grain, and CNFC 10431 and BRS Sublime, both of carioca beans, stand out in six out of the nine traits evaluated: BRS Esplendor (high grain yield, upright architecture, resistance to common bacterial blight, anthracnose, fusarium wilt, and rust); CNFC 10431 (high grain yield, upright architecture, lodging tolerance, resistance to anthracnose, angular leaf spot, and rust) and BRS Sublime (high grain yield, upright architecture, lodging tolerance, angular leaf spot, common bacterial blight, and rust).

The other cultivars present advantages concerning fewer traits and must be used in environments where these traits present greater importance. As common-bean are sowed all over the country and in different sowing seasons during the year, it is especially important the availability of new options of cultivars considered suitable to different cropping systems all around Brazil. In this way, considering the whole range of environments where the culture is cultivated, surely there will be the need for using different cultivars to suit the existing particularities of several production systems.

Conclusions

There is genetic variation among the evaluated common bean cultivars for grain yield, plant architecture, lodging tolerance, cycle, reaction to anthracnose, angular lead spot, common bacterial blight, fusarium wilt, and rust, in addition to the adaptability and stability for these traits. The genotype by environment interaction is important for these traits in the Southern region of Brazil and, consequently, common bean pre-commercial lines must be evaluated at the largest number of environments as possible.

For some of these traits, like rust and anthracnose, the breeding programs have provided several cultivars that meet the demands of farmers. For other traits like angular leaf spot, common bacterial blight, fusarium wilt and lodging, it is necessary to intensify the efforts to provide more cultivars with high resistance or tolerance level, adaptability and stability.

The black seeded cultivar BRS Esplendor and the carioca seeded cultivars CNFC 10431 and BRS Sublime present superiority for six of the nine evaluated traits: BRS Esplendor (high grain yield, upright architecture, resistance to common bacterial blight, anthracnose, fusarium wilts, and rust); CNFC 10431 (high grain yield, upright architecture, lodging tolerance, resistance to anthracnose, angular leaf spot, and rust) and BRS Sublime (high grain yield, upright architecture, lodging tolerance, angular leaf spot, common bacterial blight, and rust). Therefore, these cultivars can be indicated to be used in the Southern region of Brazil. The other cultivars present advantages concerning fewer features and must be used in environments where these features present greater importance.

Acknowledgements The authors are thankful to Embrapa Arroz e Feijão by the funds necessary to undergo this research and to Conselho Nacional de Desenvolvimento Tecnológico (CNPq) for concession of grants to Helton S. Pereira, Adriane Wendland, Thiago Lívio P.O. Souza and Leonardo C. Melo.

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