DOI: 10.5433/1679-0359.2017v38n3p1241

Genetic, environmental and genotype x environment interaction effects on the common bean grain yield and commercial quality

Efeito genético, ambiental e interação genótipos x ambientes na qualidade comercial e produtividade de grãos em feijoeiro-comum

Helton Santos Pereira[1*]; Renata Cristina Alvares[2]; Fernanda de Cássia Silva[2]; Luís Cláudio de Faria[1]; Leonardo Cunha Melo[1]

Abstract

The objective of this study was to assess the effects of environmental and genotype x environment (GxE) interaction on the commercial quality and grain yield of common bean for the identification of new cultivars for the South Central and Central regions of Brazil, that combine high adaptability/ stability for grain yield, sieve yield (SY) and 100-seed weight (100M). Sixty-two trials were performed in a randomised block design with three replicates in different sowing seasons in the South Central (Rio Grande do Sul (RS), Santa Catarina (SC), Paraná (PR), São Paulo (SP) and Mato Grosso do Sul (MS)) and Central (Goiás (GO) and Distrito Federal (DF)) regions in 2009 and 2010. In the trials, 16 "carioca"-seeded lines were evaluated, and grain yield, SY and 100M were collected. The data were then subjected to individual and joint analyses of variance and to adaptability and stability analyses using the Annichiarico method. Genetic variation was found between the lines for all three traits. Coefficient of determination estimates showed that the genotype effect was more important for commercial quality than for grain yield and that the environmental effect was equally important for all three traits, indicating that the highest possible number of environments should be tested. The highest-yielding lines in the Brazilian Central (CNFC 11954 and CNFC 11959) and South Central (CNFC 11948) regions were different, indicating the importance of GxE interactions for yield. However, the two best lines in the Central Region had low commercial grain quality. Thus, CNFC 11948 will be recommended as the new cultivar selected for broad adaptation because it combines high commercial quality with increased mean grain yield and stability in the South Central Region and better yield and stability than the main controls in the Central Region.
Key words: *Phaseolus vulgaris* L. 100-seed weight. Sieve yield.

Resumo

O objetivo desse trabalho foi estudar o efeito ambiental e da interação genótipos × ambientes para produtividade e qualidade comercial de grãos na indicação de novas cultivares de feijoeiro-comum para as Regiões Centro Sul e Central do Brasil, identificando linhagens que reúnam alta adaptabilidade/ estabilidade para produtividade, rendimento de peneira e massa de 100 grãos. Foram realizados 62 ensaios em blocos ao acaso, com três repetições, em diferentes épocas de semeadura, nas Regiões Centro Sul (RS, SC, PR, SP e MS) e Central (GO e DF), nos anos de 2009 e 2010. Os ensaios foram compostos por 16 linhagens de grãos carioca e foram obtidos dados de produtividade, rendimento de peneira e massa de 100 grãos. Os dados foram submetidos a análises de variância individuais e conjuntas e a

[1] Pesquisadores, Embrapa Arroz e Feijão, Santo Antônio de Goiás, GO, Brasil. E-mail: helton.pereira@embrapa.br; luis.faria@embrapa.br; leonardo.melo@embrapa.br

[2] Discentes, Universidade Federal de Goiás, UFG, Goiânia, GO, Brasil. E-mail: renataalvares08@hotmail.com; nandadecassiasl@hotmail.com

[*] Author for correspondence

Received: May 30, 2016 - Approved: Mar. 01, 2017

análises de adaptabilidade e estabilidade pela metodologia de Annichiaricco. Existe variação genética entre as linhagens para os três caracteres. As estimativas do coeficiente de determinação mostraram que o efeito de genótipos é mais importante para a qualidade comercial do que para produtividade de grãos e que o efeito ambiental é igualmente importante para os três caracteres, indicando que a avaliação deve ser realizada no maior número possível de ambientes. As linhagens superiores para produtividade nas Regiões Central (CNFC 11954 e CNFC 11959) e Centro-Sul (CNFC 11948) do Brasil são diferentes, indicando a importância da interação genótipos x ambientes para essa característica. Entretanto, as duas melhores linhagens na Região Central apresentaram baixa qualidade comercial dos grãos. Assim, a linhagem CNFC 11948 será indicada como nova cultivar de ampla adaptação, pois reúne ótima qualidade comercial de grãos, maior produtividade média e estabilidade na Região Centro-Sul e produtividade e estabilidade superiores as principais testemunhas na Região Central.
Palavras-chave: *Phaseolus vulgaris* L. Massa de 100 grãos. Rendimento de peneiras.

Introduction

Brazil is one of the largest producers and consumers of bean (*Phaseolus vulgaris* L.) worldwide, and it produced 2.6 million tonnes (t) of beans in 2013 (FEIJÃO, 2015). Beans are staples of the Brazilian diet, especially in low-income populations. Two main regions account for most Brazilian bean production. The South Central Region is the largest bean-producing region of the country, accounting for the production of 1,186,989 t, with a mean yield of 1,532 kg ha^{-1}; production was concentrated in the rainy (sowing between August and November) and dry (sowing between January and February) seasons on both small and large farms with highly variable usages of technology. The Central Region accounts for the production of 1,054,320 t, with a mean yield of 1,586 kg ha^{-1}; the state of Goiás (GO) and the Federal District (DF) stand out in this region with a mean yield of 2,289 kg ha^{-1}. The main sowing season is winter (sowing between May and July), predominantly on large farms with high levels of agricultural inputs, including the use of centre-pivot irrigation, which explains the achievement of a high mean yield.

Common bean is highly genetically variable when considering seed shape, size and colour, resulting in the sale of large numbers of grain types. Consumer preference for grain type varies depending on country, region and even micro-region. In Brazil, the “carioca” grain type (beige seeds with brown stripes) is preferred, accounting for 70% of Brazilian production.

The commercial quality of the grains has become increasingly important, especially when considering the “carioca” grain, because it defines consumer acceptance of new cultivars and therefore the price paid to farmers when selling their grain. This quality is related to factors including grain size and shape, which may be measured using the 100-seed weight (100M) and oblong-hole sieve yield (SY), and visual appearance, which is evaluated by grain colour. The commercial standard of “carioca” grains is high SY (90%), 100M above 25 g and beige backgrounds with brown stripes, both in light shades. Grain quality is also affected by the different environmental conditions (temperature, humidity, soil type) that may occur during the crop cycle, harvest and storage period (CARBONELL et al., 2010).

In Brazil, common bean is grown under different crop systems; therefore, the genotype x environment (GxE) interaction is highly relevant, particularly for grain yield, as reported in several studies (GONÇALVES et al., 2010; TORGA et al., 2013). Thus, alternatives should be sought to reduce the GxE interaction effect, and the identification of adapted/stable lines stands out among the alternatives. Stability/adaptability studies, especially on grain yield, have helped to determine common bean lines for various regions (PERINA et al., 2010; PEREIRA et al., 2009a, 2009b). However, few studies on commercial grain quality-related traits have been performed, particularly using a wide assessment network (DALLA CORTE et al., 2003; CARBONELL et al., 2010; PEREIRA et al., 2012, 2013).

Thus, the objective of this study was to assess the genetic, environmental and GxE interaction effects on grain yield and commercial quality with the goals of identifying new common bean cultivars for the Brazilian South Central and Central regions and lines the combine high adaptability/stability for yield, SY and 100M.

Materials and Methods

Each trial consisted of 12 elite lines of "carioca" common bean (CNFC 11944, CNFC 11945, CNFC 11946, CNFC 11948, CNFC 11951, CNFC 11952, CNFC 11953, CNFC 11954, CNFC 11956, CNFC 11959, CNFC 11962 and CNFC 11966) and four controls (BRS Estilo, BRS Cometa, IPR Juriti and Pérola). The trials were conducted in 2009 and 2010 in 62 environments (different combinations of site, sowing season and year) in the rainy, dry and winter sowing seasons in 30 different locations in the states of Paraná (PR), Santa Catarina (SC), Rio Grande do Sul (RS), Mato Grosso do Sul (MS), São Paulo (SP), Goiás (GO) and Federal District (DF). All trials were performed in a randomised block design with three replicates and plots with four-metre rows spaced 0.5 m apart.

Grain yield (kg ha^{-1}) was assessed in the 62 environments, and SY and 100M were tested in 37 environments. SY in each plot was estimated using 300-g seed samples with 13% moisture. Each sample was classified using a 0.45-mm-thick oblong-hole sieve (Sieve 12), i.e., 12/64 inches, which is considered to be the most rigorous sieve for commercial classification of beans. The seeds retained on the sieve were weighed, and SY was estimated in percentage; 100M was estimated by counting 100 seeds retained on the sieve, followed by weighing them on a precision scale.

Data from each trial were subjected to individual analyses of variance. Furthermore, selective accuracy (SA) was estimated to assess the informativeness of each experiment (RESENDE; DUARTE, 2007) using the following equation:

$$SA = \left(1 - \frac{1}{F_c}\right)^{0.5},$$

to $F_c < 1$, where F_c is the F-test value for lines. Joint analysis of variance was also performed assuming the genotype effect to be fixed and the environment effect to be random for each trait. For the grain yield, the trials were grouped into two regions: South Central, encompassing the PR, SC, RS, SP and MS states and Central, encompassing the GO state and DF.

The degrees of freedom of the mean error and the GxE interaction were adjusted (COCHRAN, 1954) when the ratio between the highest and lowest residual mean squares was higher than seven, indicating non-homogeneous residual variances (PIMENTEL-GOMES, 2000). The means were compared using the Scott-Knott test at 10% probability to decrease the probability of non-discrimination between genotypes due to a type II error. This procedure is recommended when small differences between treatments are expected, as in the case of elite line trials (ZIMMERMANN, 2004).

The contributions of each source of variation in the joint analysis of variance to the total genetic variation were estimated using the coefficient of determination (R^2) estimate and the following equation:

$$R_i^2 = \frac{SS_i}{SS_t},$$

where SS_i is the sum of squares of the source of variation i and SS_t is the total sum of squares.

Stability analysis was also performed for the three traits using the Annicchiarico (1992) method, which is based on the genotypic reliability index and estimated using the following equation: $\omega_{i(g)} = \hat{\mu}_{i(g)} - z_{(1-\alpha)}\hat{\sigma}_{z_i(g)}$, where $\hat{\mu}_{i(g)}$ is the mean percentage of genotypes i; $\hat{\sigma}_{z_i(g)}$ is the standard deviation of values z_{ij} associated with the i-th genotype; and $z_{(1-\alpha)}$ is the percentile of the standard normal distribution function. The index was also calculated for favourable and unfavourable environments. A confidence level of 75% was adopted, that is, α=0.25. The GENES (CRUZ, 2013) software package was used to perform the statistical analysis.

Results and Discussion

Grain Yield

The mean grain yields of the trials varied significantly in both regions (from 955-4616 kg ha^{-1} and 917-3337 kg ha^{-1} in the South Central and Central regions, respectively), indicating wide variation between environments. Altitudes varied between 147-969 m and 396-1171 m, latitudes varied between 18°47'-28°38'South and 13°26'-17°47'South, and longitudes varied between 48°49'-54°48'West and 47°36'-50°55'West in the South Central and Central regions, respectively. Furthermore, different crop years and sowing seasons were used. Experimental accuracy was considered to be good, with coefficients of variation (CV) ranging from 8.7-25.2% and from 8.9-25.2% in the South Central and Central regions, respectively, and with high or very high selective accuracy (SA≥0.70) estimates in 67% and 77% of the trials, respectively (RESENDE; DUARTE, 2007).

The overall mean grain yield was higher in the South Central Region (2313 kg ha^{-1}) than in the Central Region (2090 kg ha^{-1}). This difference may be explained by the low grain yields of the harvests from the rainy and dry seasons in the Central region, primarily due to the high rainfall concentration over short periods during the rainy season and the lack of rainfall, combined with high temperatures, in the dry season. The same seasons generated higher grain yields in the South Central Region than in the Central Region (FEIJÃO, 2015).

The joint analyses indicated that all genotype, environment and GxE interaction effects were significant, confirming the environmental differences and indicating the existence of genetic differences between genotypes and GxE interaction in both regions (Table 1). The significance of these effects was reported in the same regions in other studies (CARBONELL et al., 2010; PEREIRA et al., 2009a, 2009b, 2012).

In the South Central Region, the highest mean grain yields were obtained by the CNFC 11948 and IPR Juriti genotypes; they were not different from each other (Table 2) and were higher than the other controls. Five other lines (CNFC 11954, CNFC 11946, CNFC 11951, CNFC 11962 and CNFC 11966) had similar grain yields to the BRS Estilo cultivar, which has been widely used by farmers (MELO et al., 2010). All of these genotypes surpass the mean grain yield of the Pérola cultivar, which is still the most sown in Brazil. This result indicates that the lines have the potential to produce good grain yields compared with the controls.

Table 1. Summary of the joint analysis of variance of grain yield assessed in the Brazilian South Central and Central regions, sieve yield (SY) and 100-seed weight (100M) of 16 "carioca" common bean genotypes.

Source of variation	South Central Yield			Central Yield			SY			100M		
	DF	MS	p-value	DF	MS	p-value	DF	MS	p-value	DF	MS	p-value
Genotype (G)	15	2514763	0.000	15	1306778	0.001	15	13283.5	0.000	15	245.9	0.000
Environment (E)	35	40317209	0.000	25	24185199	0.000	36	12188.9	0.000	36	147.4	0.000
GxE	362[1]	437526	0.000	218[1]	513422	0.000	332[1]	385.1	0.000	332[1]	5.2	0.000
Error	738[1]	186053	-	446[1]	213986	-	674[1]	44.8	-	674[1]	1.9	-
Mean	2313			2090			79.7			23.9		
CV (%)	18.6			22.1			8.4			5.8		

[1]Degrees of freedom adjusted using the Cochran (1954) method due to the heterogeneity of the residual mean squares (MS).

Table 2. Estimates of phenotypic stability and adaptability parameters for the grain yields of 16 common bean genotypes tested in 36 environments in the Brazilian South Central Region in 2009 and 2010 using the Annicchiarico method, divided into favourable (Wif) and unfavourable (Wiu) environments.

Genotype	Mean (kg ha^{-1})	Wi[1]	C[2]	Wif	C	Wiu	C
CNFC 11948	2629 a	111.2	1	109.5	1	112.2	1
IPR Juriti	2531 a	104.0	2	107.1	2	102.5	3
CNFC 11954	2421 b	101.9	3	100.5	5	103.1	2
CNFC 11946	2404 b	100.7	4	100.2	6	101.0	5
CNFC 11951	2390 b	98.4	7	101.3	4	97.0	7
BRS Estilo	2362 b	99.3	6	101.7	3	98.0	6
CNFC 11962	2360 b	99.3	5	96.2	12	101.2	4
CNFC 11966	2328 b	96.6	8	99.4	7	95.1	9
CNFC 11944	2296 c	96.4	9	97.7	9	95.6	8
Pérola	2289 c	95.1	10	98.2	8	93.5	10
CNFC 11952	2283 c	93.2	12	97.3	11	91.0	13
CNFC 11945	2246 c	94.7	11	97.5	10	93.2	11
CNFC 11959	2190 c	91.3	13	88.9	15	93.0	12
CNFC 11953	2140 d	86.2	14	90.8	13	84.0	14
BRS Cometa	2094 d	85.8	15	89.2	14	84.0	15
CNFC 11956	2045 d	82.9	16	83.7	16	82.7	16

Means followed by the same letter are not significantly different from each other according to the Scott-Knott test at 10% probability.
[1]Genotypic reliability index; [2]Classification of genotypes in terms of stability based on the method used.

Based on the adaptability/stability parameters assessed using the Annicchiarico (1992) method, the CNFC 11948, IPR Juriti, CNFC 11954 and CNFC 11946 genotypes were considered to be the most stable and adapted (Table 2) because their reliability index (Wi) was higher than 100% in the mean of all environments and in favourable and unfavourable environments, indicating high adaptability/stability. Those genotypes surpassed the overall mean of the environments by 12.2%, 7.1%, 3.1% and 1.0%, respectively. CNFC 11948 stands out among those genotypes, with values always 9.5% or more greater than the overall mean.

Conversely, in the Central Region, the highest mean grain yields were obtained by the CNFC 11954 and CNFC 11959 lines, which surpassed all of the controls (Table 3), including the Pérola cultivar, which is widely used in this region in winter due to its good tolerance of soil diseases and the commercial appeal of its grains. Three other lines (CNFC 11962, CNFC 11966 and CNFC 11948) had similar grain yields to the Pérola cultivar (2,190 kg ha^{-1}; Table 3). CNFC 11954 and CNFC 11959 were the most stable and adapted lines and also widely used, with Wis higher than 100% in all conditions tested (Table 3). These lines surpass the mean grain yield of the environments tested by 10.8% and 6.6%, respectively. Three genotypes showed specific adaptation to favourable environments, including the Pérola cultivar (Wi favourable (Wif)=105.6% and Wi unfavourable (Wiu)=90.6%), which has high productive potential in the absence of limiting factors, including drought and the occurrence of leaf diseases (CARBONELL et al., 2010). BRS Estilo was considered to be a very stable and adapted cultivar in studies conducted in the Brazilian Central Region (PEREIRA et al., 2009a, 2012), but that result was not confirmed in this study. Stability analysis is always comparative between genotypes, and six new lines were superior to BRS Estilo in the present study, indicating success of the breeding program in generating superior lines. Genetic progress were also reported by other common bean breeding programmes (MATOS et al., 2007; FARIA et al., 2013).

Table 3. Estimates of phenotypic stability and adaptability parameters for the grain yields of 16 common bean genotypes tested in 26 environments in the Brazilian Central Region in 2009 and 2010 using the Annicchiarico method, divided into favourable (Wif) and unfavourable (Wiu) environments.

Genotype	Mean (kg ha^{-1})	Wi[1]	C[2]	Wif	C	Wiu	C
CNFC 11954	2357 a	110.8	1	105.9	2	115.2	1
CNFC 11959	2282 a	106.6	2	106.3	1	106.7	2
CNFC 11962	2192 b	99.6	3	102.8	5	97.0	5
Pérola	2190 b	97.0	7	105.6	3	90.6	14
CNFC 11966	2171 b	97.5	6	103.0	4	93.1	8
CNFC 11948	2156 b	99.3	4	99.8	6	98.8	4
CNFC 11946	2109 c	97.9	5	92.6	12	102.9	3
IPR Juriti	2092 c	95.4	8	98.5	7	92.9	9
BRS Estilo	2065 c	95.1	9	96.2	8	94.2	7
CNFC 11951	2060 c	94.6	10	94.0	9	95.2	6
CNFC 11944	2017 c	92.0	12	92.4	13	91.6	12
BRS Cometa	1998 d	91.2	13	93.3	10	89.3	15
CNFC 11952	1989 d	92.0	11	92.7	11	91.6	13
CNFC 11956	1931 d	90.1	14	87.2	14	92.6	10
CNFC 11945	1925 d	88.3	15	84.6	16	91.6	11
CNFC 11953	1909 d	87.0	16	86.7	15	87.1	16

Means followed by the same letter are not significantly different from each other according to the Scott-Knott test at 10% probability.
[1]Genotypic reliability index; [2]Classification of genotypes in terms of stability based on the method used.

The performance of the lines in both regions indicated that different lines might be appropriate for each region, thus capitalising on the interaction effect between genotypes and environments, which may be explained by the significant differences in the climatic conditions of the regions. CNFC 11948 (South Central Region) and CNFC 11954 and CNFC 11959 (Central Region) were the best lines. Differential genotype adaptation to these regions is commonly observed, as reported in previous studies (PEREIRA et al., 2009a, 2009b). However, the identification of lines as new common bean cultivars is not exclusively dependent on yield because several other traits are very important. Some of those traits, including grain quality-related traits, are limiting because cultivars with low commercial quality will fail to meet market demands and therefore will not succeed.

SY and 100M

There are two main issues for common bean farmers when choosing cultivars: the ability of the cultivar to generate high-grain yield in a wide variety of environments (increased resistance to biotic stress, tolerance to abiotic stress and production stability), which is reflected in the quantity of product farmers may sell, and product quality, which is reflected in the value that farmers will receive. In Brazil, common-beans are used for direct human consumption, that is, without processing, and therefore, commercial quality is extremely important when adopting a new cultivar. Thus, lines with good commercial grain quality are more likely to be accepted.

The parameters SY and 100M are included in commercial grain quality analysis. The mean SY ranged from 35.1-97.0%, and 100M ranged from 20.3-26.8g in the environments tested, indicating wide variation between environments. The CV values (1.1-18.5% for SY and 2.2-8.7% for 100M) indicated good experimental accuracy, which was confirmed by high or very high SA estimates in 95% of tests for both traits. Joint analysis of variance confirmed the environmental variation and indicated the presence of genetic differences between the lines and GxE interactions (Table 1), also showing the importance of assessing commercial grain quality in multiple environments (CARBONELL et al., 2010; PEREIRA et al., 2012, 2013).

The highest SY means were obtained by BRS Cometa (90.0%) and CNFC 11962 (89.7%; Table 4). The second highest means were obtained by four lines (CNFC 11945, CNFC 11944, CNFC 11948 and CNFC 11946) and the cultivar BRS Estilo, which is considered to be a new standard of commercial grain quality. The SY (84.6%) of the Pérola cultivar, the historical standard of grain quality, was included in the third group of means with two other lines (CNFC 11959 and CNFC 11954), which shows the potential of these seven lines for this trait.

Table 4. Estimates of phenotypic stability and adaptability parameters for the SY of 16 common bean genotypes tested in 37 environments in Brazil in 2009 and 2010 using the Annicchiarico method, divided into favourable (Wif) and unfavourable (Wiu) environments.

Genotype	Mean		Wi[1]	C[2]	Wif	C	Wiu	C
BRS Cometa	90.0	A	110.9	1	104.4	4	124.4	1
CNFC 11962	89.7	A	109.9	2	103.5	7	123.7	2
CNFC 11945	87.8	B	108.6	5	105.3	2	115.0	5
CNFC 11944	87.8	B	108.8	4	105.4	1	115.4	4
CNFC 11948	87.6	B	109.0	3	104.4	3	118.4	3
CNFC 11946	87.2	B	107.6	6	104.3	5	114.9	6
BRS Estilo	86.9	B	107.6	7	104.2	6	113.8	8
CNFC 11959	85.8	C	105.6	8	101.2	10	114.5	7
Pérola	84.6	C	104.0	9	102.9	9	106.2	9
CNFC 11954	84.4	C	102.8	10	103.3	8	102.8	10
IPR Juriti	77.4	D	92.2	11	99.7	11	83.4	11
CNFC 11951	69.9	E	82.8	12	90.8	12	73.2	12
CNFC 11966	69.9	E	80.5	13	89.8	14	68.8	13
CNFC 11952	67.2	F	77.1	14	90.1	13	62.2	14
CNFC 11956	62.9	G	70.5	15	84.9	15	54.0	15
CNFC 11953	55.9	H	61.0	16	75.1	16	44.2	16

Means followed by the same letter are not significantly different from each other according to the Scott-Knott test at 10% probability. [1]Genotypic reliability index; [2]Classification of genotypes in terms of stability based on the method used.

The same seven lines and BRS Cometa, BRS Estilo and Pérola were considered to be broadly adapted and the most stable and adapted cultivars (Table 4). The variation in adaptability/stability estimates of these 10 genotypes in terms of SY was low for the mean of all environments and for unfavourable environments. Conversely, the CNFC 11962 and CNFC 11948 lines and the BRS Cometa cultivar had relatively high Wif in the unfavourable environments, indicating good performance in those environments. With respect to the means and adaptability/stability estimates for SY, the CNFC 11962 line performed best, although five other lines (CNFC 11945, CNFC 11944, CNFC 11948, CNFC 11946 and CNFC 11959) performed well.

In the case of "carioca" beans, Brazilians prefer seeds with weights above 25 g/100 seeds, and there has been a demand for increasingly larger seeds over the years. The highest 100M means were obtained by the CNFC 11948 line (26.4 g) and the Pérola cultivar (26.1 g). Three other lines (CNFC 11952, CNFC 11951 and CNFC 11946) had smaller seeds than the Pérola cultivar, although they were similar in size or larger than the seeds of the BRS Estilo cultivar (24.5 g). The other lines had smaller seeds than BRS Estilo, thereby decreasing the possibility of their acceptance as a new cultivar.

The same seven genotypes were considered to be broadly adapted genotypes and the most stable and adapted based on 100M (Table 5). It should be noted that the CNFC 11948, Pérola and CNFC 11952 genotypes had 9.2%, 8.3% and 6.0% higher 100M than the overall mean, respectively. In terms of means and adaptability/stability estimates for 100M, the CNFC 11948 line performed best, and three other lines (CNFC 11952, CNFC 11951 and CNFC 11946) performed very well.

Table 5. Estimates of phenotypic stability and adaptability parameters for the 100M (g) of 16 common bean genotypes tested in 37 environments in Brazil in 2009 and 2010 using the Annicchiarico method, divided into favourable (Wif) and unfavourable (Wiu) environments.

Genotype	Mean		Wi[1]	C[2]	Wif	C	Wiu	C
CNFC 11948	26.4	a	109.2	1	108.5	1	109.9	1
Pérola	26.1	a	108.3	2	108.2	2	108.3	2
CNFC 11952	25.5	b	106.0	3	104.7	3	107.2	3
CNFC 11951	25.0	c	103.8	4	102.4	5	105.3	4
BRS Estilo	24.5	d	101.6	5	101.9	6	101.3	5
CNFC 11946	24.4	d	101.1	6	102.9	4	99.5	7
CNFC 11953	23.8	e	98.9	7	98.1	10	99.7	6
CNFC 11945	23.7	e	98.3	9	99.8	7	97.1	11
CNFC 11944	23.7	e	98.4	8	99.5	8	97.3	9
IPR Juriti	23.7	e	98.2	10	98.7	9	97.8	8
CNFC 11954	23.5	e	97.1	11	97.1	11	97.2	10
CNFC 11966	23.3	f	96.5	12	96.8	12	96.1	13
BRS Cometa	23.1	f	95.8	13	96.7	13	95.0	14
CNFC 11956	22.9	f	95.0	14	93.8	14	96.3	12
CNFC 11962	21.4	g	88.1	15	87.0	15	89.2	15
CNFC 11959	20.8	h	85.9	16	86.2	16	85.6	16

Means followed by the same letter are not significantly different from each other according to the Scott-Knott test at 10% probability. [1]Genotypic reliability index; [2]Classification of genotypes in terms of stability based on the method used.

SY and 100M are indirect measurements of seed shape and size; together with seed colour, they are essential for the acceptance of a new cultivar. Some genotypes, such as CNFC 11962 (SY=89.7% and 100M=21.4 g), have high SY, albeit with small seeds (low 100M), which may be explained by the seed shape. Thus, genotypes with rounder-shaped seeds, including CNFC 11962, tend to have higher SY, even with not-so-large seeds. The opposite situation, when the genotype has low SY and high 100M, may also occur; for example, this situation occurs with CNFC 11952 (SY=67.2% and 100M=25.5 g), which may be explained by the more elongated and flat shape of the seeds.

It is desirable that a line will have high SY and high 100M, which may occur with rounded, large seeds or with elongated, non-flat, large seeds. The standard cultivars for grain quality, Pérola (SY=84.6% and 100M=26.1 g) and BRS Estilo (SY=86.9% and 100M=24.5 g) have good values for both traits. Two lines also had good values for these traits and could therefore have high commercial value with strong potential for adoption in the common bean production chain: CNFC 11948 (SY=87.6% and 100M=26.4 g) and CNFC 11946 (SY=87.2% and 100M=24.4 g).

The CNFC 11948 (South Central Region; Table 2) and CNFC 11954 and CNFC 11959 (Central Region) lines were identified as superior for grain yield (Table 3). CNFC 11948 has excellent commercial grain quality (Tables 4 and 5), thereby supporting its identification as a new cultivar for the

South Central Region. Conversely, the best lines for yield in the Central Region had low commercial quality. CNFC 11954 had low 100M (23.5 g), and CNFC 11959 had very low 100M (20.8 g; Table 5), which decreased the likelihood of their commercial acceptance. When comparing the two lines with good commercial quality, CNFC 11948 showed better yield performance than CNFC 11946 in the Central Region (Table 3), with the highest mean yield and lowest variation amplitude of the adaptability/stability estimates. Thus, CNFC 11948 will be recommended as the new cultivar selected for broad adaptation in both regions.

As previously mentioned, genotype, environment and their interaction effects (Table 1) were significant for all traits. The environmental effect (seasons, years and sites) was the most important for the expression of the three traits, with R^2 estimates accounting for 80.1% and 72.7% of yield variation in the South Central and Central regions, respectively; R^2 estimates were 55.1% for SY and 44.4% for 100M. However, the environmental effect was most important for yield, which corroborates the literature (PEREIRA et al., 2012, 2013).

Conversely, the genotype effect was proportionally more important for grain quality-related traits (R^2=25.0% for SY and R^2=30.8% for 100M) than for yield (R^2=2.2% and 2.4%, in the South Central and Central regions, respectively). This result indicates that selecting for a cultivar with higher grain quality is more determinant and effective for producing grains of good quality rather than yield. The genotype effect on yield is proportionally smaller, as reported by Pereira et al. (2012, 2013). The GxE interaction effect was similar between the three traits: 7.9% and 11.5% for yield, 16.1% for SY and 11.2% for 100M.

Conclusions

Genetic variation was observed between the lines for grain yield, SY and 100M. The genotype effect was more important for determining commercial quality than grain yield.

The environmental effect is important for grain yield and quality, indicating that these traits should be tested in the greatest number of environments (seasons, years and sites) possible.

The best lines for grain yield in the Central (CNFC 11954 and CNFC 11959) and South Central (CNFC 11948) regions were different, indicating the occurrence of GxE interaction for this trait. However, the best lines in the Central Region had low commercial grain quality. Thus, the CNFC 11948 line will be recommended as the new cultivar selected for broad adaptation because CNFC 11948 combines high commercial quality with higher mean yield and stability than controls in the South Central Region and higher yield and stability than the main controls in the Central Region.

Acknowledgements

The authors thank the Embrapa Arroz e Feijão for funding the study, the partner institutions for help in testing the lines, the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for funding the study and granting the Productivity Scholarship in Technological Development to the first and fifth authors and a PhD scholarship to the second author and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for granting a PhD scholarship to the third author.

References

ANNICCHIARICO, P. Cultivar adaptation and recommendation from alfafa trials in Northern Italy. *Journal of Genetics and Plant Breeding,* v. 46, n. 1, p. 269-278, 1992.

CARBONELL, S. A. M.; CHIORATO, A. F.; GONÇALVES, J. G. R.; PERINA, E. F.; CARVALHO, C. R. L. Tamanho de grão comercial em cultivares de feijoeiro. *Ciência Rural,* Santa Maria, v. 40, n. 10, p. 2067-2073, 2010.

COCHRAN, W. G. The combination of estimates from different experiments. *Biometrics,* Washington, v. 10, n. 4, p. 101-129, 1954.

CRUZ, C. D. GENES – a software package for analysis in experimental statistics and quantitative genetics. *Acta Scientiarum. Agronomy*, Maringá, v. 35, n. 3, p. 271-276, 2013.

DALLA CORTE, A.; MODA-CIRINO, V.; SCHOLZ, M. B. S.; DESTRO, D. Environment effect on grain quality in early common bean cultivars and lines. *Crop Breeding and Applied Biotechnology*, Londrina, v. 3, n. 3, p. 193-202, 2003.

FARIA, L. C.; MELO, P. G. S.; PEREIRA, H. S.; DEL PELOSO, M. J.; BRÁS, A. J. B. P.; MOREIRA, J. A. A.; CARVALHO, H. W. L.; MELO, L. C. Genetic progress during 22 years of improvement of carioca-type common bean in Brazil. *Field Crops Research*, Amsterdã, v. 142, n. 1, p. 68-74, 2013.

FEIJÃO: dados conjunturais do feijão (área, produção e rendimento) – Brasil – 1985 a 2013. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2015. Disponível em: <http://www.cnpaf.embrapa.br/apps/ socioeconomia/ index.htm>. Acesso em: 20 maio 2015.

GONÇALVES, J. G. R.; CHIORATO, A. F.; MORAIS, L. K.; PERINA, E. F.; FARIAS, F. L.; CARBONELL, S. A. M. Estudo da estabilidade fenotípica de feijoeiro com grãos especiais. *Ciência e Agrotecnologia*, Lavras, v. 34, n. 4 p. 922-931, 2010.

MATOS, J. W.; RAMALHO, M. A. P.; ABREU, A. F. B. Trinta e dois anos do programa de melhoramento genético do feijoeiro comum em Minas Gerais. *Ciência e Agrotecnologia*, Lavras, v. 31, n. 6, p. 1749-1754, 2007.

MELO, L. C.; DEL PELOSO, M. J.; PEREIRA, H. S.; FARIA, L. C.; COSTA, J. G. C.; DÍAZ, J. L. C.; RAVA, C. A.; WENDLAND, A.; ABREU, A. F. B. BRS Estilo: common bean cultivar with Carioca grain, upright growth and high yield potential. *Crop Breeding and Applied Biotechnology,* Viçosa, v. 10, n. 4, p. 377-379, 2010.

PEREIRA, H. S.; ALMEIDA, W. M.; MELO, L. C.; FARIA, L. C.; WENDLAND, A.; DEL PELOSO, M. J.; MAGALDI, M. C. S. Influência do ambiente em cultivares de feijoeiro-comum em cerrado com baixa altitude. *Bragantia,* Campinas, v. 71, n. 2, p. 165-172, 2012.

PEREIRA, H. S.; COSTA, A. F.; MELO, L. C. ; DEL PELOSO, M. J.; FARIA, L. C.; WENDLAND, A. Interação entre genótipos de feijoeiro e ambientes no Estado de Pernambuco: estabilidade, estratificação ambiental e decomposição da interação. *Semina: Ciências Agrárias*, Londrina, v. 34, n. 6, p. 2603-2614, 2013.

PEREIRA, H. S.; MELO, L. C.; FARIA, L. C.; DEL PELOSO, M. J.; COSTA, J. G. C.; RAVA, C. A.; WENDLAND, A. Adaptabilidade e estabilidade de genótipos de feijoeiro-comum com grãos tipo carioca na Região Central do Brasil. *Pesquisa Agropecuária Brasileira,* Brasília, v. 44, n. 1, p. 29-37, 2009b.

PEREIRA, H. S.; MELO, L. C.; FARIA, L. C.; DIAZ, J. L. C.; DEL PELOSO, M. J.; COSTA, J. G. C.; WENDLAND, A. Stability and adaptability of carioca common bean genotypes in states of the central South Region of Brazil. *Crop Breeding and Applied Biotechnology*, Viçosa, v. 9, n. 2, p. 181-188, 2009a.

PERINA, E. F.; CARVALHO, C. R. L.; CHIORATO, A. F.; GONÇALVES, J. G. R.; CARBONELL, S. A. M. Avaliação da estabilidade e adaptabilidade de genótipos de feijoeiro (*Phaseolus vulgaris* L.) baseada na análise multivariada da performance genotípica. *Ciência e Agrotecnologia*, Lavras, v. 34, n. 2, p. 398-406, 2010.

PIMENTEL-GOMES, F. P. *Curso de estatística experimental.* São Paulo: Editora Nobel, 2000. 466 p.

RESENDE, M. D. V.; DUARTE, J. B. D. Precisão e controle de qualidade em experimentos de avaliação de cultivares. *Pesquisa Agropecuária Tropical,* Goiânia, v. 37, n. 3, p. 182-194, 2007.

TORGA, P. P.; MELO, P. G. S.; PEREIRA, H. S.; FARIA, L. C.; DEL PELOSO, M. J.; MELO, L. C. Interaction of common bean cultivars of the black group with years, locations and sowing seasons. *Euphytica,* Wagening, v. 189, n. 2, p. 239-248, 2013.

ZIMMERMANN, F. J. P. *Estatística aplicada à pesquisa agrícola.* Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2004. 402 p.