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Adaptability and stability of carioca bean pre-cultivars in Agreste-Sertão Pernambucano

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ABSTRACT: Adaptability and stability estimates are used by plant breeding programs to identify cultivars that exhibit predictable behavior and great performance in more than one environment. Thus, the objective of this work was to compare biometric techniques for simultaneous selection of carioca bean pre-cultivars for high adaptability, stability and yield of grains under the conditions of Agreste-Sertão Pernambucano of the Brazil. The trials were conducted in the municipalities of Arcoverde, São João, and Belém de São Francisco. Ten pre-cultivars and four commercial witnesses were used and the randomized complete block design was employed, with three repetitions. Grain yield was evaluated in the period 2014-2015. Variance analyzes were performed and the adaptability and stability were estimated by the techniques of Eberhart & Russell, Lin & Binn modified by Carneiro, and AMMI. The techniques were compared using Spearman's correlation. No correlation was observed between Eberhart & Russell and Lin & Binns modified. AMMI is the most complete for isolated use. The pre-cultivars CNFC 15460, CNFC 15462, CNFC 15504 and CNFC 15507 contemplate wide adaptability, stability and productivity, and are indicated for Agreste-Sertão of Pernambuco.

Key words: complex interaction; cultivar indication; parameters; prediction; selection

Adaptabilidade e estabilidade de pré-cultivares de feijão carioca no Agreste-Sertão Pernambucano

RESUMO: As estimativas de adaptabilidade e estabilidade são utilizadas em programas de melhoramento de plantas para identificar cultivares que expressam comportamento previsível e ótimo desempenho em mais de um ambiente. Assim, o objetivo deste trabalho foi comparar técnicas biométricas para seleção simultânea de pré-cultivares de feijão carioca para alta adaptabilidade, estabilidade e produtividade de grãos nas condições do Agreste-Sertão Pernambucano do Brasil. Os ensaios foram realizados nos municípios de Arcoverde, São João e Belém de São Francisco. Foram utilizados dez pré-cultivares e quatro testemunhas comerciais e o delineamento em blocos casualizados com três repetições. A produtividade de grãos foi avaliada no período 2014-2015. As análises de variância foram realizadas e a adaptabilidade e estabilidade foram estimadas pelas técnicas de Eberhart & Russell, Lin & Binn modificado por Carneiro, e AMMI. As técnicas foram comparadas por meio da correlação de Spearman. Nenhuma correlação foi observada entre Eberhart & Russell e Lin & Binns. AMMI é o mais completo para uso isolado. As pré-cultivares CNFC 15460, CNFC 15462, CNFC 15504 e CNFC 15507 contemplam ampla adaptabilidade, estabilidade e produtividade, sendo indicadas para o Agreste-Sertão de Pernambuco.

Palavras-chave: interação complexa; recomendação de cultivar; parâmetros; predição; seleção

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Introduction

The common bean (*Phaseolus vulgaris*) is a species of great socioeconomic value, mainly due to the combination of four characteristics: nutritional quality, high production potential, high genetic variability and wide adaptability (Lima et al., 2020). In Brazil, the preference in almost all states refers to beans from the carioca group, representing 85% of consumption in the country (Conab, 2021), having a very important role in subsistence agriculture, but also standing out in the national business aspect.

Common bean production has increased by about 35% over the past 40 years, parallel to a 30% reduction in planted area, mainly in response to the use of new cultivars, obtained through breeding programs with a focus on increasing crop productivity (Embrapa, 2017).

In the Agreste-Sertão region of Pernambuco, common bean cultivation is carried out in several areas, including contrasting edaphoclimatic conditions, which directly influence grain productivity (Rocha et al., 2020). It is worth noting that in the pre-cultivar evaluation process, one of the main challenges that breeders face refers to the interaction between genotypes and environments on the behavior of materials. The genotype × environment interaction (G × E) is explained as the differential behavior of genotypes as a function of variations in the environments in which they are selected (Ramalho et al., 2012).

After the interaction is estimated, a pertinent alternative is the use of biometric techniques to discriminate the adaptability and stability of genotypes (Tavares et al., 2017). Adaptability is the ability of genotypes to take advantage of environmental changes and stability refers to the predictability of genotype behavior in the face of environmental variations (Santos et al., 2018).

In the bean culture, the most used biometric techniques are: Eberhart & Russell (1966) that show adaptability and stability from different parameters, facilitating the independent observation of these two attributes; AMMI (Zobel et al., 1988), which stands out for the treatment of the waste, reducing the experimental error from the separation of the noises and the results shown graphically; and Lin & Binns (1988) modified by Carneiro (1998); standing out for its ease of understanding, since it use a single parameter in the classification of materials. However, each technique has its particularity and there are still few studies on the complementarities and divergences of these techniques in the selection of more productive genotypes, adapted and stable, and when it comes to Agreste-Sertão region of Pernambuco, this work is a pion in the approach of combining these biometric analyzes.

In this work, the objective was to compare biometric techniques to establish strategies for simultaneous selection of carioca bean pre-cultivars for high adaptability, stability and grain productivity in the conditions of Agreste-Sertão Pernambucano.

Materials and Methods

The experimental data used, relative to grain productivity (kg ha^{-1}), were obtained from the Network of Tests for the Evaluation of Genotypes of Carioca Beans, coordinated by Embrapa Rice and Beans, Agronomic Institute of Pernambuco (IPA) and Federal Rural University of Pernambuco (UFRPE), and they come from competition trials of common bean pre-cultivars, type carioca, conducted in the State of Pernambuco, from 2014 to 2015. These data came from six experimental trials, these being carried out in three municipalities in the Agreste-Sertão of Pernambuco (Table 1).

The number of genotypes between the trials was 14, including strains and cultivars, provided by the National Center for Carioca Beans (CNFC) (Table 2). In the experiments, four witnesses were used, cultivars that are recommended for cultivation in the state of Pernambuco.

The experimental design used was completely randomized blocks, using three replications, with experimental portions composed of four rows, with 4 m in length and 0.5 × 0.2 m of spacing between and within rows, respectively. The useful area took into account only the two central lines.

The soil was prepared in a conventional way and chemical fertilization was carried out before the implementation of the experiments, using 200 kg ha^{-1} of chemical fertilizer 04-20-20. The control of invasive plants consisted of manual weeding and the pest was carried out through the application of the insecticide Metamidofós Fersol (600 in the dose 0.5 L sha^{-1}). Irrigation was performed when necessary, using a conventional sprinkler system. The harvest was carried out 90 days after sowing, in the R9 phase, and the grain yield was recorded in each experiment.

Statistical analyzes were performed considering each location-year combination as an environment. The homogeneity of the residual variance was verified using of the ratio between the largest and smallest mean square of the residue (Pimentel-Gomes, 2009). Joint analyzes were performed according to the model for random blocks:

Table 1. Characteristics of the municipalities of Pernambuco, where the genotypes of carioca beans were evaluated in the years 2014 and 2015.

Municipalities	Topography	Climate	Alt (m)	Soil type	Year 2014		Year 2015	
					Prec (mm)	Temp (°C)	Prec (mm)	Temp (°C)
Arcoverde	Wavy	BSh	689	Lithosol	666.5	24.3	356.2	25.2
Belém de São Francisco	Smooth-wavy	BSh	339	Plain Soil	464.9	25.6	272.4	26.2
São João	Wavy	As	687	Regosol	844.5	21.2	526.5	22.0

As - Tropical; BSh - Semiarid (Agritempo, 2021); Alt - Altitude; Prec - Precipitation; Temp - Temperature.

Table 2. Carioca bean genotypes evaluated in competition trials between 2014 and 2015, treatment identification number (IG).

IG	Genotype	Type	IG	Genotype	Type
1	IPR 139	Cultivar	8	CNFC15504	Inbred line
2	CNFC15458	Inbred line	9	CNFC15507	Inbred line
3	CNFC15460	Inbred line	10	CNFC15513	Inbred line
4	CNFC15462	Inbred line	11	CNFC15534	Inbred line
5	CNFC15475	Inbred line	12	BRS Estilo	Cultivar
6	CNFC15480	Inbred line	13	BRS Notável	Cultivar
7	CNFC15497	Inbred line	14	BRS Pérola	Cultivar

$$Y_{ijk} = \mu + \left(\frac{B}{E}\right)_{jk} + G_i + E_j + GE_{ij} + \varepsilon_{ijk}$$

where, Y_{ijk} - phenotype value of genotype i in environment j; μ - general mean; $(B/E)_{jk}$ - effects blocks (k = 1, 2, ..., r) inside environments (j = 1, 2, ..., q); G_i - effect of genotypes (i = 1, 2, ..., p); E_j - environments effects (j = 1, 2, ..., q); GE_{ij} - effect of genotypes × environments interaction; ε_{ijk} - random error (Cruz et al., 2012).

Disposing of the analysis of variance and the presence of GxE interaction, the parameters of adaptability and stability of the genotypes were estimated, using the biometric techniques of Eberhart & Russell (1966), Lin & Binns (1988) modified by Carneiro (1998), and by the AMMI (Zobel et al., 1988) method.

Eberhart & Russell (1966) method is based on linear regression analyses simple, according to the following mathematical model:

$$Y_{ij} = \beta 0_i + \beta 1_i I_j + \delta_{ij} + \varepsilon_{ijk}$$

where, Y_{ij} - average of the i-th genotype in the j-th environment; $\beta 0_i$ - general mean of the i-th genotype; $\beta 1_i$ - coefficient of linear regression which measures the response of i-th genotype to the variation on the environment; I_j - encoded environment index

$$\sum_{j}^{i} I_j = 0,$$

and

$$I_j = \overline{y}_j - \overline{y}_n;$$

δ_{ij} - regression deviation of the i-th genotype in the j-th environment; ε_{ijk} - experimental error (Cruz et al., 2012).

The adaptability and stability parameter proposed by the Lin & Binns (1988) method is estimated by measuring of Pi superiority using the following equation:

$$Pi = \sum_{j=1}^{n} \frac{\left(Y_{ij} - M_j\right)}{2n}$$

where, Y_{ij} - yield of the i-th genotype in the j-th environment; M_j - maximum response obtained among all genotypes in the j-th environment; n - number of environments (Cruz et al., 2012).

Analyses by the AMMI method (Zobel et al., 1988) considers the effects of genotypes and environments as fixed and the model according to the model:

$$Y_{ij} = \mu + G_i + E_j + \sum_{k=1}^{n} \lambda_k Y_{ik} \alpha_{jk} + \rho_{ij} + \varepsilon_{ijk}$$

where, Y_{ij} - phenotypic value of genotype i in environment j; μ - general mean of the trials; G_i - effect of genotypes (i = 1, 2, ..., p); E_j - environments effects (j = 1, 2, ..., q); λ_k - the k-th singular (scalar) value of the original interaction matrix (G × E); Y_{ik} - the element corresponding to the i-th genotype in the k-th vector single column of the matrix G × E; α_{jk} - corresponding to the j-th environment in the k-th vector single line of the G × E matrix; ρ_{ij} - the noise associated with the term $(ge)_{ij}$ of the classical interaction G × E; ε_{ijk} - random error (Cruz et al., 2012).

The environments were classified according to the environmental index, as of the subtraction of the average grain productivity from the environment by the average grain productivity, classifying as favorable those with a positive index and unfavorable those with a negative index. The techniques were compared using Spearman's correlation. The analyzes were performed with the aid of the computer software GENES (Cruz, 2016).

Results and Discussion

In the summaries of the joint analysis of variance of the trials, significant differences were observed by the F test ($P < 0.01$) between the sources of variation corresponding to genotypes, environments and G × E interaction, indicating genetic variability between genotypes, heterogeneity in the environmental conditions in which the experiments were conducted and that the genotypes present different responses to different environments (Table 3). The G × E interaction interferes in the stage of genotype selection and subsequent indication of cultivars, since the observed phenotype may not be befitting with the real potential of the genotype, requiring the choice of more adapted and stable genotypes in order to take advantage of information on the interaction, justifying the application of statistical analyzes of adaptability and stability (Souza et al., 2018).

The F Max, equivalent to the ratio between the largest and smallest mean square of the residue, was less than 7, validating the assumption of homogeneity of the residual variances and

Table 3. Summary of the joint variance analyzes of the carioca bean competition trials, evaluated in the state of Pernambuco, from 2014 to 2015.

Sources of variation	GL	Mean squares
Blocks/Environments	12	81,924.65
Environments	5	15,096,199.01**
Genotypes	13	1,118,781.75**
G × E	65	500,612.02**
Residual	156	58,810.04
Mean (kg ha^{-1})		2,203.62
CV (%)		11.00
F Maximum		6.10

** Significant at 1% probability by the F test.

enabling the joint analysis of the experiments (Pimentel-Gomes, 2009). The coefficient of variation (CV) was 11.00 %, indicating good experimental precision, being in accordance with other experiments carried out with common beans, as observed by Rocha et al. (2020), who recorded CV of 8.37 % in genotypes of carioca bean group in Pernambuco State (Table 3).

The municipalities of Belém de São Francisco and Arcoverde, presented average productivity above the general average productivity of the environments, being classified as favorable (Table 4). In contrast, São João presented average productivity below the general average productivity of the environments, being classified as unfavorable (Table 4).

In all environments, the evaluated genotypes showed average productivity above the state average (748 kg ha^{-1}), regional (412 kg ha^{-1}) and national (984 kg ha^{-1}) (CONAB, 2021; IBGE, 2021). It's worth pointing out that, the heterogeneity of the municipalities of Agreste-Sertão of Pernambuco provided a high contrast in productivity, incurring in the classification of some environments as unfavorable from the calculation of the environmental index. Similar results were found by Souza et al. (2018); Santos et al. (2018); Santos et al. (2019), and Lima et al. (2020), confirming that heterogeneity alters the classification of environments.

Average grain productivity for the 2014-2015 biennium ranged from 1,875 to 2,632 kg ha^{-1}, with an overall average of 2,203 kg ha^{-1}. In the total of fourteen evaluated genotypes, it was observed that seven obtained angular coefficient estimates equivalent to unit (β1 = 1) and seven presented different unit estimates (β1 ≠ 1), according to the t test, showing the existence of some genotypes with wide adaptability and others with specific adaptability, respectively (Table 5).

Genotypes with specific adaptability have a complex interaction under the conditions of Agreste and Sertão in Pernambuco, since the position of the genotypes it is not maintained throughout the environments and those with higher productivity in one environment are not necessarily in the others. Similar results were observed by Oliveira et al. (2020), who observed the performance of complex interaction

Table 4. General means and environmental indices referring to grain yield, in kg ha^{-1}, of carioca bean genotypes, evaluated in the state of Pernambuco from 2014 to 2015.

Environments	Harvest	Mean	Environmental index	Classification
Arcoverde	2014	2,265.2	61.56	Favorable
Arcoverde	2015	2,237.7	34.12	Favorable
Belém de São Francisco	2014	2,278.2	74.59	Favorable
Belém de São Francisco	2015	3,220.2	1,016.62	Favorable
São João	2014	1,454.0	-749.63	Unfavorable
São João	2015	1,766.4	-437.25	Unfavorable

Table 5. Estimates of the parameters of adaptability and phenotypic stability, obtained by the biometric technique of Eberhart & Russell (1966), and the Lin & Binns modified by Carneiro (1998) for the carioca bean competition trials in the period 2014-2015, evaluated at Agreste-Sertão of Pernambuco.

Ebehart & Russell					Lin & Binns			
IG	β0	β1	s^2d/1000	r^2 (%)	IG	Pi	PiF	PiU
1	2224.03	0.815^{ns}	625.15**	31.6	1	57662	80795	11395
2	2350.00	1.035^{ns}	197.44**	68.9	2	31664	39322	16348
3	2260.55	1.153^{ns}	-8.67^{ns}	98.2	3	30361	37088	16907
4	2219.58	0.773*	249.94**	49.9	4	48949	65575	15697
5	2029.30	0.710**	55.29**	75.1	5	59275	81061	15706
6	2586.25	1.468**	218.69**	80.2	6	20052	29104	1948
7	1818.47	0.887^{ns}	111.54**	72.9	7	82885	111718	25217
8	2117.92	0.982^{ns}	0.33^{ns}	95.6	8	44192	57443	17689
9	1907.08	0.783*	21.75^{ns}	86.9	9	70726	96732	18714
10	1875.69	0.292**	83.80**	27.0	10	87670	125468	12076
11	2125.00	1.497**	73.20**	91.5	11	43652	40162	50632
12	2632.36	1.650**	-9.05^{ns}	99.1	12	8902	7397	11914
13	2453.61	0.991^{ns}	48.10**	86.7	13	20917	28133	6486
14	2250.83	0.965^{ns}	30.05*	89.4	14	35780	48509	10322

IG - genotype identification; β0 - general mean of genotype; β1 - linear regression coefficient; s^2d/1000 - stability parameter; r^2 - determination coefficient; Pi - Pi parameter for general environment; PiF - Pi parameter for favorable environments; PiU - Pi parameter for unfavorable environments; ns, * and **: not significant, significant at the level of 5 and 1% respectively, by the t test (H0: β1 = 1.0) and by the F test (H0: s^2d = 0).

in their research about the bean genotype selection in the Agreste-Sertão region of Pernambuco.

The genotypes CNFC 15458 (2), CNFC 15460 (3) and the cultivars IPR 139 (1), BRS Notável (13) and BRS Pérola (14), stood out for presenting $\beta1 = 1$ and $\beta0$ > general average, indicating that they have the capacity to present good results in contrasting environmental conditions of Agreste-Sertão Pernambucano, keeping their productivity around the general average (Table 5).

Regarding the materials that presented $\beta1 \neq 1$, the inbred lines CNFC 15462 (4), CNFC 15475 (5), CNFC 15507 (9) and CNFC 15513 (10), obtained values of $\beta1 < 1$, indicating that they have specific adaptation to unfavorable environments, that is, they have the capacity to maintain productivity close to the general average in environments where conditions are not ideal for cultivation. The inbred lines CNFC 15480 (6), CNFC 15534 (11) and the cultivar BRS Estilo (12), presented values of $\beta1>1$, pointing out that these genotypes have specific adaptation for favorable environments, therefore, they have the capacity to take advantage of the improvements offered by environments with good cultivation conditions (edaphoclimatic or inherent to agricultural management techniques), responsive and with productivity that surpass the general average (Table 5).

As for the behavior predictability, the cultivars BRS Estilo (12) and the inbred lines CNFC 15460 (3), CNFC 15504 (8), and CNFC 15507 (9), obtained non-significant deviations from the regression by the F test ($s^2d = 0$), demonstrating stability and indicating that the average productivity of these genotypes is constant over the years and municipalities in the Agreste-Sertão of Pernambuco (Table 5).

It is worth mentioning that, in some situations, it is possible that many of the genotypes that were evaluated and stood out with productivity above the general average, could present regression deviations statistically different from zero and in these cases the determination coefficient (r^2) can be used as an auxiliary measure for comparing the stability of genotypes, where r^2 greater than 80% indicates low dispersion of experimental data and show high predictability in the type of environmental response (Peluzio et al., 2010). Considering the genotypes that presented r^2 > 80%, it was possible to classify three more materials as stable, corresponding to the inbred lines CNFC 15534 (11) and the cultivars BRS Notável (13) and BRS Pérola (14).

The Pi values obtained from the Lin & Binns technique for all environments, as well as the unfolding according to the proposal of Carneiro (1998), for favorable and unfavorable environments, are shown in Table 5. The genotypes with the lowest general Pi values were the cultivars BRS Estilo (12) and BRS Notável (14), and the inbred lines CNFC 15458 (2), CNFC 15460 (3), and CNFC 15480 (6), and it indicates that they are among the most productive and have responsiveness and stability.

It was found that the genotypes BRS Estilo (12), CNFC 15480 (6) and BRS Notável (13), were classified among the five lowest Pi values, both when considering environments in general, and in favorable and unfavorable, indicating that they have wide adaptability and high stability to Agreste-Sertão of Pernambuco, in addition to having the first (2,632.36 kg ha^{-1}), second (2,586.25 kg ha^{-1}) and third (2,453.61 kg ha^{-1}) higher productivity averages, respectively (Table 5). In the method of Eberhart & Russell, these genotypes were also classified as widely adapted, however, the inbred line CNFC 15480 (6), did not have its behavior considered as stable. Franceschi et al. (2010) point out Lin & Binns method as practical and simple to understand, however, they emphasize that the genotypes selected through this method do not always relate high stability to greater productivity.

Despite the inbred lines CNFC 15458 (2) and CNFC 15460 (3), have been classified with wide adaptation, their lower Pi values in the decomposition of environments, demonstrate that they have preferential adaptation to favorable environments. In contrast, the cultivars IPR 139 (1) and BRS Pérola (14), presented well-defined behaviors, evidenced by lower Pi values for unfavorable environments when compared with favorable or general environments, pointing out that they have specific adaptation to unfavorable conditions (Table 5).

The occurrence of inbred lines that presented similar Pi values for the general environment, favorable and unfavorable environments, parallel to the identification of inbred lines with specific values, with well-defined behavior for just one type of environment, were also noticed by Oliveira et al. (2006), when using Lin & Binns technique in their research on adaptability and stability of common bean inbred lines in Minas Gerais.

From the AMMI technique, it is possible to observe that the São João in 2015 environment and the inbred lines CNFC 15460 (3), CNFC 15462 (4), CNFC 15504 (8) and CNFC 15507 (9), are the points that are closest to the origin and demonstrate in turn, the lowest contributions to the GxE interaction (Figure 1B).

There is a positive interaction between inbred lines CNFC 15504 (8), CNFC 15507 (9) and CNFC 15513 (10) with São João in 2014, Arcoverde in 2015 and São João in 2015 environments (Figure 1B), demonstrated by scores of the same sign and small angle between the vectors from the origin.

In the graphical representation of the AMMI1 analysis (Figure 1A), the data are distributed according to Cartesian coordinates, where the abscissa axis represents the main effects, referring to the average of genotypes and environments and the ordinate axis refers to the scores of genotypes and environments for the interaction axis, in this way, the genotypes and environments that approach to the origin are considered stable (Ferreira & Hongyu, 2018).

Grain productivity in relation to the general average, both for environments and for genotypes, can be easily noticed in Figure 1A, through the vertical reference line. The inbred lines CNFC 15458 (2), CNFC 15460 (3), CNFC 15462 (4), CNFC 15480 (6) and in the IPR 139 (1), BRS Estilo (12), BRS Notável (13) and BRS Pérola (14), presented averages above the general average (> 2,203.62 kg ha^{-1}), and the other genotypes showed productivity below the general average. Regarding the average of the environments, those that were below and above the

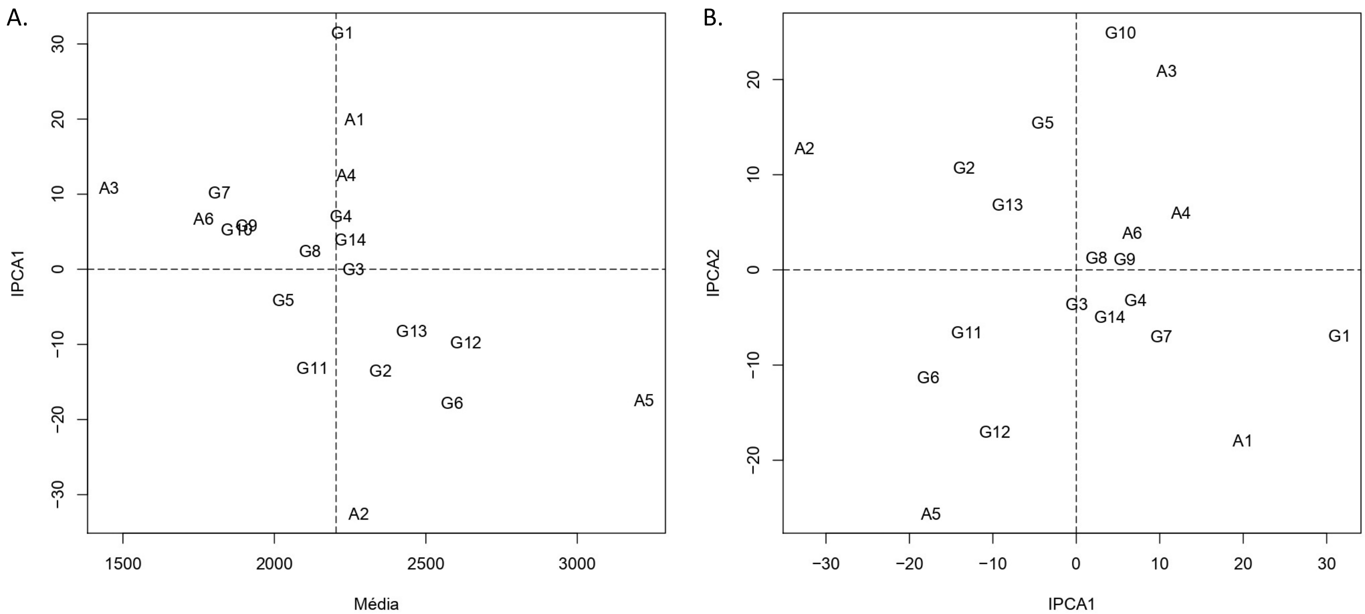

Figure 1. Analysis biplot: (A) AMMI1 and (B) AMMI2, for grain productivity of 14 carioca bean genotypes evaluated in the 2014-2015 biennium, in Agreste-Sertão of Pernambuco. G1 - IPR 139; G2 - CNFC 15458; G3 - CNFC 15460; G4 - CNFC 15462; G5 - CNFC 15475; G6 - CNFC 15480; G7 - CNFC 15497; G8 - CNFC 15504; G9 - CNFC 15507; G10 - CNFC 15513; G11 - CNFC 15534; G12 - BRS Estilo; G13 - BRS Notável; G14 - BRS Pérola; A1 - Arcoverde-2014; A2 - Belém de São Francisco-2014; A3 - São João-2014; A4 - Arcoverde-2015; A5 - Belém de São Francisco-2015; A6 - São João-2015.

general average coincide with those already classified in Table 4 as unfavorable and favorable, respectively, since the environmental index also separates the environments according to the general average.

Regarding stability, the inbred lines CNFC 15460 (3), CNFC 15415 (5), CNFC 15504 (8) and the cultivar BRS Pérola (14), were the closest to zero in relation to the horizontal axis (IPCA1), indicating that they are associated with high stability, being in consonance with what was observed in the Eberhart & Russell method, with the exception of inbred line CNFC 15475 (5), which was not indicated as stable (Figure 1A).

The environments Arcoverde in 2014, Belém de São Francisco in 2014 and Belém de São Francisco in 2015 were the most unstable, but all associated with high grain productivity. The inbred lines CNFC 15458 (2) and CNFC 15480 (6), and the cultivars BRS Notável (13) and BRS Estilo (12), were the most productive (> 2,203.62 kg.ha^{-1}), however, due to their high deviation, they show instability. The cultivar BRS Pérola (14) and inbred line CNFC 15460 (3), produced slightly above average and showed high stability (Figure 1A). In studies carried out with common beans, such as by Melo et al. (2018) and Rocha et al. (2020), the results found were similar when using AMMI.

The similarities and differences between the methods used can be seen more precisely from the Spearman coefficients shown in Table 6. The high significant and negative correlation between the average grain productivity and the Pi parameters (-0.9516) and PiF (-0.9341), means that the higher the productivity values, the lower the Pi values for general and favorable environments, as predicted by the technique.

It was observed agreement between the methods of Eberhart & Russell, Lin & Binns and AMMI in the classification of genotypes with wide and specific adaptability, through the high and negative correlation between β1 and the parameters Pi (-0.8461), PiF (-0.8593), and IPCA1 (-0.7099) since higher β1 values indicate wide (β1 = 1) or specific (β1 > 1) adaptability to favorable environments, while in the Lin & Binns and AMMI techniques the lowest values are associated with adapted genotypes (Table 6).

Regarding the classification of genotypes according to stability, there was a discrepancy between the Eberhart & Russell method and the Lin & Binns method, since the correlation between s^2d and the parameters Pi (0.2923) and PiF (0.3055) shows that lower values of s^2d are associated with higher values of Pi and PiF. Considering that the stability condition is associated with $s^2d = 0$, the inverse proportion between the parameters indicates a lack of coincidence between them, evidencing the disagreement between the methods and reinforcing that the most productive genotypes are not always the most stable. The same type of disagreement was found between these methods in relation to parameter r^2 (Table 6).

Significant interaction was not observed between parameters IPCA1 with s^2d (0.2000) and r^2 (-0.4066), indicating that they are independent, so that they allow admitting agreement between the Eberhart & Russell and AMMI methods regarding the stability of the materials (Table 6). In the classification of genotypes from unfavorable environments, almost all parameters showed no correlation between the methods, indicating that for these environments the use of any of the four methods alone would be efficient.

There was a significant positive correlation between IPCA1 and the parameters Pi (0.7275) and PiF (0.7363), indicating that these methods have a coincidence in the classification

Table 6. Spearman correlation coefficients between the general average grain productivity (kg ha^{-1}) of carioca bean genotypes and the adaptability and stability parameters of Eberhart & Russell (1966), Lin & Binns (1988) modified by Carneiro (1998), and AMMI (Zobel et al., 1988), in competition trials conducted in the period 2014-2015, in Agreste-Sertão of Pernambuco.

	Eberhart & Russell			Lin & Binns			AMMI
	β1	s^2d	r^2	Pi	PiF	PiD	IPCA1
Mean	0.7143**	-0.1121^{ns}	0.3538^{ns}	-0.9516**	-0.9341**	-06220*	-0.6220*
β1		-0.3187^{ns}	0.6721**	-0.8461**	-0.8593**	-0.3297^{ns}	-0.7099**
s^2d			0.8505**	0.2923^{ns}	0.3055^{ns}	0.1956^{ns}	0.2000^{ns}
r^2				-0.3136*	-0.3524*	0.1912^{ns}	-0.4066^{ns}
Pi					0.9912**	0.4505^{ns}	0.7275**
PiF						0.3978^{ns}	0.7363**
PiU							01648^{ns}

β1 - slope; s^2d - variance of the regression deviations; r^2 - coefficient of determination; Pi - General Pi values, PiF - Pi for favorable environments; PiU - Pi for unfavorable environments; IPCA1 - value of the main interaction component.

of genotypes, corroborating with what was observed by Domingues et al. (2013), in his research on adaptability analysis and stability for the identification of promising bean inbred lines for cultivation in Rio Grande do Sul, which reported a correlation between Lin & Binns and AMMI methods (Table 6).

The results obtained from Spearman's correlation corroborate with what was reported by Pereira et al. (2009), Franceschi et al. (2010) and other authors who showed no correlation between the Lin & Binns and the Eberhart & Russell methods, but disagree about the correlation between the Lin & Binns method with the AMMI method.

It is worth mentioning that, the different information offered by these methods justifies the combination of them for the identification of materials in terms of adaptability and stability, entailing to greater reliability in recommending the best genotypes for certain environments (Franceschi et al., 2010).

The classification of genotypes by the method of Lin & Binns, aimed at those who showed higher productivity and the conformity of the classification by the AMMI and Eberhart & Russell methods, focusing on the most stable genotypes, reveals the harmony and potential for using the combination of these methods, allowing a more complete view, which allows to more efficiently attend the selection of materials that contemplate high productivity, adaptability and stability.

Conclusions

The biometric techniques of Lin & Binns prioritize high productivity, while, Eberhart & Russell and AMMI are more judicious and efficient in discriminating carioca bean pre-cultivars for adaptability and stability to the Agreste-Sertão of Pernambuco.

The joint use of the Lin & Binns technique with the Eberhart & Russell technique is indicated, since they present complementary information, high productivity associated with adaptability and stability.

The biometric techniques AMMI is the most complete for isolated use, simultaneously associating genotypes with the attributes of high grain productivity, responsiveness and predictability to the environments of the Agreste-Sertão of Pernambuco.

The pre-cultivars CNFC 15460, CNFC 15462, CNFC 15504 and CNFC 15507 contemplated wide adaptability, stability and productivity, according to the AMMI technique, and may be indicated for Agreste-Sertão de Pernambuco.

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Compliance with Ethical Standards

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