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# Indication of cowpea cultivars for the production of dry grain in the state of Ceará[1]

## Indicação de cultivares de feijão-caupi para produção de grãos secos no estado do Ceará

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**ABSTRACT** – The aim of this work was to evaluate the interaction between genotypes and environments, as well as to indicate, for the state of Ceará, superior cowpea cultivars in terms of adaptability, stability and productivity of dry grains. The experiments were conducted in four different municipalities in the state of Ceará: Crateús, Madalena, Bela Cruz and Limoeiro do Norte; two tests carried out in Crateús (irrigated and rainfed), totaling five assessment environments. The experimental design used in each assay was randomized blocks with 12 genotypes and four replications. Analysis of variance and path analysis were performed, and the averages of the quantitative characters were grouped by the Scott-Knott test. After detecting the significance of the genotype x environment interaction, the adaptability and phenotypic stability of the genotypes were analyzed using the GGE biplot methodology. The municipality of Crateús, in the irrigated system, was discriminative and representative, and can be considered ideal for genotype evaluation. The cultivars BRS Pajeú and BRS Potengi can be recommended for cultivation in the state of Ceará due to their high productivity of dry grains, adaptability and stability, and for having excelled in most of the production components. The number of pods per plant had the greatest direct effect on grain yield.

**Key words**: *Vigna unguiculata*. Plant breeding. Genotypes x environments interaction. GGE biplot. Path analysis.

**RESUMO –** Objetivou-se com este trabalho, avaliar a interação entre genótipos e ambientes, bem como indicar, para o estado do Ceará, cultivares de feijão-caupi superiores quanto à adaptabilidade, estabilidade e produtividade de grãos secos. Os experimentos foram conduzidos em quatro diferentes municípios do estado do Ceará: Crateús, Madalena, Bela Cruz e Limoeiro do Norte; sendo dois ensaios realizados em Crateús (irrigado e sequeiro), totalizando cinco ambientes de avaliação. O delineamento experimental utilizado em cada ensaio foi o de blocos casualizados com 12 genótipos e quatro repetições. Foram realizadas análises de variância e análise de trilha, e as médias dos caracteres quantitativos foram agrupadas pelo teste de Scott-Knott. Depois de detectar a significância da interação genótipos x ambientes, a adaptabilidade e a estabilidade fenotípica dos genótipos foram analisadas pela metodologia GGE biplot. O município de Crateús, no sistema irrigado, foi discriminativo e representativo, podendo ser considerado ideal para avaliação de genótipos. As cultivares BRS Pajeú e BRS Potengi podem ser recomendadas para o cultivo no estado do Ceará por apresentarem alta produtividade de grãos secos, adaptabilidade e estabilidade, e por terem se destacado quanto à maioria dos componentes de produção. O número de vagens por planta apresentou o maior efeito direto sobre a produtividade de grãos.

**Palavras-chave**: *Vigna unguiculata*. Melhoramento vegetal. Interação genótipos x ambientes. GGE biplot. Análise de trilha.

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## INTRODUCTION

The cowpea [*Vigna unguiculata* (L.) Walp.] is one of the most relevant and strategic food sources for tropical and subtropical regions of the world (FREIRE FILHO, 2011). In Brazil, the production of cowpea is concentrated in the North and Northeast regions, the latter being responsible for 64% of the total production in the 2019 harvest, with emphasis on the state of Ceará, with the largest planted area (359.5 thousand ha); however, presenting the second lowest productivity (305 kg ha$^{-1}$) (COMPANHIA NACIONAL DE ABASTECIMENTO, 2020). The main factors that contribute to the low productivity of the crop in Ceará are: the use of low technological level, rainfall irregularity and the use of cultivars poorly adapted to the cultivation conditions (FREIRE FILHO, 2011).

In the state of Ceará, cowpea is cultivated in environments whose soil and climate factors vary considerably. As the state seed production and distribution service is not structured to meet specific regional demands, cultivars recommended for other states are commonly distributed (CEARÁ, 2019), resulting in production below expectations. In this sense, the cowpea improvement programs must direct their efforts towards the launch of productive cultivars that are well adapted to the specific conditions of each state and/or cultivation region. However, decision making for the launch of new cultivars is hampered by the occurrence of interaction between genotypes and environments. Nevertheless, the decision making for the launching of new cultivars is hindered by the occurrence of interaction between genotypes and environments. (ABREU *et al*., 2019).

The interaction genotypes x environments (G x E) consists in the inconstant response of genotypes to environmental variations, contributing to reduce the correlation between phenotype and genotype. This low correlation indicates that the superior genotype in one environment will not have the same performance in another environment (GAUCH JUNIOR, 2013). However, the simple analysis of the G x E interaction does not provide complete information about the behavior of each genotype under various environmental conditions. In this context, it is essential to know the adaptability and stability of the genotypes, in order to make better use of the G x E interaction and increase the efficiency of the recommendation of cultivars (CRUZ; REGAZZI; CARNEIRO, 2014).

Among the most commonly used methodologies for estimating adaptability and stability parameters, the additive main effects and multiplicative interaction (AMMI) model and the GGE biplot analysis stand out. The main difference between these methods lies in the first step of the analysis: the AMMI model separates the effect of genotypes (G) from the G x E interaction, while the GGE model directly analyzes the effects of G + G x E, exploring more efficiently the effect of the interaction (YAN, 2011). Moreover, GGE analysis is more suitable for the identification of mega-environments, selection of representative and discriminative environments, and also for the indication of cultivars more adapted and stable to specific environments (HONGYU *et al*., 2015; SILVA; BENIN, 2012).

In the last stages of breeding programs aiming at the recommendation of superior cultivars, the study of the G x E interaction requires greater investments, since these cultivars must be evaluated in a network of experiments, which must be repeated in several locations, crops and years, the so-called Value for Cultivation and Use (VCU) trials (BRASIL, 2020). In recent years, several authors have evaluated the adaptability and yield stability of cowpea genotypes from VCU trials (ABREU *et al*., 2019; SANTOS *et al*., 2016; SOUSA *et al*., 2018). However, the demand for more productive cowpea cultivars that are well adapted to the specific cultivation conditions of each region is constant.

Therefore, the objectives of this work were: to evaluate the interaction between genotypes and environments and to indicate, for the state of Ceará, superior cultivars regarding stability, adaptability and dry grain yield.

## MATERIAL AND METHODS

The experimental evaluated material consisted of 12 cowpea genotypes (ten cultivars and two lines) from the Active Germplasm Bank of the Genetic Improvement Program of Embrapa Meio-Norte. The main characteristics of the cultivars evaluated are described in Table 1.

Five VCU trials were conducted between the years 2018 and 2020, in four different municipalities in the state of Ceará: Crateús, Madalena, Bela Cruz and Limoeiro do Norte (Figure 1 and Table 2). The experiments were conducted at different times of the year: in the first semester (rainy period), under rainfed conditions, they were conducted in the municipalities of Crateús, Madalena and Limoeiro do Norte (Figure 2); and in the second semester (non rainy period), under irrigated systems, they were conducted in Crateús and Bela Cruz.

In each trial, a randomized complete block design was used with four repetitions, where the genotypes constituted the treatments. Each plot consisted of four 5.0 m long rows, with the two central rows being considered useful. The spacing was 0.50 m between rows and 0.25 m between holes. Three seeds were sown per hole, and thinning was performed 15 days after planting, leaving the two most vigorous plants per

**Table 1** - Cowpea genotypes cultivated in five environments in the state of Ceará, in the period from 2018 to 2020, and their respective growth habits, commercial subclass and mass of 100 grains (M100G)

| Code | Genotypes | Growth habits | Commercial Subclass | M100G (g) |
|---|---|---|---|---|
| G1 | BR 17-Gurguéia(1) | Prostrated | Evergreen | 12.5 |
| G2 | BRS Marataoã(1) | Semi-prostrated | Evergreen | 15.5 |
| G3 | BRS Guariba(1) | Semi-erect | White | 19.5 |
| G4 | BRS Novaera(1) | Semi-erect | White | 20.0 |
| G5 | BRS Xiquexique(1) | Semi-prostrated | White | 16.5 |
| G6 | BRS Tumucumaque(1) | Semi-erect | White | 19.5 |
| G7 | BRS Aracê(1) | Semi-prostrated | Green | 18.0 |
| G8 | BRS Cauamé(1) | Semi-erect | White | 17.0 |
| G9 | BRS Pajeú(1) | Semi-prostrated | Mulatto | 21.0 |
| G10 | BRS Potengi(1) | Semi-erect | White | 21.0 |
| G11 | Pingo-de-Ouro 1-2(2) | Semi-prostrated | Crowder | 19.0 |
| G12 | Inhuma(2) | Semi-prostrated | Crowder | 23.0 |

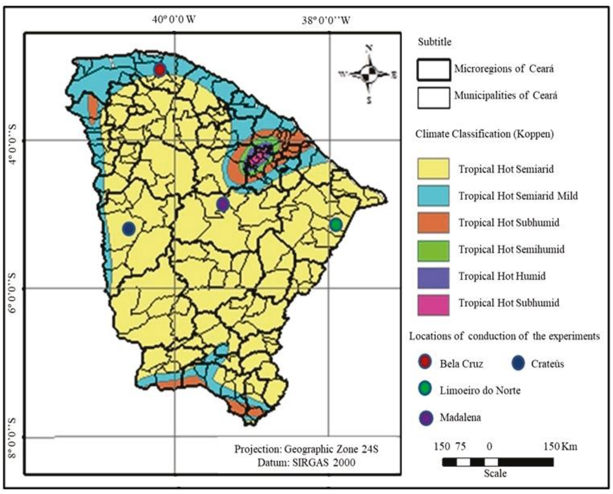
(1) Cultivars, (2) Lines

**Table 2** - List of municipalities in the state of Ceará where the trials were conducted and their respective sowing dates, geographic coordinates and rainfall

| Code | Location | Sowing | Height | Latitude | Longitude | Rainfall* |
|---|---|---|---|---|---|---|
| E1 | Crateús | 09/15/2018 | 275 m | 05°16'04" S | 40°50'01" W | 7.2 mm |
| E2 | Crateús | 03/15/2019 | 275 m | 05°16'04" S | 40°50'01" W | 351.5 mm |
| E3 | Madalena | 02/21/2019 | 302 m | 04°47'43" S | 39°39'24" W | 212.6 mm |
| E4 | Bela Cruz | 07/24/2019 | 9 m | 03°04'16" S | 40°06'14" W | 3.1 mm |
| E5 | Limoeiro | 01/30/2020 | 143 m | 05º06'38" S | 37º06'14" W | 427.6 mm |

* Rainfall accumulated during the test period

**Figure 1** - Climatic classification and geographical distribution of the environments for evaluation of cowpea genotypes in the state of Ceará

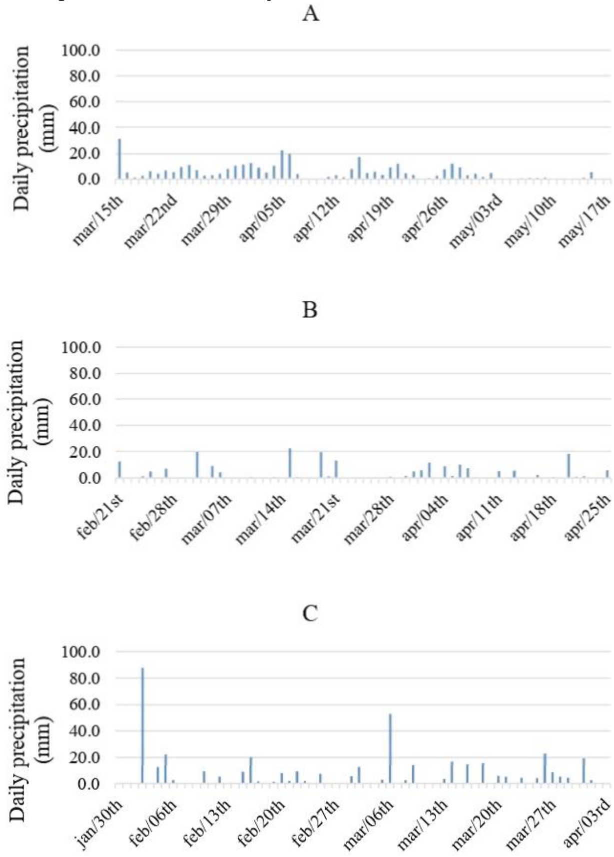



hole. Therefore, after thinning, each experiment had a planting density of 160,000 plants ha$^{-1}$. The control of pests, diseases and weeds was performed according to the need observed in the field.

For the trials conducted in Crateús, in 2018, and Bela Cruz, in 2019, the localized drip and microjet irrigation system was used, respectively. An average irrigation blade of 6.0 mm day$^{-1}$ was applied for both environments, totaling 348 mm cycle$^{-1}$, sufficient to meet the water demand of the crop (NASCIMENTO *et al*., 2011). Irrigation was started after planting and suspended seven days before harvest, which was performed manually when 90% of the pods in the usable area of each plot were dry.

According to the development stages of the plants, the following agronomic characters were visually evaluated in the field, in the useful area of the plot: number of days to flowering (NDF); lodging (LODG); architecture (ARC); and cultivation value (CV).

**Figure 2** - Average daily rainfall of the cities of Crateús (A), Madalena (B) and Limoeiro do Norte (C), during the period of the experiments in rainfed system




Source: Adapted from Fundação Cearense de Meteorologia e Recursos Hídricos – Rainfall Calendar (2020)

After harvesting, the following characters were evaluated: number of pods per plant (NPP): determined by the ratio between the number of pods harvested and the number of plants in the plot; pod length (PL): determined by the average estimated in a sample of five pods randomly collected from the plot; number of grains per pod (NGP): determined by averaging the number of grains from the same sample of five pods used previously; mass of one hundred grains (M100G): determined by weighing one hundred grains from the useful area and then corrected for 13% humidity; grain index (GI): determined by the ratio between the weight of grains from a sample of five pods and the total weight of these pods; and grain yield (GY) determined by weighing the grains harvested from the useful area, with correction for 13% humidity.

Initially, individual analyses of variance were performed for each environment for all characters according to the following statistical model:

$$Y_{ijk} = \mu + \gamma_i + \beta_j + \varepsilon_j \qquad (1)$$

where: $Y_{ij}$ is the observed value of genotype i in block j; $\mu$ is the overall average of the character; $\gamma_i$ is the effect of genotype i; $\beta_j$ is the effect of block j; and $\varepsilon_{ij}$ is the random error associated with treatment i in block j.

After performing the individual analysis of variance, it was proceeded to the joint analysis of variance for the grain yield character, aiming to determine possible interactions between genotypes and environments. The statistical model used followed equation 2:

$$Y_{ijk} = \mu + \gamma_i + \alpha_j + \gamma\alpha_{ij} \qquad (2)$$

where: $Y_{ijk}$ is the observed value of genotype i in environment j and block k; $\mu$ is the overall average of the character; $\gamma_i$ is the effect of genotype i, considered as fixed; $\alpha_j$ is the effect of environment j, considered as random; $\gamma\alpha_{ij}$ is the effect of the interaction of genotype i with environment j, considered as random; and $\varepsilon_{ijk}$ is the experimental error associated with plot ijk.

The average of the different treatments were grouped using the Scott-Knott test at 5% probability level. The accuracy was estimated as A = (1-1/F)1/2, where F corresponds to the F test value for genotypes (RESENDE; DUARTE, 2007).

Aiming to quantify the effects of the interaction between genotypes and environments for subsequent recommendation of cultivars more adapted and stable as to grain yield, multivariate analysis was performed via GGE biplot. This methodology does not separate the effect of genotypes from the effect of the G x E interaction, keeping them together in two multiplicative terms, represented in the following equation:

$$Y_{ij} - \mu - \beta_j = \gamma_{i1}\alpha_{j1} + \gamma_{i2}\alpha_{j2} + \varepsilon_{ij} \qquad (3)$$

where: $Y_{ij}$ is the average yield of genotype i in environment j; $\mu$ is the overall average of the observations; $\beta_j$ is the main effect of environment j; $\gamma_{i1}$ and $\alpha_{j1}$ are the main scores of the i-th genotype in the j-th environment, respectively; $\gamma_{i2}$ and $\alpha_{j2}$ are the secondary scores for genotype i and environment j, respectively; and $\varepsilon_{ij}$ is the residue not explained by both effects, called noise.

Accordingly, the construction of the GGE biplot model was performed by scattering $\gamma_{i1}$ and $\gamma_{i2}$ for genotypes and $\alpha_{j1}$ and $\alpha_{j2}$ for environments, through the decomposition into singular values of the G x E interaction matrix, according to equation 4:

$$Y_{ij} - \mu - \beta_j = \lambda_1\xi_{i1}\eta_{j1} + \lambda_2\xi_{i2}\eta_{j2} + \varepsilon_{ij} \qquad (4)$$

where: $\lambda_1$ and $\lambda_2$ are the largest eigenvalues of the first and second principal components, PC1 and PC2, respectively; $\xi_{i1}$ and $\xi_{i2}$ are the eigenvalues of the i-th genotype for PC1 and PC2, respectively; $\eta_{j1}$ and $\eta_{j2}$ are the values of the j-th environment for PC1 and PC2, respectively.

In order to evaluate the suitability of a biplot to display the patterns of a double-entry table, the information ratio (IR) was estimated. IR can be calculated for each principal component (PC) using the proportion of the total variance explained by each PC multiplied by *k*. If there is no correlation between the environments, all *k* PCs must be completely independent and the proportion of total variance explained by each PC must be precisely 1/*k* (YAN; TINKER, 2006).

Aiming to estimate the direct and indirect effects of the primary variables on grain yields, it was carried out a trail analysis according to the methodology proposed by Li (1975), according to equation 5:

$$r_{ix} = P_{ix} + \sum r_{ij} P_{jx} \quad (5)$$

where: $r_{ix}$ is the correlation between grain yield and the i-th explanatory variable; $P_{ix}$ is the direct effect of variable i on grain yield; and $r_{ij}P_{jx}$ is the indirect effect of variable i on grain yield, via variable j.

The statistical analyses described were performed using the GENES program (CRUZ, 2013). The behavior of each genotype in each environment was represented graphically by GGE biplot analyses using the GGEBiplotGUI package (FRUTOS; GALINDO; LEIVA, 2014), implemented in the R software (R CORE TEAM, 2020). In order to construct the biplot charts, the 12 genotypes were labeled as G1 to G12 and the five environments as E1 to E5.

## RESULTS AND DISCUSSION

The individual analysis of variance showed significant differences ($p < 0.01$) for the effect of genotypes, regarding grain yield, for all evaluated environments (Table 3). The average grain yield ranged from 873 kg ha$^{-1}$ (Madalena) to 1742 kg ha$^{-1}$ (Crateús).

The genotypes with grain yields above the general average were, in descending order: BRS Potengi, BRS Pajeú, BRS Guariba, BRS Tumucumaque, BRS Cauamé, Inhuma and BR 17-Gurguéia (Table 4). It is worth noting that the trials performed in Crateús (E2), Madalena (E3) and Limoeiro do Norte (E5) were conducted under rainfed conditions, which justifies the lower average productivity of the genotypes due to the irregularity of rainfall in E2 and E5 and the low levels of rainfall in E3 (Figure 2).

The use of the coefficient of variation, proposed by Pimentel-Gomes (1990) to evaluate the quality of agricultural experiments, has been questioned for being broad, for not considering the particularities of the crop and, especially, for not distinguishing between the nature of the evaluated characters. Thus, the use of accuracy as a measure of experimental precision would be more appropriate because it considers, in addition to residual variation, the number of repetitions and the genetic control of the characters (RESENDE; DUARTE, 2007). According to the authors mentioned above, accuracy values below 0.50 are low, from 0.50 to 0.70 are medium, from 0.70 to 0.90 are high and above 0.90 are very high. Therefore, the accuracy values obtained in this study (Table 3) showed high experimental accuracy and reliability of the estimates.

Through the joint analysis of variance, statistical differences were verified regarding the effects of genotypes, environments and G x E interaction (Table 5). Similar results were obtained by Abreu *et al.* (2019) and Torres *et al.* (2016), who also found significant differences for these three sources of variation, evaluating cowpea genotypes for adaptability and productive stability. The detection of the significant effect for the G x E interaction shows that the genotypes presented distinct behaviors regarding grain yield in the different locations of cultivation. The value found for accuracy was greater than 0.70, indicating a strong correspondence between estimated and actual values.

**Table 3** - Summary of individual analysis of variance for grain yield of 12 cowpea genotypes, cultivated in five environments in the state of Ceará, from 2018 to 2020

| Environments | Mean Squares | | Average (kg ha$^{-1}$) | Accuracy |
|---|---|---|---|---|
| | Genotypes | Residue | | |
| DF | 11 | 33 | | |
| Crateús, 2018 | 701010.33** | 62105.13 | 1742 | 0.95 |
| Crateús, 2019 | 801921.11** | 67029.53 | 1015 | 0.96 |
| Madalena, 2019 | 128801.96** | 33826.36 | 873 | 0.86 |
| Bela Cruz, 2019 | 137648.17** | 18375.38 | 1411 | 0.93 |
| Limoeiro do Norte, 2020 | 241313.03** | 38190.87 | 890 | 0.92 |

DF: Degrees of freedom; ** Significant at $p < 0.01$ by the F test

The GGE biplot methodology groups the additive effect of genotypes (G) with the multiplicative effect of the G x E interaction, and subjects them to principal components analysis (YAN, 2011). In order to perform the construction of the biplot, usually, the first *k* principal components that capture more than 60% of the total variation of the data are considered (YAN; TINKER, 2006). Thus, from the decomposition into singular values of G + G x E, there was greater relevance of the first two principal components (PC1 and PC2) that expressed the respective values of 54.79% and 30.22%, explaining 85.01% of the total variance for grain yield (Table 6). Thus, the GGE biplot method explained a large part of the sum of squares of genotypes and the G x E interaction, indicating that there is a high level of confidence in the results produced.

**Table 4** - Average grain yield (kg ha$^{-1}$) of 12 cowpea genotypes, cultivated in five environments in the state of Ceará, from 2018 to 2020

| Genotypes | E1 | E2 | E3 | E4 | E5 | Average |
|---|---|---|---|---|---|---|
| BR 17-Gurguéia | 1960 Ab | 790 Dc | 1034 Ca | 1499 Ba | 657 Db | 1188 |
| BRS Marataoã | 1385 Ac | 392 Cc | 867 Ba | 1341 Ab | 552 Cb | 907 |
| BRS Guariba | 2112 Aa | 1566 Ba | 883 Da | 1220 Cb | 634 Db | 1283 |
| BRS Novaera | 1257 Ac | 1182 Ab | 993 Aa | 1307 Ab | 1155 Aa | 1179 |
| BRS Xiquexique | 736 Bd | 555 Bc | 682 Bb | 1136 Ab | 622 Bb | 746 |
| BRS Tumucumaque | 1985 Ab | 1432 Ba | 865 Ca | 1310 Bb | 771 Cb | 1273 |
| BRS Aracê | 1552 Ac | 1176 Bb | 520 Cb | 1298 Bb | 800 Cb | 1069 |
| BRS Cauamé | 1553 Ac | 1675 Aa | 681 Cb | 1369 Ab | 1138 Ba | 1283 |
| BRS Pajeú | 2322 Aa | 1261 Cb | 810 Db | 1756 Ba | 1176 Ca | 1465 |
| BRS Potengi | 2132 Aa | 1181 Cb | 1178 Ca | 1684 Ba | 1152 Ca | 1466 |
| Pingo-de-Ouro-1-2 | 1750 Ab | 417 Dc | 938 Ca | 1443 Bb | 937 Ca | 1097 |
| Inhuma | 1991 Ab | 548 Dc | 1131 Ca | 1565 Ba | 1038 Ca | 1255 |
| Average | 1742 | 1015 | 873 | 1411 | 886 | 1184 |

Means followed by the same uppercase letter horizontally and the same lowercase letter vertically constitute a statistically homogeneous group using the Scott-Knott test at $p < 0.5$. E1: Crateús, 2018; E2: Crateús, 2019; E3: Madalena, 2019; E4: Bela Cruz, 2019; E5: Limoeiro do Norte, 2020

**Table 5** - Summary of the joint analysis of variance for grain yield (kg ha$^{-1}$) of 12 cowpea genotypes, cultivated in five environments in the state of Ceará, from 2018 to 2020

| Sources of Variation | Degrees of Freedom | Mean Squares |
|---|---|---|
| Genotypes (G) | 11 | 872534.72** |
| Environments (E) | 4 | 6644203.41** |
| G x E | 44 | 324476.41** |
| Residue | 180 | 42502.58 |
| Average | | 1185 |
| Accuracy (%) | | 0.79 |

** Significant at $p < 0.01$ by the F test

**Table 6** - Importance of principal components (PC) and information ratio (IR) for GGE biplot analysis of 12 cowpea genotypes, cultivated in five environments in the state of Ceará, from 2018 to 2020

| PC | Explained Variation (%) | Accumulated Variation (%) | IR |
|---|---|---|---|
| PC1 | 54.79 | 54.79 | 2.47 |
| PC2 | 30.22 | 85.01 | 1.31 |
| PC3 | 9.71 | 94.72 | 0.73 |
| PC4 | 4.27 | 98.99 | 0.43 |
| PC5 | 1.01 | 100.00 | 0.06 |

According to the information ratio (IR), of the five PCs presented in Table 6, only the first two contain important patterns (IR > 1). Therefore, the dimension-two biplot adequately represents the interaction-related patterns. Similar results were found by Sousa *et al.* (2018) who, evaluating the adaptability and stability parameters of 40 cowpea genotypes in Brazilian Cerrado regions found, for grain yield, the first two PCs explaining most of the total variation (66.05%). It is worth noting that these authors used nine test environments and that, the greater the number of evaluated environments, the less information is captured by the first two p.

The vectors from the origin of the biplot (dotted blue lines) divided the chart, named "Who-wins-where", into seven sectors (Figure 3). The genotypes G12, G11, G2, G5, G8, G3 and G9, positioned in the vertices of the polygon, present specific adaptation to the respective sectorial environment (YAN; TINKER, 2006). Thus, the genotypes G12 and G11 presented the best performances in environment A3; the genotypes G8 and G3, in environment E2; and the genotype G9, in environments E1, E4 and E5. It is worth noting that environments E1 and E2, despite representing the same municipality (Crateús) in the 2018 and 2019 harvests, respectively, were allocated in different sectors of the chart (Figure 3). This occurs due to the variations of environmental effects, in particular, the adoption of the irrigation system in environment E1.

The sectors where the genotypes G2 and G5 were allocated have no grouped environments (Figure 3). This result indicates that these genotypes are poorly adapted to the environments tested, presenting low productivity in some or all environments (KARIMIZADEH *et al.*, 2013), and are therefore unfavorable for recommendation. All other genotypes, namely G1, G4, G7, G6 and G10, are contained within the polygon and have smaller vectors, that is, they are less sensitive to the interaction with the environments of each sector (YAN; TINKER, 2006), being more suitable for a broad recommendation.

The behavior of the genotypes regarding average grain yield and stability is shown in Figure 4. In this biplot, PC1 indicates the adaptability of the genotypes, being highly correlated with yield. Thus, the genotypes positioned closer to the arrow on the x-axis, present higher average yield. On the other hand, PC2 indicates the magnitude of stability, so that the greater the vertical projection of the genotype (dotted line) in both directions, the greater its instability and, consequently, the greater its contribution to the G x A (YAN, 2011).

Considering the genotypes with above average grain yield (positioned to the left of the vertical axis), the genotypes G9 and G10 were identified as the most stable. Although they showed instability, genotypes G8 and G12 expressed maximum performance in environments E2 and E3, respectively, and can be recommended specifically for these locations. The genotypes G7, G11, G4 and G2 showed low yield and stability, and should be discarded, as well as the genotype G5 which, despite being stable, showed the lowest average grain yield among all evaluated genotypes (Figure 4 and Table 4).

**Figure 3** - GGE biplot (Who-wins-where) for grain yield (kg ha$^{-1}$) of 12 cowpea genotypes (G1 to G12), cultivated in five environments in the state of Ceará (E1 to E5), in the period from 2018 to 2020

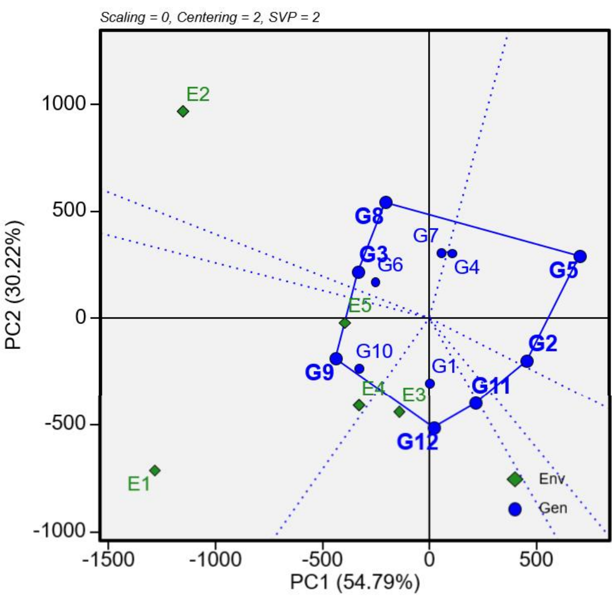
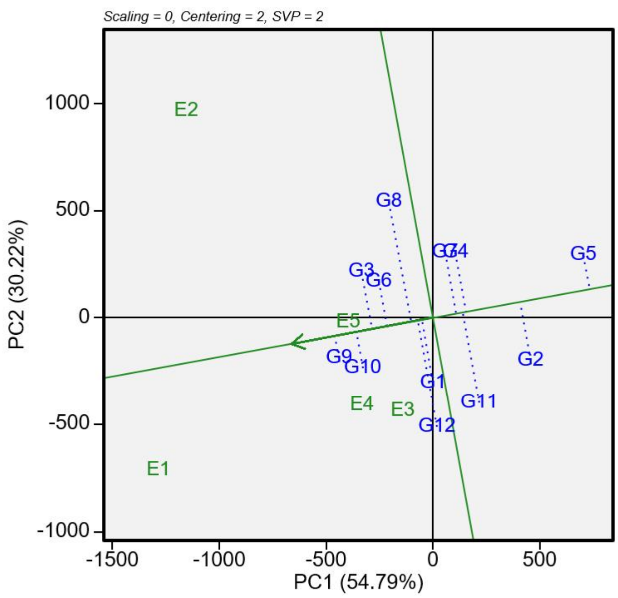



**Figure 4** - GGE biplot (Average x stability) for grain yield (kg ha$^{-1}$) of 12 cowpea genotypes (G1 to G12), cultivated in five environments in the state of Ceará (E1 to E5), in the period 2018 to 2020



According to Yan and Tinker (2006), a genotype is considered ideal if it consistently presents high average grain yield in all environments evaluated. In Figure 5, this ideotype is represented by the arrow in the center of the concentric circles. Several authors use this model as a reference for the evaluation of superior genotypes (ABREU *et al*., 2019; SANTOS *et al*., 2016; SOUSA *et al*., 2018). Thus, the cultivars BRS Pajeú (G9), present in the second concentric circle, and BRS Potengi (G10), in the third circle, are the closest to the ideal genotype in terms of high yield and phenotypic stability, being considered promising for cultivation in the state of Ceará (Figure 5).

The GGE biplot approach allows for the identification of optimal environments, which should be representative and effectively discriminate superior genotypes (YAN, 2011). In Figure 6, the discriminative environments are those represented by the largest vectors (dotted lines that connect each environment to the center of the biplot) and the representative environments are those that form small angles between their vectors and MEC (line on the x-axis that passes through the average environment and the origin of the graph). Based on these criteria, environments E1 and E2 showed greater discriminatory power; and environments E1, E4 and E5 showed greater representativeness. Environment E2 was considered not representative; environments E3, E4 and E5 were not discriminative and, therefore, should not be used as test environments. Thus, only environment E1 (in the irrigated system) was, simultaneously, discriminatory and representative, and can be considered ideal for the evaluation of genotypes.

The correlation between the environments is represented by the cosine of the angle between their vectors (YAN; TINKER, 2006), so that the smaller the angle between two vectors, the greater the correlation between the environments (positive cosine values). In this sense, most environments correlated positively, with the exception of environments E2 with E3, which formed an obtuse angle (> 90º) between their vectors (Figure 6). Positive and negative correlations between test environments were also verified by Santos *et al.* (2017), who used the GGE biplot methodology to evaluate cowpea genotypes and their production environments.

Although environments E1 and E4 are located in different micro-regions (Figure 3), they were strongly correlated (Figure 6). This may have occurred due to the constant supply of irrigation throughout the crop cycle, favoring the development of the genotypes and, consequently, grain yields in both trials (Table 4). Although the amount of rainfall in environments E2 and E5 exceeded the minimum required by the crop for its full development, the poor distribution may have acted negatively on the yield of the genotypes (Figure 2), since the duration and timing of the water deficit affect in greater or lesser intensity the production components of the cowpea (NASCIMENTO *et al*., 2011).

**Figure 5** - GGE biplot (Ideal genotype) for grain yield (kg ha$^{-1}$) of 12 cowpea genotypes (G1 to G12), cultivated in five environments in the state of Ceará (E1 to E5), in the period from 2018 to 2020

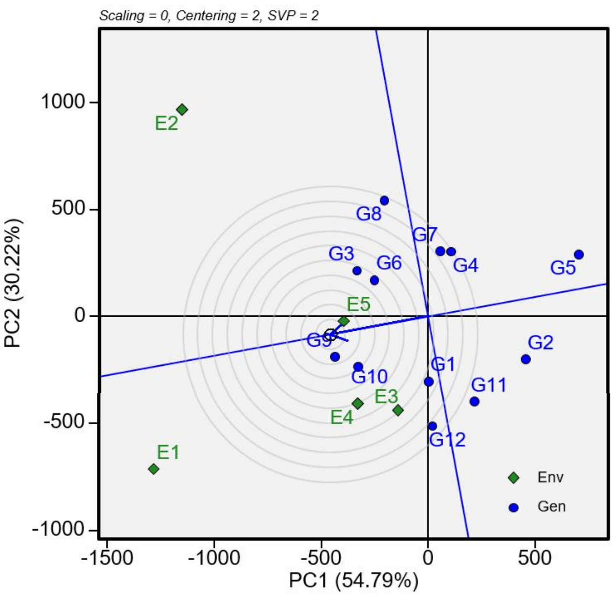
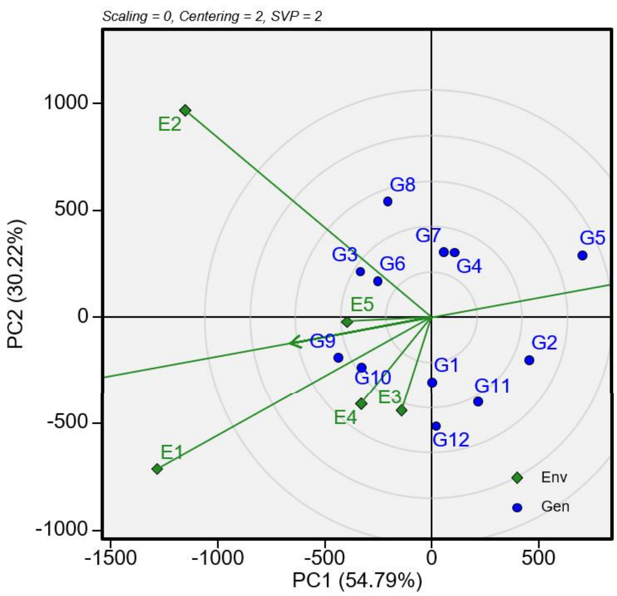



**Figure 6** - GGE biplot (Discrimination x representativeness) for grain yield (kg ha$^{-1}$) of 12 cowpea genotypes (G1 to G12), cultivated in five environments in the state of Ceará (E1 to E5), in the period from 2018 to 2020



In the case of environment E3, both the quantity and regularity of rainfall were less than ideal for the cultivation of cowpea (Figure 2). According to Nascimento *et al.* (2011), the occurrence of water deficit in the phases of flowering and grain filling can cause severe reductions in the grain yield of cowpea. Therefore, the lower productive performance of the genotypes cultivated in environments E2, E3 and E5 is mainly due to the shortage of rainfall in phenological stages of greater water demand.

In studies of adaptability and stability for the recommendation of cowpea genotypes, the most relevant character is the grain yield. Nevertheless, aiming a more accurate recommendation, it is necessary to study the other characters of economic interest, given the possibility that a highly productive genotype, stable and adapted, present some unattractive feature to the market, such as pod length and grain weight less than the commercial standard. Accordingly, there were significant differences regarding the effect of genotypes for the characters number of days to flowering, number of pods per plant, pod length, number of grains per pod, mass of 100 grains and grain index (Table 7).

With respect to the characters of lodging, architecture and cultivation value, there was no significant difference. Most of the evaluated genotypes are cultivars already launched in the market, except the elite lines Pingo-de-Ouro-1-2 (G11) and Inhuma (G12). This fact presupposes that the 12 genotypes used in this research already have desirable characteristics for the cowpea market.

For all characters, the Scott-Knott test distributed the genotypes in three or more groups (Table 8). According to Freire Filho (2011), the northeastern consumer has a preference for large seeds (on average 20 g/100 seeds), pod length of 18 cm and 14 grains per pod, on average. It was verified, therefore, that the genotypes evaluated in this study presented their characters with a general average close to the commercial standards. It is also noteworthy that the cultivars BRS Pajeú (G9) and BRS Potengi (G10) stood out for most of the production components, thus confirming the result obtained by the GGE biplot methodology, through which, these cultivars were indicated as promising for cultivation in the state of Ceará.

The trail analysis was applied in order to provide the improvers with more information when recommending cultivars, especially regarding the relevance of the evaluated characters. To perform this analysis, the following primary production components were considered: NPP, PL, NGP, M100G and GI. Due to the influence of the irrigation system on the performance of the genotypes, the trail analysis was performed considering the different water regimes adopted: rainfed and irrigated.

Regarding irrigated environments, it was found that grain yield showed a positive correlation of small to medium magnitude with all the evaluated characters, especially NPP (0.61) (Table 9). Considering the direct effects on productivity, the number of pods per plant was the character that showed the highest effect, followed by the mass of 100 grains and the number of grains per pod. This result shows that increases in the NGP character reflect positively on grain yield. Similar conclusions were presented by Almeida *et al.* (2014) and Silva and Neves (2011) who, when investigating the associations between grain yield in cowpea and some of its production components, found that selection for number of pods per plant can provide genetic gains on grain yield.

For trials conducted under rainfed conditions, the number of pods per plant and grain index showed the highest correlations with yield (Table 9). Small and medium negative correlations were established between grain yield and the variables PL and NGP. Similar to the

**Table 7** - Summary of the joint analysis of variance of the characters, number of days to flowering (NDF), number of pods per plant (NPP), pod length (PL), number of grains per pod (NGP), mass of 100 grains (M100G) and grain index (GI), evaluated in 12 cowpea genotypes cultivated in five environments in the state of Ceará, in the period from 2018 to 2020

| SV | DF | Mean Squares | | | | | |
|---|---|---|---|---|---|---|---|
| | | NDF | NPP | PL | NGP | M100G | GI |
| Genotype | 11 | 60.12** | 10.40* | 36.74** | 67.40** | 151.73** | 116.64** |
| Environment | 4 | 342.16** | 71.84** | 34.34** | 62.00** | 115.35** | 411.38** |
| G x E | 44 | 14.59** | 4.08** | 1.53$^{ns}$ | 5.43** | 8.10** | 20.59** |
| Residue | 180 | 5.74 | 0.98 | 1.11 | 1.69 | 3.59 | 6.25 |
| Average | | 40.82 | 3.85 | 20.01 | 14.02 | 18.83 | 78.37 |
| Accuracy | | 0.87 | 0.78 | 0.98 | 0.96 | 0.97 | 0.91 |

SV: Sources of Variation; DF: Degrees of Freedom; G: Genotype; E: Environment; $^{ns}$ Not significant; **,* Significant at $p < 0.01$ and $p < 0.05$ by the F test, respectivatly behavior presented in irrigated environments, the number of pods per plant also expressed the greatest direct effect on productivity in rainfed environments (0.69), showing its relevance during the process of cultivar recommendation. Due to its low direct influence on grain yield in both water regimes, the pod length character may be discarded in future evaluations of this nature.

In general, the results found ratify the importance of the character related to the number of pods per plant in improvement programs, by enabling an efficient correlated response on grain yield. Accordingly, the cultivars with the highest NPP were BR 17-Gurguéia (G1), BRS Cauamé (G8), BRS Pajeú (G9) and BRS Potengi (G10) (Table 8). Nonetheless, among these, only the last two expressed

**Table 8** - Averages of the characters number of days to flowering (NDF), number of pods per plant (NPP), pod length (PL), number of grains per pod (NGP), mass of 100 grains (M100G) and grain index (GI), evaluated in 12 cowpea genotypes cultivated in five environments in the state of Ceará, in the period from 2018 to 2020

| Genótipos | NDF (days) | NPP (unity) | PL (cm) | NGP (unity) | M100G (g) | GI (%) |
|---|---|---|---|---|---|---|
| BR 17-Gurguéia | 43 d | 5 a | 18.1 d | 16 b | 12.3 d | 75.2 d |
| BRS Marataoã | 44 d | 3 c | 19.7 c | 16 b | 17.3 c | 73.7 d |
| BRS Guariba | 39 a | 4 b | 20.6 b | 13 e | 20.6 b | 80.5 a |
| BRS Novaera | 42 c | 4 b | 17.9 d | 11 f | 22.4 a | 77.9 b |
| BRS Xiquexique | 42 c | 3 c | 21.0 b | 14 d | 17.6 c | 76.9 c |
| BRS Tumucumaque | 38 a | 4 b | 22.1 a | 13 e | 19.8 b | 78.7 b |
| BRS Aracê | 41 b | 4 b | 20.3 c | 14 d | 16.8 c | 76.4 c |
| BRS Cauamé | 41 b | 5 a | 18.3 d | 12 f | 17.7 c | 78.4 b |
| BRS Pajeú | 39 a | 5 a | 21.9 a | 17 a | 18.6 c | 80.3 a |
| BRS Potengi | 39 a | 5 a | 19.9 c | 13 e | 20.2 b | 80.9 a |
| Pingo-de-Ouro-1-2 | 42 c | 3 c | 20.3 c | 15 c | 20.9 b | 80.2 a |
| Inhuma | 40 b | 3 c | 20.0 c | 16 b | 21.7 a | 81.2 a |
| Average | 41 | 4 | 20.0 | 14 | 18.8 | 78.4 |

**Table 9** - Estimation of direct and indirect effects of primary yield components on grain yield in 12 cowpea genotypes

| Effects | Production components | | | | |
|---|---|---|---|---|---|
| | NPP | PL | NGP | M100G | GI |
| | | | Water regime: Irrigated | | |
| Direct on productivity | 0.85 | 0.21 | 0.72 | 0.84 | 0.31 |
| Indirect by NPP | - | -0.34 | -0.11 | -0.39 | -0.24 |
| Indirect by PL | -0.06 | - | 0.09 | 0.04 | 0.10 |
| Indirect by NGP | -0.07 | 0.31 | - | -0.32 | -0.09 |
| Indirect by M100G | -0.39 | 0.23 | -0.47 | - | 0.85 |
| Indirect by GI | 0.07 | -0.15 | 0.04 | -0.25 | - |
| Total | 0.61 | 0.26 | 0.27 | 0.14 | 0.31 |
| | | | Water regime: Dryland | | |
| Direct on productivity | 0.69 | 0.22 | 0.16 | 0.14 | 0.26 |
| Indirect by NPP | - | -0.51 | -0.69 | 0.07 | 0.28 |
| Indirect by PL | -0.12 | - | 0.08 | 0.05 | 0.04 |
| Indirect by NGP | -0.11 | 0.06 | - | -0.06 | -0.01 |
| Indirect by M100G | 0.01 | 0.03 | -0.05 | - | 0.07 |
| Indirect by GI | 0.07 | 0.05 | -0.02 | 0.13 | - |
| Total | 0.84 | -0.15 | -0.53 | 0.33 | 0.64 |

NPP: Number of pods per plant; PL: Pod length; NGP: Number of grains per pod; Mass of 100 grains; GI: Grain index above average yields (Table 4) associated with high stability and adaptability (Figure 3). Therefore, the results of the trail analysis showed agreement with the results obtained by the GGE biplot analysis and the grouping of averages, confirming the cultivars BRS Pajeú and BRS Potengi as those with the greatest potential for cultivation in the state of Ceará, since they met the standard of preference of the producer from Ceará, stood out for most of the production components and showed high yield of dry grains, adaptability and stability.

## CONCLUSIONS

1. The municipality of Crateús, in the irrigated system, was discriminative and representative, and can be considered ideal for the evaluation of genotypes;
2. The cultivars BRS Pajeú and BRS Potengi can be recommended for cultivation in the state of Ceará because they present high yields of dry grains, adaptability and stability, as well as the fact that they stood out in most production components;
3. The number of pods per plant had the greatest direct effect on grain yield.

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