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Grain yield adaptability and stability of blackeyed cowpea genotypes under rainfed agriculture in Brazil

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The present study aimed to evaluate the grain yield adaptability and stability of 20 blackeyed cowpea genotypes under rainfed agriculture in North, Northeastern and Central/Western Brazil. Three parametric methodologies and one non-parametric methodology were used. We found significant differences among genotypes, environments, and interaction between genotypes and environments. The traditional method indicated that the MNC05-832B-230-2-3 line was the most stable but had low grain yield. The linear regression indicated that the California Blackeye-3 and California Blackeye-5 cultivars had wide adaptability and stability. The bi-segmented regression model indicated that the MNC04-783B-7-3 and California Blackeye-3 genotypes exhibited adaptation to favorable and unfavorable environmental conditions, respectively. The non-parametric method characterized the MNC04-783B-7-3 line as the most suitable and stable genotype. Spearman´s rank correlation showed that some methodologies should not be used simultaneously and that others should be used complementary to each other.

Key words: *Vigna unguiculata*, genotype × environment interaction, non-parametric method, parametric method, seed yield.

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] is a legume grown and consumed worldwide, but predominately in tropical regions where rainfed agriculture predominates. In Brazil, several grain types of this crop, which exhibit variations in size, shape, color, and tegument texture, are produced and consumed according to different market demands. Among these grain types, the blackeyed pea subclass (*fradinho* in Portuguese) stands out, and this subclass is characterized by a white, wrinkled tegument with a large black halo (Freire et al., 2012). This subclass is grown mainly in the states of Sergipe, Bahia and Rio de Janeiro and is currently in a process of expansion in the states of São Paulo and Minas Gerais (Freire et al., 2005). The Brazilian blackeyed pea (*fradinho*) is identical to the common blackeyed pea, which is the most grown and marketed blackeyed pea in the United States both as dry and canned beans (Fery, 1990). In Brazil, the blackeyed grain type has great commercial prospects. However, few blackeyed pea cultivars exist with this type of grain. Therefore, to fulfill this shortage and to release cultivars

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Table 1. List of locations from North, Northeastern, and Central/Western Brazil where the assays to evaluate the grain yield (kg ha^{-1}) of the blackeyed cowpea genotypes were performed and their respective geographical coordinates, altitude, soil type and biome.

Location	Federation State	Federation Region	Altitude (m)	Latitude	Longitude	Soil	Biome
Augusto Corrêa	Pará	North	20	1°01'S	46°38'O	Yellow Latosol (Oxisol)	Amazon
Tracuateua	Pará	North	20	1°04'S	46°53'O	Yellow Latosol (Oxisol)	Amazon
Balsas	Maranhão	Northeast	283	7°31'S	46°02'O	Yellow Latosol (Oxisol)	Cerrado (Brazilian savannah)
Gurupi	Tocantins	North	287	11°43'S	49°04'O	Red-Yellow Latosol (Oxisol)	Cerrado (Brazilian savannah)
Primavera do Leste	Mato Grosso	Central-Western	636	15°33'S	54°17'O	Yellow Latosol (Oxisol)	Cerrado (Brazilian savannah)

for the productive sector, an evaluation of genotypes with this type of grain must be performed, including the evaluation of yield, yield adaptability and yield stability in different environments.

Many methodologies using one or more parameters have been proposed to explain the behavior of genotypes tested across a range of environments as follows: methodologies based on the variance of the Genotype × Environment (G × E) interaction (Yates and Cochran, 1938); simple linear regression (Eberhart and Russell, 1966); bi-segmented regression (Silva and Barreto, 1986); modified bi-segmented regression (Cruz et al., 1989); and non-parametric methodologies (Lin and Binns, 1988); Lin and Binns modified by Carneiro (1998). In Brazil, different adaptability and stability methodologies have been adopted in cowpea (Freire et al., 2001, 2002, 2003; Rocha et al., 2007; Barros et al., 2013). The most suitable method for the evaluation and interpretation of results depends mainly on the number of environments assessed, accuracy of data, type of data desired, simplicity of the analysis and simplicity of the interpretation of the results (Cruz et al., 2004). Another aspect that should be considered is the relationship among the methodologies assessed, as it is possible to identify the methodology that best meets the demands of a given improvement program. Studies on other legumes have been conducted aiming to compare methodologies that evaluate the yield adaptability and stability, for example, the assessment of the common bean (*Phaseolus vulgaris* L.) by Pereira et al. (2009). However, there are few studies comparing yield stability and adaptability methodologies in cowpea (Aremu et al., 2007; Almeida et al., 2012). Therefore, the aim of the present study was to assess grain yield adaptability and stability of a group of blackeyed cowpea genotypes cultivated under rainfed agriculture in Brazil.

In addition, this study aimed to perform a comparative study among several methodologies to identify the most suitable methodology for the study of adaptability and stability of cowpea as well as to subsidize the release and/or recommendation of blackeyed cowpea cultivars for agribusiness in Northern, Northeastern and Central/Western Brazil.

MATERIALS AND METHODS

Twenty cowpea genotypes comprising lines of the *Embrapa Meio-Norte* Improvement Program, genotypes introduced from other countries and a commercial cultivar (Poços de Caldas-MG) were assessed. The study was conducted in Northern, Northeastern, and Central/Western Brazil under rainfed conditions in the 2007/2008 crop years. The experiments were carried out in the following locations: Tracuateua and Augusto Corrêa in the state of Pará (PA) in 2007 and 2008; Balsas in the state of Maranhão (MA) in 2008; Gurupi in the state of Tocantins (TO) in 2008; and Primavera do Leste in the state of Mato Grosso (MT) in 2008 (Table 1). Plantings were performed during the same period of commercial cowpea cultivation in each area. Randomized complete block experiments were performed with 20 treatments and four replications. The experimental plots (1.6 × 5.0 m) were similar in all experiments with a 0.5-m spacing between rows and a 0.125-m spacing between pits within rows. The useful plot area comprised the two central rows where data collection for dry grain yield was performed. For statistical analysis, it was assumed that the combination of year and location represented an environment. Thus, although the assays were conducted in five locations, there were seven experimental environments because in two locations, the assays were conducted for two years. Data were subjected to individual analysis of variance for each environment, and a subsequent joint analysis of the environments was performed after assessing the homogeneity of residual variances, through the Bartlett's test. The Scott-Knott test at 5% probability was used for comparison of means. The evaluation of genotype adaptability and stability was performed using the following methods: traditional method (Yates and Cochran, 1938); the method of Eberhart and Russell (1966); the method of Cruz et al. (1989); and the method of Lin and Binns as modified by Carneiro (1998). A comparative study of the methodologies used was conducted to evaluate the existence of a relationship among them. The parameters estimated by the four methods were used to estimate Spearman´s rank correlation coefficient, which was applied to the rank-order of genotypes obtained in each method. The adaptability and stability order was defined based on its own concepts

Table 2. Summary of the individual analysis of variance of grain yield (kg ha^{-1}) for blackeyed cowpea genotypes in the seven environments (location and year) assessed under rainfed conditions in North, Northeastern and Central/Western Brazil.

Location Year	Mean square			$CV^{1/}$ (%)
	Blocks	Genotypes	Error	
	GL = 3	GL = 19	GL = 57	
Tracuateua 2007	73220.96^{ns}	129520.12**	148681.19	17.54
Augusto Corrêa 2007	141900.52*	252258.42**	40069.56	12.75
Tracuateua 2008	152328.09^{ns}	352092.73**	61642.86	13.41
Augusto Corrêa 2008	90132.07^{ns}	311707.05**	96215.13	21.58
Primavera do Leste 2008	254378.01*	505733.61**	89431.67	14.21
Balsas 2008	9860.79^{ns}	420860.60**	103162.23	27.41
Gurupi 2008	33913.94^{ns}	334676.57**	53822.30	15.48

**, * Significant at 1 and 5% probability levels, respectively, according to the F-test; ^{ns} Non-significant. $^{1/}$ Residual coefficient of variation.

and in the number of parameters of each method. Therefore, the genotypes were ranked from 1 to 20 with 1 representing the genotypes exhibiting higher adaptability and stability and 20 representing the less adapted and stable genotypes. The exception to this ranking method included cases where two or more genotypes exhibited equal parameters. In the present study, we adopted the procedure reported by Pereira et al. (2009). Thus, in the traditional method (Yates and Cochran, 1938), which uses a single parameter of stability, the rank-order was attributed based on the environment mean square within the genotype ($MS_{E/G}$). As for the Eberhart and Russell (1966) method, the rank-order number was obtained from the β_{1i} and δ_{ij} values. The parameters β_{1i} and δ_{ij} describe the response of the genotype "i" in all environments, and deviation of the regression of genotype "i" in environment "j", respectively. For the β_{1i} parameter, the difference between the parameter value and unit was used. This difference and the δ_{ij} parameter were ranked in an increasing order, and then the rank-order numbers of these two parameters were averaged allowing the rank-order number for the correlation study to be obtained.

For the Cruz et al. (1989) methodology, the same ranking procedure adopted by Eberhart and Russell (1966) for the β_{1i} and δ_{ij} parameters was used. The parameter β_{1i} accounts response of the ith genotype at improvement of the unfavorable environments. As for the β_{1i} + β_{2i} parameters, which describe response of the ith genotype at improvement of the favorable environments, the ranking was the reverse of β_{1i}, so the genotype with the greatest value for β_{1i} + β_{2i} was ranked first. From the ranking average of these three parameters, the ranking used in the correlation study was obtained. In the Lin and Binns method modified by Carneiro (1998), the genotypes were ranked based on the estimations of P_{if} and P_{id} representing the parameter stability and adaptability of the genotype "i" in favorable and unfavorable environments, respectively. Subsequently, the ranking average of the P_{if} and P_{id} parameters was obtained for the correlation study. As the mean yield is important for recommendation and/or release of cultivars, Pereira et al. (2009) suggested a ranking where the mean yield is added as a parameter for the correlation analysis. Thus, a second ranking was also obtained in the Eberhart and Russell (1966) and Cruz et al. (1989) methods taking account simultaneously the ranking based on mean yield.

All analyses were performed using SAS (Sas Institute, 2002) and Genes (Cruz, 2006) statistical packages.

RESULTS AND DISCUSSION

In this study, the results indicated significant difference among blocks in only two environments, thereby indicating that the experimental areas were fairly uniform. However, genotypes effect showed significant differences in all environments, thereby indicating a genetic variability for yield among genotypes (Table 2). The Bartlett's test, which evaluate if the residual variances are homogenous, allowed the joint analysis of the assays in the present study. The residual coefficients of variation ranged from 12.75 to 27.41% indicating a satisfactory experimental accuracy. The joint variance analysis showed significant differences (P<0.01) for the effects of environments, genotypes and the genotype × environment interaction. The magnitude of environment effect (89.23%) was higher than the genotype effect (7.83%), which itself was higher than the G × E interaction (2.94%). This result indicated a large difference among environments resulting in differences among environmental means and, consequently, in the genotype yields. Akande (2007), Rocha et al. (2007) and Sarvamangala et al. (2010) found similar results in cowpea studies for the effect of genotypes, environments and the G × E interaction. The joint analysis showed a residual coefficient of variation of 17.05% indicating good experimental accuracy (Table 3). Significant differences among genotypes were found in six assays. The evaluation of the yield behavior of genotypes in different environments showed that the yield ranged from 759.19 (for the Poços de Caldas-MG cultivar in the Balsas location) to 2695.00 kg ha^{-1} (for the MNC04-783B-7-3 line in the Primavera do Leste location) in 2008. In 2007, significant differences were found only among genotypes in the Augusto Corrêa location, especially for

Table 3. Summary of the joint analysis of variance of grain yield (kg ha^{-1}) for the 20 blackeyed cowpea genotypes assessed in seven environments under rainfed agriculture in North, Northeastern and Central/Western Brazil.

Source of variation	df	Mean square	Percentage of variation
Blocks/environments	21	107962.15^{ns}	
Environments (E)	6	8104813.48**	89.23
Genotypes (G)	19	711890.72**	7.83
G × E	114	265826.40**	2.94
Error	399	71133.20	
Mean (kg ha^{-1})		1564.24	
CV (%)		17.05	

df = Degrees of freedom, CV = coefficient of variance, ** significant at P<0.01 according to the F-test; ^{ns} non-significant difference.

the MNC05-820B-173-2-1 line. In 2008, two or more yield groups were found for each environment based on the Scott-Knott test (P<0.05), and the highest yield was found for the MNC04-783B-7-2-1 line in all groups.

In addition to this line, the MNC04-786B-87-2, MNC04-785B-77, and MNC04-789B-119 lines stood out because they were ranked in the first yield group in at least four environments. When considering only the mean of the locations, the yields ranged from 1171.43 kg ha^{-1} in Balsas to 2103.53 kg ha^{-1} in Primavera do Leste in 2008 (Table 4). The grain yields of the lines mentioned earlier in the present study were greater than the mean grain yield of cowpea cultivars released in Northern, Northeastern, and Central/Western Brazil regions with average yields of 1100.50, 1083.00, and 1265.20 kg ha^{-1}, respectively (Freire et al., 2012). The traditional method identified MNC05-832B-230-2-3 and California Blackeye-3 genotypes as the most stable among the groups assessed, but they exhibited low yield (Table 5). These data confirmed the assumption of Cruz et al. (2004), who assumed that genotypes with regular behavior [that is, low $MS_{(G/E)}$] in a range of environments are generally not productive. The adaptability and stability analysis through linear regression (Eberhart and Russell, 1966), excluding parameter of mean yield, indicated that the California Blackeye-5 and California Blackeye-3 cultivars as well as the UCR-2-1 and MNC04-789B-2-3 lines were the best genotypes. Although, they did not have the best grain yields, the aforementioned genotypes exceeded the overall mean of the assays and showed a highly predictable behavior ($\delta_{ij} = 0$) and wide adaptability ($\beta_{1i} = 1$).

Freire et al. (2001, 2002), Santos et al. (2008) and Yousaf and Sarwar (2008) found similar results with cowpea. These authors found that the best-adapted and stable genotypes in most of the cases are not the most productive genotypes but that they achieve an above average yield. Using the method proposed by Cruz et al. (1989), only the MNC05-832B-230-2-3 line, MNC05-832B-230-2-1 line and California Blackeye-3 cultivar of the genotypes assessed showed a β_{1i} estimate lower than 1 (P < 0.05) indicating that these genotypes were adapted to less favorable environments. As for the $\beta_{1i} + \beta_{2i}$ parameter, only the MNC04-783B-7-3 and MNC04-789B-119 lines showed results significantly greater than 1 ($\beta_{1i} + \beta_{2i} \neq 1$), which indicated that they were adapted to more favorable environments and responsive to environmental improvement. As for the δ_{ij} parameter, all genotypes, except for the MNC05-832B-230-2-1 line, showed a deviation of the regression equal to zero ($\delta_{ij} = 0$), which indicated that they were classified as stable in both favorable and unfavorable environments. Based on these results, the best genotype (that is, the one that features a high mean value, $\beta_{1i} < 1$, $\beta_{1i} + \beta_{2i} > 1$ and $\delta_{ij} = 0$) was not found among the genotypes evaluated.

According to the Lin and Binns (1988) method modified by Carneiro (1998), the best genotype was the MNC04-783B-7-3 line because it obtained the lowest estimate of the overall P_i parameter, the second lowest estimate for favorable environments, the lowest estimate for unfavorable environments, and the highest overall mean for yield, which indicated general adaptation and high predictability. In studies with cowpea, Adewale et al. (2010) and Shiringani and Shimelis (2011) found similar results regarding the P_i parameter, thereby confirming that the most adapted and stable genotypes are always related to high yields. According to Cruz and Carneiro (2006) and Pereira et al. (2009), a great advantage of the Lin and Binns (1988) method is the immediate identification of the most stable genotypes due to the uniqueness of the P_i parameter, but this method shows only one parameter estimate for the general recommendation of cultivars. However, the modification of the method proposed by Carneiro (1998) enables an estimation of P_i for favorable and unfavorable environments conferring more robustness to the method.

In the assessment of relative efficiency of methodologies using Spearman's correlation, we found that nine of the 21 correlations estimated were significant. Therefore, it can be inferred that at a greater or lesser efficiency level, the methods used assessed the adaptability and stability of the genotypes and that there was a certain level of

Table 4. Mean grain yield (kg ha^{-1}) of 20 blackeyed cowpea genotypes assessed in seven environments (location and year) under rainfed agriculture in North, Northeastern and Central/Western Brazil.

Genotype	Grain yield (kg ha^{-1})[1]							Overall mean (kg ha^{-1}) (to show the Scott-Knott test)
	2007		2008					
	Tracuateua	Augusto Corrêa	Tracuateua	Augusto Corrêa	Balsas	Gurupi	Primavera do Leste	
MNC04-783B-7-3	1316.69[a]	1749.46[b]	2431.13[a]	1928.83[a]	1776.31[a]	1886.53[a]	2695.00[a]	1969.13[a]
MNC04-786B-87-2	1147.69[a]	1872.99[b]	2315.81[a]	1877.10[a]	1674.69[a]	1193.70[c]	2655.00[a]	1819.56[b]
MNC04-789B-119	1159.00[a]	1346.50[c]	2085.13[a]	1510.78[a]	1675.81[a]	1832.78[a]	2249.50[b]	1694.21[c]
MNC04-785B-77	1504.81[a]	1832.58[b]	1738.81[b]	1391.90[b]	1302.00[b]	1428.48[c]	2630.25[a]	1689.83[c]
California Blackeye-5	1529.13[a]	1585.22[c]	1783.17[b]	1678.88[a]	1217.75[b]	1873.32[a]	2043.00[c]	1672.92[c]
UCR-A-31	1453.38[a]	1554.14[c]	1726.63[b]	1718.35[a]	795.03[b]	1745.11[a]	2288.50[b]	1611.59[c]
UCR-2-1	1262.63[a]	1388.05[c]	1881.44[b]	1553.38[a]	1080.13[b]	1857.45[a]	2236.25[b]	1608.41[c]
California Blackeye-3	1508.63[a]	1402.17[c]	1830.13[b]	1455.15[a]	1455.31[a]	1485.80[b]	2105.25[c]	1604.63[c]
MNC04-789B-2-3	1473.94[a]	1588.06[c]	1684.94[b]	1272.85[b]	1191.25[b]	1708.13[a]	2228.75[b]	1592.56[c]
MNC04-789B-2-1	1126.56[a]	1663.85[b]	2121.88[a]	1105.40[b]	925.38[b]	1545.53[b]	2438.00[b]	1560.94[c]
MNC05-820B-173-2-1	1229.75[a]	2178.86[a]	1688.69[b]	1351.40[b]	1140.88[b]	1261.43[c]	1993.25[c]	1549.18[d]
MNC05-820B-240	1303.63[a]	1497.08[c]	1865.00[b]	1774.45[a]	1063.19[b]	1531.18[b]	1731.75[d]	1538.04[d]
MNC05-832B-230-2-3	1432.63[a]	1823.23[b]	1807.69[b]	1464.89[a]	1644.00[a]	1103.10[c]	1466.00[d]	1534.50[d]
TVu-1489	1412.06[a]	1570.78[c]	1785.13[b]	1551.03[a]	966.94[b]	1153.80[c]	1976.75[c]	1488.07[d]
MNC05-832B-230-2-1	1614.69[a]	1071.18[d]	2383.72[a]	1043.70[b]	1245.19[b]	1486.83[b]	1376.00[d]	1460.18[d]
Vaina Blanca	1077.19[a]	1632.91[c]	1812.62[b]	1493.78[a]	981.56[b]	1106.10[c]	1933.75[c]	1433.98[e]
California Blackeye-27	922.56[a]	1469.42[c]	1437.81[c]	1344.38[b]	902.69[b]	1571.38[b]	2183.25[b]	1404.49[e]
Poços de Caldas-MG	1398.00[a]	1441.75[c]	1832.13[b]	942.90[b]	759.19[b]	1245.60[c]	2094.75[c]	1387.76[e]
MNC05-820B-173-2-2	1345.19[a]	1553.33[c]	1539.72[c]	1273.53[b]	827.88[b]	1092.38[c]	1979.25[c]	1373.04[e]
IT82D-60	1165.56[a]	1164.20[d]	1264.43[c]	1016.23[b]	803.56[b]	1862.35[a]	1766.50[d]	1291.83[e]
Overall mean (kg ha^{-1})	1319.16	1569.28	1850.80	1436.94	1171.43	1498.54	2103.53	1564.24

[1]Means followed by the same letters in the column belong to the same clustering according to the Scott-Knott test at P<0.05; CV = coefficient of variance.

Table 5. Parameters of adaptability and stability of 20 blackeyed cowpea genotypes assessed in seven environments under rainfed agriculture in North, Northeastern, and Central/Western Brazil according to the traditional method (Yates and Cochran, 1939), Eberhart and Russell method (1966), Cruz et al. (1989) method, and the Lin and Binns method modified by Carneiro (1998).

Genotype	Mean (kg ha^{-1})	Traditional		Eberhart and Russell (1966)				Cruz et al. (1989)					Carneiro (1998)			
		$MS_{(E/Gi)}$	R[1]	β_{1i}	δ_{ij}	R[1]	R_m[2]	β_{1i}	$\beta_{1i}+\beta_{2i}$	δ_{ij}	R[1]	R_m[2]	P_i	P_{if}	P_{id}	R[1]
MNC04-783B-7-3	1969.13	839927.01**	17	1.26[ns]	39655.87**	11	5	1.10	1.78	-452007.39[ns]	1	1	19.51	30.73	11.10	1
MNC04-783B-87-2	1819.56	1209658.01**	19	1.39*	108300.37**	17	12	1.37	1.46	-435868.64[ns]	5	3	58.54	18.07	88.88	2
MNC04-789B-119	1694.21	614469.45**	10	0.92[ns]	62498.78**	5	4	0.68	1.70	-245590.13[ns]	3	2	100.45	168.50	49.42	3

Table 5. Contd.

MNC04-785B-77	1689.83	832584.66**	15	1.27^{ns}	34525.27*	12	8	1.21	1.45	-433026.72^{ns}	4	4	95.61	100.56	91.89	4
California Blackeye-5	1672.92	283237.68**	3	0.70^{ns}	611305^{ns}	14	3	0.66	0.85	-125768.58^{ns}	12	9	112.80	199.56	47.74	5
UCR-A-31	1611.59	797178.51**	14	1.20^{ns}	43676.18**	8	10	1.16	1.36	-300611.75^{ns}	8	6	150.36	175.30	131.65	9
UCR-2-1	1608.41	654189.49**	11	1.14^{ns}	17838.81^{ns}	7	2	1.01	1.59	-384330.95^{ns}	2	5	134.90	189.66	93.84	6
California Blackeye-3	1604.63	275685.05**	2	0.73^{ns}	9842.00^{ns}	13	6	0.54	1.31	-188402.16^{ns}	6	7	130.07	218.70	63.60	7
MNC04-789B-2-3	1592.56	469322.24**	5	0.96^{ns}	872969.00^{ns}	2	1	0.90	1.18	-258952.22^{ns}	10	10	139.10	187.20	103.03	8
MNC04-789B-2-1	1560.94	1263236.70**	20	1.72**	-1121.78^{ns}	19	9	1.81	1.45	-895455.08^{ns}	7	8	155.97	71.15	219.58	10
MNC05-820B-173-2-1	1549.18	669213.00**	12	0.93^{ns}	77804.04**	4	14	1.33	-0.37	-381560.77^{ns}	20	17	165.69	173.94	159.51	11
MNC05-820B-240	1538.04	321647.63**	4	0.67*	22784.76*	15	16	0.74	0.45	-96044.92^{ns}	18	13	176.32	285.52	94.42	12
MNC05-832B-230-2-3	1534.50	250672.86**	1	0.10**	56155.62**	20	17	0.33	-0.65	858994.00^{ns}	17	15	207.51	337.59	109.95	14
TVu-1489	1488.07	484632.08**	6	0.96^{ns}	14481.89^{ns}	3	7	1.02	0.75	-248348.75^{ns}	16	16	191.33	217.16	171.97	13
MNC05-832B-230-2-1	1460.18	837062.17**	16	0.51**	200659.96**	18	19	0.47	0.64	189018.03**	15	14	299.59	494.82	153.16	18
Vaina Blanca	1433.98	583850.49**	8	1.08^{ns}	14868.42^{ns}	6	11	1.24	0.56	-353042.58^{ns}	19	20	212.78	210.01	214.85	15
California Blackeye-27	1404.49	751545.67**	13	1.22^{ns}	26646.39*	9	15	1.19	1.30	-398143.97^{ns}	9	11	245.35	291.97	210.39	16
Poço de Caldas-MG	1387.76	875686.30**	18	1.34*	24091.44*	16	18	1.38	1.22	-501831.91^{ns}	11	12	266.19	210.4	308.04	17
MNC05-820B-173-2-2	1373.04	542949.72**	7	1.03^{ns}	15475.92^{ns}	1	13	1.10	0.78	-291337.72^{ns}	14	18	266.45	283.03	254.03	19
IT82D-60	1291.83	598767.94**	9	0.76^{ns}	89833.50**	10	20	0.66	1.11	-62004.04^{ns}	13	19	373.87	542.13	247.67	20

**, * Significantly different at P<0.01 and P<0.05, respectively, according to the t-test; ^{ns} Non-significant difference; [1] R, genotype rating considering the average positioning between the parameters of methodologies; [2] R_m, rating obtained based on the average positioning between R and the mean yield of the genotype.

association among them (Table 6). The ranking of genotype yields showed the highest correlations with the rankings of the parameters obtained from the Cruz et al. (1989) method, the $Cruz_{mean}$ method, and Lin and Binns method modified by Carneiro (1988). This result showed that the genotypes identified as the most stable and adapted through these methods were also the most productive. Conversely, the Eberhart and Russell (1966) and traditional methods showed no significant correlation with yield indicating that the genotypes considered the most stable and adapted according to these methods were not the most productive. The Lin and Binns method modified by Carneiro (1988) showed median correlation (0.69) with method of Cruz et al. (1989). Conversely, the Lin and Binns method modified by Carneiro (1988) and the Cruz et al. (1989) method showed no significant correlation with the traditional and Eberhart and Russell (1966) methods. The results may be explained by the fact that traditional and Eberhart and Russell (1966) methods assess the adaptability and stability through the minimum variance between environments. Therefore, the Lin and Binns method modified by Carneiro (1988) and the Cruz et al. (1989) methods were the most efficient in the estimation of adaptability and stability of genotypes compared to the traditional and Eberhart and Russell (1966) methods. Pereira et al. (2009) and Almeida et al. (2012) found similar results for the correlation between the Lin and Binns method modified by Carneiro (1988) and the Eberhart and Russell (1966) method.

Conclusion

The MNC04-783B-7-3, MNC04-786B-87-2, MNC04-789B-119, and MNC04-785B-77 lines stood out with high yields, high yield adaptability, and high yield stability, and these lines have the potential to be released for cultivation in Northern, Northeastern and Central/Western Brazil. The Lin and Binns method modified by Carneiro (1988) and the Cruz et al. (1989) method were the most efficient to estimate yield adaptability and stability of the genotypes. The Lin and Binns method modified by Carneiro (1988) and the Cruz et al. (1989) method should not be used concurrently in

Table 6. Estimates of Spearman's rank correlation for each pair of methods and grain yield (kg ha^{-1}) from 20 blackeyed cowpea genotypes assessed in seven environments under rainfed agriculture.

Method	Traditional	E and R[(1)]	E and R_{mean}[(4)]	Cruz [(2)]	$Cruz_{mean}$ [(4)]	L and B [(3)]
Yield	-0.18	-0.04	0.47*	0.67**	0.85**	0.98**
Traditional		0.39	0.34	-0.42	-0.35	0.13
E and R			0.80**	0.01	-0.03	-0.06
E and R_{mean}				0.37	0.43	0.55*
Cruz					0.92**	0.69**
$Cruz_{mean}$						0.85**

[(1)] Eberhart and Russell (1966), [(2)] Cruz et al. (1989), [(3)] Lin and Binns modified by Carneiro (1998), [(4)] Eberhart and Russell (1966) and Cruz et al. (1989) using the mean as one of the parameters. **, * significant at 1 and 5% probability, respectively, according to the t-test.

the evaluation of adaptability and stability of cowpea genotypes.

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