Revista Ciência Agronômica, v. 48, n. 5 (Especial), p. 862-871, 2017
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Artigo Científico
ISSN 1806-6690

Yield adaptability and stability of semi-erect cowpea genotypes in the Northeast region of Brazil by REML/BLUP[1]

Adaptabilidade e estabilidade produtiva de genótipos de feijão-caupi semieretos no Nordeste do Brasil via REML/BLUP

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ABSTRACT - Cowpea is grown in the various soil and climatic conditions of the Northeast region of Brazil. Thus, selecting and developing cultivars with high yield, stability, and adaptability for this region is necessary due to the genotype × environment interaction. The objective of this work was to select cowpea lines of semi-erect plant simultaneously for high yield, adaptability, and genotypic stability in the Northeast region of Brazil by the REML/BLUP procedure. Twenty semi-erect genotypes—15 lines and five cultivars—were evaluated in 37 environments of the Northeast region from 2013-2015. The experiments were carried out under rainfed conditions in a randomized complete block design with four replications. The adaptability and genotypic stability were evaluated by the REML/BLUP procedure. The environmental variance was the largest factor in the phenotypic variance and the genotype × environment interaction was complex-type, with a grain yield ranging from 277 kg ha^{-1} (Serra Talhada PE, 2015) to 2,845 kg ha^{-1} (São Raimundo das Mangabeiras MA, 2013), and an overall mean of 1,342 kg ha^{-1}. According to the Harmonic Mean of Relative Performance of Genetic Values (HMRPGV) estimates, the lines MNC04-795F-153 and MNC04-795F-159 were those that simultaneously had high yield, adaptability, and genotypic stability, and can be recommended and grown with greater probability of success in the evaluated environments in the Northeast region of Brazil.

Key words: *Vigna unguiculata*. Grain yield. Genotype × environment interaction. Mixed models.

RESUMO - O feijão-caupi é cultivado em diferentes condições edafoclimáticas da região Nordeste do Brasil. Devido à existência da interação entre genótipos e ambientes, torna-se necessário selecionar e desenvolver cultivares para essa região com alta produtividade, estabilidade e adaptabilidade. Este trabalho teve como objetivo selecionar linhagens de feijão-caupi de porte semiereto, simultaneamente, para alta produtividade, adaptabilidade e estabilidade genotípica na região Nordeste do Brasil, via procedimento REML/BLUP. Foram avaliados 20 genótipos de porte semiereto, sendo 15 linhagens e cinco cultivares, em 37 ambientes da Região Nordeste, no período de 2013 a 2015. Os experimentos foram conduzidos em condições de sequeiro, em delineamento de blocos completos casualizados, com quatro repetições. A adaptabilidade e estabilidade genotípica foram avaliadas via procedimento REML/BLUP. A variância ambiental foi o maior componente da variância fenotípica e a interação genótipos x ambientes foi do tipo complexa, com a produtividade de grãos variando de 277 kg ha^{-1} (Serra Talhada-PE, 2015) a 2.845 kg ha^{-1}(São Raimundo das Mangabeiras-MA, 2013) e média geral de 1.342 kg ha^{-1}. De acordo com as estimativas de média harmônica de desempenho relativo de valores genotípicos (MHPRVG), as linhagens MNC04-795F-153 e MNC04-795F-159 reúnem simultaneamente alta produtividade, estabilidade e adaptabilidade genotípica, podendo ser indicadas com maior probabilidade de sucesso para o cultivo nos ambientes de avaliação da região Nordeste do Brasil.

Palavras-chave: *Vigna unguiculata*. Produtividade de grãos. Interação genótipos x ambientes. Modelos Mistos.

DOI: 10.5935/1806-6690.20170102
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Recebido para publicação em 31/08/2016; aprovado em 08/03/2017
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INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important legume in the Northeast region of Brazil, and a source of energy and protein. The cultivation of this species generates employment and income for the population of this region. Cowpea is the second most consumed type of bean in Brazil, and its cultivation is concentrated in the North, Northeast, and Center-West regions. There are no official statistics on cowpea production in Brazil; thus, based on the estimates of CONAB (2017), the Northeast region presented in 2016 an area of 1,029,600 ha with a production of 196,100 Mg. This represents 82.56% and 54.00% of the area and production of this legume in Brazil, respectively. The largest national producers are the states of Mato Grosso, Ceará, and Maranhão. The total area for cowpea production in Brazil is 1,247,100 ha and its production is 362,500 Mg, which represents 14.43% of all beans produced in Brazil.

Considering that cowpea is cultivated in a wide range of environments in Brazil, but the occurrence of genotype × environment interaction (G×E) may hinder the selection of superior genotypes and the recommendation of cultivars (CARVALHO *et al*., 2016; OLIVEIRA; FONTES; ROCHA, 2015; ROCHA *et al*., 2012). Thus, in the final stages of a breeding program, elite lines are tested in various environments; this allows an investigation of the magnitude of the G×E, adaptability, and yield stability, which subsidize the recommendation of cultivars for broad or specific conditions of adaptation.

In the last 60 years, several methodologies to study the adaptability and stability of genotypes in multiple environments were developed to help the breeder to select the most stable and suitable genotypes for crops in different environments (CARVALHO *et al*., 2016). The most commonly methodologies used in cowpea are the AMMI (BARROS *et al*., 2013; DDAMULIRA *et al*., 2015; SANTOS *et al*., 2015), GGE Biplot (OKORONKWO; NWOFIA, 2016; OLAYIWOLA; SOREMI; OKELEYE, 2015; SANTOS *et al*., 2016), Bayesian approache (BARROSO *et al*., 2016; TEODORO *et al*., 2015), and artificial neural networks (TEODORO *et al*., 2015).

The REML/BLUP procedure has been one of the most used techniques in studies on adaptability and genotypic stability; it is based on mixed models. This procedure estimates the components of variance by the Restricted Maximum Likelihood (REML) and the prediction of genetic values by the Best Linear Unbiased Prediction (BLUP) (CARIAS *et al*., 2014). It was originally recommended for studies on quantitative genetics and selection of perennial plants (RESENDE, 2007a,b); however, it has also been used in annual species such as rice (BORGES *et al*., 2010), common bean (CHIORATO *et al*., 2008; PEREIRA *et al*., 2016), soybean (TESSELE *et al*., 2016), and wheat (SILVA *et al*., 2011).

Adaptability and stability studies in cowpea using the REML/BLUP procedure have increased (SANTOS *et al*., 2016; TORRES *et al*., 2015, 2016). This is because it allows simultaneous selection for yield, adaptability, and stability in the context of mixed models through the use of the Harmonic Mean of Relative Performance of Genetic Values (HMRPGV) method, proposed by Resende (2004).

The objective of this work was to select semi-erect cowpea lines simultaneously for high yield, adaptability, and genotypic stability in the Northeast region of Brazil by the REML/BLUP procedure.

MATERIAL AND METHODS

Twenty cowpea genotypes of semi-erect plant were evaluated—15 lines and five cultivars—from the Embrapa Meio-Norte Cowpea Breeding Program (Table 1). These lines are part of the value-of-cultivation and use (VCU) trials, which are required for registering new cultivars by the National Register of Cultivars (RNC) of the Ministry of Agriculture, Livestock, and Food Supply (MAPA). These genotypes were selected in intermediate trials, which precede the VCU trials.

The genotypes were evaluated for grain yield (kg ha^{-1}) in 22 locations in the Northeast region of Brazil (Table 2) under rainfed conditions from 2013 to 2015. Some VCU trials were conducted in 1, 2, or 3 crop seasons totaling 37 environments. Each environment was represented by the location initial letters and year of the crop season: APOD13, ARAP13, BARR13, CARI13, FREI13, ITAP13, MATA13, REDE13, SRMA13, UMBA13, URUC13, ARAR14, CARI14, BARR14, FEIR14, FREI14, GOIA14, IPAN14, ITAP14, MATA14, SERT14, SUMBA14, ARAR15, AROE15, CAMP15, FEIR15, FREI15, IPAN15, GOIA15, LAGS15, NSDO15, PACA15, SAOJ15, SERT15, SRMA15, UMBA15, and URUC15.

The planting season varied according to the rainy season in the states, which occurred in January to March, except in Alagoas and Sergipe, which occurred in June. All the trials were conducted in a complete randomized block design with 20 treatments and four replications. The treatments were represented by a plot of 2.0 m x 5.0 m with four 5.0 m rows spaced 0.50 m apart, with 0.25 m between plants. The evaluation area was represented by the two central rows. Four seeds were sown per hole, and 20 days after sowing the plants were thinned, leaving two plants per hole. Cultural practices were carried out for the crop as recommended.

Individual analysis of variance for environments and joint analysis of variance for all environments were performed. The joint analysis of variance considered the effect of genotypes as fixed, and the effect of environments as random. The statistical model used followed the equation:

$$Y_{ijk} = \mu + g_i + e_j + ge_{ij} + \beta_{k(J)} + \varepsilon_{ijk} \quad (1)$$

where in: Y_{ijk} is the observed value of the genotype *i* in the environment *j* and block *k*; μ is the overall mean of the trait; g_i is the effect of the genotype *i*; e_j is the effect of the environment *j*; ge_{ij} is the effect of the interaction of the genotype *i* with the environment *j*; $\beta_{k(J)}$ is the effect of the block *k* within the environment *j*; and ε_{ijk} is the experimental error associated with the plot *ijk*.

The mixed models approach through Restricted Maximum Likelihood (REML) and Best Linear Unbiased Prediction (BLUP) multivariate, i.e., REML/BLUP procedure, (RESENDE, 2007b) was used for the analysis of adaptability and stability. This procedure is a method for ordering the genotype simultaneously regarding their genetic values (yield) and stability; it represents the BLUP procedure under the harmonic mean of the data. The lower the standard deviation of the genotypic behavior in the environments, the greater the harmonic mean of genotypic values (HMGV) in the environments. Thus, selection by the highest HMGV implies both selection for yield and stability (RESENDE, 2007b).

In the context of the mixed models, a simple and efficient measure is the relative performance of genotypic values (RPGV) in the environments, i.e., the adaptability of genetic values. The quantity RPGV*OM refers to the relative performance genotypic value multiplied by the overall mean of all environments, providing the average genotypic value, capitalizing the adaptability (RESENDE, 2007b).

Simultaneous selection for yield adaptability and stability in the context of mixed models can be performed by the Harmonic Mean of Relative Performance of Genetic Values (HMRPGV), proposed by Resende (2004). The quantity HMRPGV*OM refers to the HMRPGV multiplied by the overall mean of all environments, which

Table 1 - Semi-erect cowpea genotypes evaluated in the Northeast region of Brazil, from 2013 to 2015, their genealogy and commercial subclass (CS)

GC	Genotype	Genealogy	CS
G21	MNC04-762F-3	TE96-282-22G × (TE96-282-22G × Vita 7)	BL
G22	MNC04-762F-9	TE96-282-22G × (TE96-282-22G × Vita 7)	BL
G23	MNC04-769F-30	CE-315 × TE97-304G-12	ML
G24	MNC04-769F-48	CE-315 × TE97-304G-12	ML
G25	MNC04-792F-146	MNC00-553D-8-1-2-3 × TV×5058-09C	ML
G26	MNC04-769F-62	CE-315 × TE97-304G-12	ML
G27	MNC04-782F-104	(TE97-309G-24 × TE96-406-2E-28-2) × TE97-309G-24	SV
G28	MNC04-792F-143	MNC00-553D-8-1-2-3 × TV×5058-09C	ML
G29	MNC04-792F-144	MNC00-553D-8-1-2-3 × TV×5058-09C	SV
G30	MNC04-792F-148	MNC00-553D-8-1-2-3 × TV×5058-09C	ML
G31	MNC04-795F-153	MNC99-518G-2 × IT92KD-279-3	ML
G32	MNC04-795F-154	MNC99-518G-2 × IT92KD-279-3	SV
G33	MNC04-795F-155	MNC99-518G-2 × IT92KD-279-3	ML
G34	MNC04-795F-159	MNC99-518G-2 × IT92KD-279-3	ML
G35	MNC04-795F-168	MNC99-518G-2 × IT92KD-279-3	BR
G36	BRS Guariba	IT85F-2687 × TE87-98-8G	BL
G37	BRS Tumucumaque	TE96-282-22G × IT87D-611-3	BL
G38	BRS Novaera	TE97-404-1F × TE97-404-3F	BR
G39	BRS Itaim	MNC01-625E-10-1-2-5 × MNC99-544D-101-2-2	FR
G40	BRS Cauamé	TE93-210-13F × TE96-282-22G	BL

GC = Genotype code; ML = Mulato; FR = Fradinho; SV = Sempre-verde; BL = Branco Liso; BR = Branco rugoso provides the mean genotypic value penalized by instability and capitalized by adaptability.

The following statistical model was used for the randomized block designs with one observation per plot and several environments:

$$Y = Xb + Zg + Wga + e \quad (2)$$

where in: *y*, *b*, *g*, *ga*, and *e* are the data vectors of fixed effects (mean of blocks through environments), of genotypic effects of the genotype (random), of effects of the genotype × environment interaction (G×E) (random), and of random errors, respectively; *X*, *Z* and *W* are the incidence matrices for *b*, *g*, and *ga*, respectively.

The Harmonic Mean of Genotypic Values (HMGV) was used for the evaluation of stability; the RPGV was used for the simultaneous evaluation of yield and adaptability; and the HMRPGV was used for the simultaneous evaluation of yield, adaptability, and stability. These evaluation were carried out using the following expressions:

$$HMGV_i = a / \sum_{i=1}^{a} 1 / Vg_j \quad (3)$$

$$RPGV_i = 1 / a[\sum Vg_j / M_j] \quad (4)$$

$$HMRPGV_i = n / [\sum_{j=1}^{n} 1 / Vg_{ij}] \quad (5)$$

where in: *n* is the number of evaluation environments of the genotype *i*; Vg_{ij} is the genotypic value of the genotype *i* in the environment *j*, expressed as a proportion of the average of this environment.

The HMRPGV method (RESENDE, 2007a) has the advantages of providing adaptability and genotypic—rather than phenotypic—stability; allowing the managing

Table 2 - Altitude, geographic coordinate, biome, ecosystem, and climate of the locations where the value-of-cultivation and use trials of semi-erect cowpea were conducted in the Northeast region of Brazil, from 2013 to 2015

Location	Altitude	Latitude	Longitude	Biome	Ecosystem	Climate
Arapiraca-AL	264 m	09º45’07’’ S	36º39’39’’ W	Caatinga	Agreste	TSu
Feira de Santana-BA	234 m	12º16’01’’ S	38º58’01’’ W	Caatinga	Sertão	BSh
Barreira-CE	123 m	04º17’13’’ S	38º38’34’’ W	Caatinga	Sertão	BSh
Itapipoca-CE	109 m	03º29’38’’ S	39º34’44’’ W	Caatinga	Sertão	TAs
Redenção-CE	88 m	04º13’30’’ S	38º43’46’’ W	Caatinga	Sertão	TQSu
Pacajus-CE	60 m	04º10’22’’ S	38º27’39’’ W	Caatinga	Sertão	BSh
Mata Roma-MA	73 m	03º37’30’’ S	43º06’39’’ W	Cerrado	Meio-Norte	TAw
São R. Mangabeiras-MA	225 m	07º01’19’’ S	45º26’51’’ W	Cerrado	Meio-Norte	TAw
Lagoa Seca-PB	634 m	07º10’15’’ S	35º51’14’’ W	Caatinga	Agreste	TAs
Aroeiras-PB	363 m	07º32’42’’ S	35º42’28’’ W	Caatinga	Agreste	TAs
Araripina-PE	622 m	07º34’33’’ S	40º29’52’’ W	Caatinga	Sertão	BSh
Serra Talhada-PE	444 m	07º59’09’’ S	38º17’45’’ W	Caatinga	Sertão	BSh
Goiana-PE	444 m	07º33’39’’ S	35º00’10’’ W	Caatinga	Zona da Mata	TAs
São João do Piauí-PI	222 m	08º21’28’’ S	42º14’49’’ W	Caatinga	Sertão	BSh
Campo Grande do Piauí-PI	443 m	07º07’55’’ S	41º02’09’’ W	Caatinga	Sertão	BSh
Uruçuí-PI	167 m	07º13’44’’ S	44º33’41’’ W	Cerrado	Meio-Norte	TAw
Apodi-RN	67 m	05º39’50’’ S	37º47’56’’ W	Caatinga	Sertão	BSh
Ipanguaçu-RN	16 m	05º29’52’’ S	36º51’18’’ W	Caatinga	Sertão	BSh
Carira-SE	351 m	10º21’29’’ S	37º42’03’’ W	Caatinga	Sertão	BSh
Frei Paulo-SE	272 m	10º32’56’’ S	37º32’02’’ W	Caatinga	Sertão	BSh
Umbaúba-SE	130 m	11º22’58’’ S	37º39’28’’ W	Caatinga	Sertão	TAs
Nossa S. das Dores-SE	204 m	10º29’30’’ S	37º11’36’’ W	Caatinga	Sertão	TAs

TSu = Tropical sub-humid; TQSu = Tropical hot sub-humid; BSh = Semi-arid mild; TAs = Tropical with dry summer season; Taw = Tropical with dry winter season; Ts = Tropical dry of heterogeneity of variances; and providing already-penalized genetic values of instability. Moreover, this method can be applied to any number of environments, eliminate noises of the genotype × environment interaction (G×E), while considering the heritability of these effects; and allows the computation of genetic gain with selection by the three attributes simultaneously.

The analysis of variance was performed using the SAS software (SAS INSTITUTE, 2002). The analyses of adaptability and genotypic stability were performed by the model 54 of the Selegen-Reml/Blup software (RESENDE, 2007b).

RESULTS AND DISCUSSION

The joint analysis of variance for grain yield is presented in Table 3. Although all genotypes have shown a high inbreeding level and some parentage (Table 1) and underwent several selection cycles, they differed significantly (p<0.0001), denoting the existence of selectable variability.

Barros *et al*. (2013), Santos *et al*. (2015) and Barroso *et al*. (2016), evaluated 20 cowpea genotypes for yield adaptability and stability in the Mid-North region and in Mato Grosso do Sul, Brazil, respectively, and also found differences between homozygous genotypes.

The environments also differed for grain yield (p<0.0001), denoting that their eco-physiographic differences (Table 2) combined with the climatic variations affected this trait.

Barroso *et al*. (2016) evaluated the grain yield of 20 cowpea genotypes in six environments of Mato Grosso do Sul and also found differences between the testing environments; affirming that the edaphoclimatic factors had the greatest effect on the adaptability and stability of the genotypes. Ddamulira *et al*. (2015), who evaluated the yield adaptability and stability of 25 cowpea genotypes in three environments in Uganda, and Oliveira, Fontes and Rocha (2015), who evaluated cowpea genotypes in several environments in the state of Amazonas in Brazil, also found different grain yields depending on the environment.

The overall mean grain yield was 1,342 kg ha^{-1}. This mean is well above the national (369 kg ha^{-1}) and world (461.30 kg ha^{-1}) mean for yield of cowpea (FREIRE FILHO, 2011) and is also above the means obtained in other studies on cowpea genotypes in Brazil (BARROS *et al*., 2013; BARROSO *et al*., 2016; SANTOS *et al*., 2015; TORRES *et al*., 2015, 2016). This shows the great potential of this line group in regard to grain yield and the possibility of selecting lines with higher means than the commercial cultivars.

The environment São Raimundo das Mangabeiras-MA 2013 (SRMA13) was the most favorable for grain yield (2,485 kgha^{-1}), while Serra Talhada-PE 2015 (SERT15) was the least favorable (277 kg ha^{-1}) (Figure 1).

The G×E for grain yield was highly significant (p<0.0001) (Table 3); it showed the different behavior of the genotypes depending on the testing environments. This lead to difficulties in the selection of superior genotypes and recommending cultivars (CARVALHO *et al*., 2016; ROCHA *et al*., 2012), since the cultivars adapted to a particular condition may not perform well in other environmental conditions (OLAYIWOLA, SOREMI; OKELEYE, 2015; TEODORO *et al*., 2015).

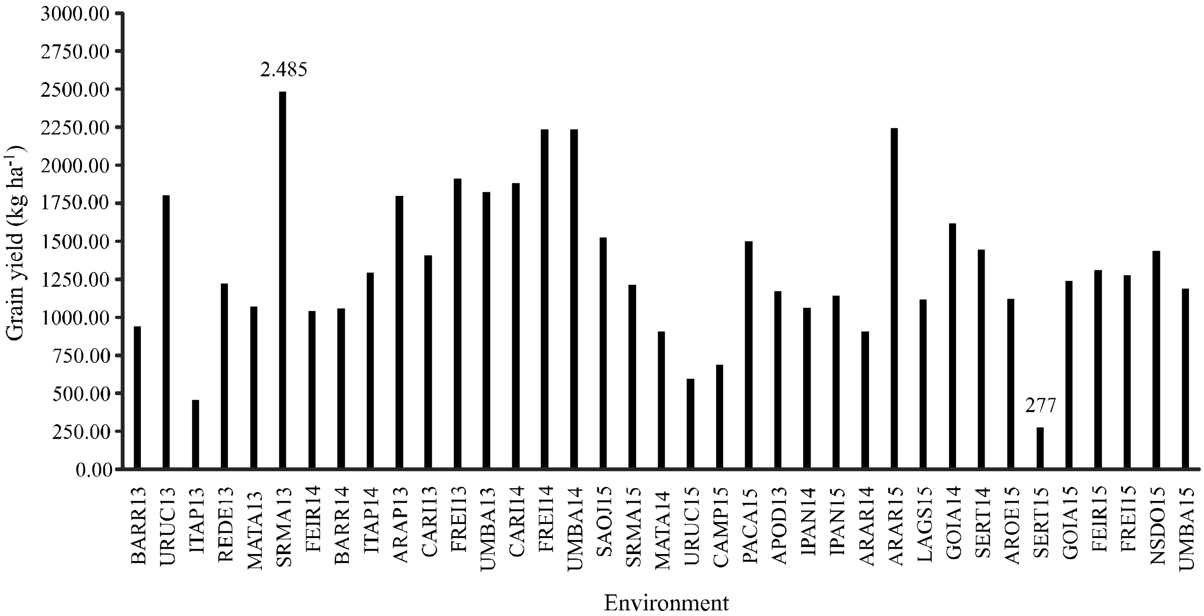
According to estimates of components of variance (REML), the environmental variance contributed most to the phenotypic variance (Table 4). It represented 64% of this variance, followed by the G×E (30%), and genotypic (6%) variances.

The preponderance of the environmental variance in relation to the other components of the phenotypic variance are in agreement with the results found in the

Table 3 - Joint analysis of variance for grain yield of 20 semi-erect cowpea genotypes evaluated in 37 environments of the Northeast region of Brazil, from 2013 to 2015

Source of variation	DF	Mean square	p>F
Blocks/Environments	111	302367.20	<.0001
Genotypes (G)	36	1319851.80	<.0001
Environments (E)	19	20318301.80	<.0001
G×E	684	199350.10	<.0001
Residue	2109	69965.00	
CV (%)	19.71		
Overall mean (kg ha^{-1})	1,342		

Figure 1 - Behavior of the grain yield of 37 testing environments obtained from evaluation of 20 semi-erect cowpea genotypes in the Northeast region of Brazil from 2013 to 2015



analysis of variance (Table 3), the information of the test environments (Table 2), and the environment means (Figure 1), which showed marked contrasts between testing environments for grain yield.

Studies evaluating genotypes of common bean (CHIORATO *et al*., 2008; PEREIRA *et al*., 2016) and cowpea (TORRES *et al*., 2015; OLIVEIRA; FONTES; ROCHA, 2015) in multi-environments also found a higher proportion of environmental variance than genotypic and environmental variances for grain yield.

The low genotype variance found in the group of genotypes evaluated (Table 4) was expected considering that some lines showed relation to each other (Table 1) and all are highly inbred, i.e., they have already undergone several selection cycles for high grain yield. Torres *et al*. (2015, 2016) evaluated the grain yield of 20 cowpea genotypes in multi-environments of Mato Grosso do Sul and also found lower estimates for the genotypic variance than environmental and G×E variances.

The trait yield is controlled by several genes and, therefore, is heavily affected by the environment. In spite of the great effect of the environmental factors, denoted by the relative coefficient of variation (0.32), the heritability at an average genotypic level among the various environments was high (0.84) since the environmental

Table 4 - Estimates of components of variance (individual REML) and genetic parameters obtained from the evaluation of 20 semi-erect cowpea genotypes in 37 environments in the Northeast region of Brazil, from 2013 to 2015

Parameter	Estimate
Genotypic variance (σ^2_g)	7162.05
Residual variance (σ^2_a)	70027.28
Genotype × environment interaction variance (σ^2_{ga})	32780.83
Phenotypic variance (σ^2_f)	109970.17
Heritability genotype mean (h^2_a)	0.84
Genotype selection Accuracy (Acgen)	0.92
Genotypic correlation between environments (rgloc)	0.18
Relative coefficient of variation (Cvg%/Cve%)	0.32

effects were minimized. This allowed a high accuracy (0.92) in the selection of lines based on the average of the environments (Table 4). The heritability obtained in the present study was higher than those estimated by Torres *et al*. (2015, 2016), who evaluated the grain yield of 20 cowpea genotypes in multi-environment of Mato Grosso do Sul and found estimates of 0.68 and 0.54.

According to Chiorato *et al*. (2008), heritability at average level is determined based on the number of replicates and evaluated plants. In the case of the present study, the size of the evaluation area in the experimental unit may have contributed positively to minimize the environmental effects, since the genotypes were represented by 80 plants in the evaluation area of the plot.

The G×E variance was the second most important (30%) (Table 4), which resulted from the low genotypic correlation between environments (0.18). These results showed the existence of G×E of complex-type, and that the best lines in one environment will not necessarily be the best in others (RESENDE, 2007a). This represents a certain difficulty in the selection of genotypes with wider adaptation, which justifies considering in the selection of the lines, their stabilities and adaptabilities.

Barros *et al*. (2013) evaluated the grain yield of 20 cowpea genotypes in the Mid-North region of Brazil and also found the G×E as the second factor affecting the phenotypic variance. On the other hand, Torres *et al*. (2016) observed similar percentages for the G×E and environmental variances.

According to the mean component estimates (BLUP) and the confidence intervals associated with genotypic values (*u+g*), the lines G31 (MNC04-795F-153), G34 (MNC04-795F-159), and G26 (MNC04-769F-62) were superior than most of the genotypes evaluated and presented the highest genetic gains compared to the overall mean, with 12.45%; 11.22%; and 9.51%, respectively (Table 5). These gains were lower than those

Table 5 - Estimates of mean components (individual BLUP) of the effects (*g*) and predicted genotypic values (*u+g*) free from interaction with environments, confidence interval lower limit (CILL), confidence interval higher limit (CIHL) and genetic gain (Gg) of 20 semi-erect cowpea genotypes evaluated in 37 environments of the Northeast region of Brazil, from 2013 to 2015

Order	G	u+g	(CILL – CIHL)1	Gg
G31	167.03	1,508.84	1,434.38 – 1,583.30	167.03
G34	134.17	1,476.85	1,401.52 – 1,550.45	150.60
G26	81.78	1,423.59	1,349.13 – 1,498.05	127.66
G36	40.59	1,382.41	1,307.95 – 1,456.87	105.90
G33	38.27	1,380.08	1,305.62 – 1,454.54	92.37
G32	37.47	1,379.28	1,304.81 – 1,453.74	83.22
G28	36.81	1,378.17	1,304.15 – 1,453.08	76.59
G25	19.26	1,361.07	1,286.61 – 1,435.53	69.42
G40	15.37	1,357.18	1,282.71 – 1,431.64	63.42
G37	-2.93	1,338.88	1,264.41 – 1,413.34	56.78
G39	-10.35	1,331.46	1,256.99 – 1,405.92	50.68
G30	-15.60	1,326.20	1,251.74 – 1,400.67	45.15
G35	-24.26	1,317.55	1,243.09 – 1,392.01	39.81
G24	-24.66	1,317.15	1,242.69 – 1,391.61	35.21
G29	-27.61	1,314.20	1,239.74 – 1,388.66	31.02
G22	-53.99	1,287.82	1,213.35 – 1,362.28	25.71
G27	-63.47	1,278.34	1,203.88 – 1,352.81	20.46
G38	-70.56	1,271.24	1,196.78 – 1,345.71	15.41
G21	-102.49	1,239.32	1,164.86 – 1,313.78	9.20
G23	-174.82	1,166.99	1,092.53 – 1,241.46	0
Overall mean (u)		1,341.81		

[1]Confidence interval associated to the genotypic value estimates, at 95% probability

observed by Torres *et al*. (2016), who evaluated the grain yield of 20 cowpea genotypes in four environments of Mato Grosso do Sul and found gain estimates for the two best genotypes of 18.79% and 18.04%.

The genetic gain depends on the differential of the selection and heritability of the trait. Although the heritability of grain yield was high, a factor that may have led to lower gains than those observed by Torres *et al*. (2015, 2016) was the differences between the overall mean and the means of the superior genotypes, which in the present study were small, relatively to the selection differentials founded by the authors above.

The results of stability (HMGV), adaptability (RPGV), and simultaneous stability and adaptability (HMRPGV) of the genotypes evaluated are presented in Table 6. The five best genotypes, based on the criteria HMGV, RPGV, and HMRPGV were not necessarily the best based on the criterion of the mean genotypic value (Table 5). The coincidence was 80% among the five best genotypes and there was an inversion of order among the coincident ones between HMGV and RPGV. According to Resende (2007a), the use of these attributes or selection criteria can provide further refinement in selection.

Similar results were obtained by Torres *et al*. (2016), who evaluated the yield of 20 cowpea genotypes in the state of Mato Grosso do Sul, and also observed the same percentage of coincidence between the ordering provided by HMGV and RPGV.

The three best lines (G31 - MNC04-795F-153, G34 - MNC04-795F-159 and G26 - MNC04-769F-62) by the criterion HMRPGV*OM, had grain yield of 1,512 kg ha^{-1}, 1,485 kg ha^{-1} and 1,419 kg ha^{-1} (Table 6), i.e., an average superiority of 13%, 11%, and 10%, respectively, over the overall mean of the 37 environments. According to Resende (2007a), these values are obtained through a process that already penalizes the lines for the instability in the environments and capitalizes the capacity of response (adaptability) to

Table 6 - Genetic value stability (HMGV), genetic values adaptability (RPGV), simultaneous genetic value adaptability and stability (HMRPGV), genotypic value capitalizing the adaptability (RPGV*OM) and genotypic value penalized by instability and capitalized by adaptability (HMRPGV*OM) of 20 semi-erect cowpea genotypes evaluated in 37 environments of Northeast region of Brazil, from 2013 to 2015

Order	HMGV	Order	RPGV	RPGV*OM	Order	HMRPGV	HMRPGV*OM
G34	1,229	G31	1.1392	1,528	G31	1.1272	1,512
G31	1,229	G34	1.1196	1,502	G34	1.1074	1,485
G36	1,175	G26	1.0734	1,440	G26	1.0578	1,419
G26	1,129	G36	1.0489	1,407	G36	1.0367	1,391
G25	1,127	G28	1.0315	1,384	G28	1.0223	1,371
G28	1,117	G25	1.0304	1,382	G32	1.0181	1,366
G37	1,117	G33	1.0296	1,381	G33	1.0162	1,363
G32	1,106	G32	1.0291	1,380	G25	1.0111	1,356
G33	1,081	G37	1.0060	1,350	G37	0.9947	1,334
G40	1,078	G40	1.0050	1,348	G40	0.9933	1,332
G22	1,070	G29	0.9882	1,326	G30	0.9719	1,304
G30	1,068	G30	0.9848	1,321	G29	0.9707	1,302
G35	1,066	G35	0.9844	1,321	G24	0.9573	1,284
G29	1,044	G39	0.9828	1,319	G22	0.9516	1,276
G39	1,041	G24	0.9674	1,298	G35	0.9503	1,275
G24	1,014	G22	0.9648	1,294	G39	0.9463	1,269
G27	1,004	G27	0.9446	1,267	G27	0.9326	1,251
G38	992	G38	0.9359	1,256	G38	0.9042	1,213
G21	918	G21	0.8953	1,201	G21	0.8811	1,182
G23	818	G23	0.8390	1,126	G23	0.8086	1,085
Overall mean							1,342

the improvement of the environment. These properties are intrinsic to the HMRPGV method.

The values of RPGV and HMRPGV (Table 6) indicate the average superiority of the genotype in relation to the average of a given environment. Thus, the line MNC04-795F-153 (G31) responds on average 1.1272 times the mean of any environment in which it is grown.

The four best genotypes in genotypic value (Table 5) were also the best in HMRPGV. Similar results were found by Torres *et al*. (2016), who evaluated the yield adaptability and stability of 20 cowpea genotypes in several environments in the State of Mato Grosso do Sul. Based on these authors, this is an indication that the genotypes evaluated in the present work had high adaptive synergism in the 37 environments tested and good predictability, i.e., maintenance of yield in the environments.

In general, the lines MNC04-795F-159 (G31) and MNC04-795F-153 (G34) were superior for yield, adaptability, and stability, and can be recommended for the evaluated environments in the Northeast region of Brazil, with a lower risk of losses in grain yield due to unpredictable environmental factors. According to Torres *et al*. (2016), genotypes that simultaneously have these three attributes can be used as selection criteria in breeding programs.

The lines G31 and G34 are sisters, presenting the same genealogy, and belong to the same commercial subclass—mulatto (Table 1). Their grain yield is also similar (Table 6). Thus, regarding the releasing of cultivars, the line G31 should be chosen, since this line better combines the attributes of yield, adaptability, and stability.

CONCLUSIONS

1. The line MNC04-795F-159 presents greater predictability of grain yield in the environmental conditions evaluated in the Northeast region of Brazil;
2. The line MNC04-795F-153 combines high yield, adaptability and genotypic stability, and can be recommended and grown with greater probability of success in the edaphoclimatic conditions evaluated in the Northeast region of Brazil.

ACKNOWLEDGEMENTS

The authors thank the partners of the genetic breeding network for cowpea in the Northeast Region for the structural support and personnel in conducting the tests; and Dr. Marcos Deon Vilela de Resende, for the assistance in the statistical analysis of adaptability and stability via REML/BLUP procedure.

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