ADAPTABILITY AND STABILITY OF GRAIN YIELD IN COWPEA UNDER DIFFERENT BIOMETRICS

Adaptabilidade e estabilidade da produtividade de grãos em feijão-caupi sob diferentes biometrias

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ABSTRACT

This study evaluated the statistical methods for adaptability and stability analysis of grain yield in cowpea genotypes and indicated the genotypes most adapted and stable to environmental conditions of Ceará State. It was used data of grain yield of cowpea from four environments in Ceará, testing 22 genotypes, and using the following methods: Traditional, Plaisted and Peterson, Wricke, Finlay e Wilkinson, Eberhart and Russell, Linn and Binns, and Annicchiarico. We recommend using the methods Annicchiriaco and Linn and Bins together with the method of Eberhart and Russell. The genotypes CE-31, CE-73, CE-77, CE-949 and CE-956 are the most adapted and stable. The latter two are suitable for cultivation in production system with more technology.

Keywords: *Vigna unguiculata*, production adaptability, genotype evaluation, biometric analysis.

RESUMO

O trabalho teve como objetivo avaliar métodos estatísticos de análise da adaptabilidade e estabilidade da produtividade de grãos em genótipos de feijão-caupi e indicar os genótipos mais adaptados e estáveis às condições ambientais do estado do Ceará. Foram utilizados dados de produtividade de grãos de feijão-caupi de quatro ambientes no Ceará, testando-se 22 genótipos. Foram utilizados os seguintes métodos: Tradicional, Plaisted e Peterson, Wricke, Finlay e Wilkinson, Eberhart e Russell, Linn e Binns e Annicchiarico. Recomenda-se utilizar os métodos Annicchiriaco e Linn e Bins em conjunto com o método de Eberhart e Russell. Os genótipos CE-31, CE-73, CE-77, CE-949 e CE-956 são mais adaptados e estáveis, sendo os dois últimos indicados para o cultivo em sistemas de produção que utilizam maiores insumos.

Palavras-chaves: V*igna unguiculata*, adaptabilidade produtiva, avaliação de genótipos, análises biométricas.

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The adaptability and stability of genotypes deserve attention in breeding programs. The adaptability refers to the ability of the genotype in taking advantage of the environmental stimuli, and the stability concerns the capability of the genotype to show a highly predictable behavior facing an environmental stimulus (CRUZ et al., 2012).

Due to the importance of assessing the interaction between genotype and environment and the adaptability and stability, numerous methods have been described, based on different principles. Given these, preference should be given to those ensuring greater reliability to the breeder of the genotypes indications (CARGNELUTTI FILHO et al., 2007).

In this way, in studies on adaptability and stability, the relationship between methods should be considered (PEREIRA et al., 2009) in order to choose the most simple and easy to interpret. This study aimed at evaluating different statistical methods to analyze the adaptability and stability of cowpea genotypes, and to indicate those most adapted and stable to the environmental conditions of Ceará State.

Initially, a pre-selection was carried out among 500 genotypes, resulting in 22 genotypes (CE-03, CE-25, CE-31, CE-46, CE-73, CE-77, CE-104, CE-113, CE-596, CE-790, CE-796, CE-798, CE-930, CE-933, CE-937, CE-939, CE-940, CE-946, CE-947, CE-949, CE-956 and CE-957) with superior traits for yield components, important for the production of grains. All accession from the cowpea Germplasm Bank (BAGCaupi) of the Center of Agrarian Sciences (CCA/UFC) were evaluated for grain yield in four environments at State of Ceará.

In the crop year of 2010, four experiments were undertaken in different sites and periods. In the municipalities of Quixadá and Cascavel, the sowings were performed in April (rainy period). The experiment consisted of a randomized block design with four replicates in plots of 2.8 x 4.0 m. In order to remove the edge effect, the useful working area was comprised of two central rows (5.6 m^2), adding up to 20 plants/plot.

The fertilization with NPK was done according to the soil analysis and applied to the foundation at sowing. The weeding and pest control were performed according to the crop need, and the thinning at 15 days after sowing, resulting in one plant per hole and a population of 35,714 plants ha^{-1} in the two locations.

In the municipalities of Pentecoste and Fortaleza, the experiments were conducted in September and October (dry period), consisting of a randomized block design with four replicates in plots of 4.0 x 4.0 m (Pentecoste) and 2.0 m x 3.0 m (Fortaleza), totaling a working area of 8 m^2 (Pentecoste) and 3 m^2 (Fortaleza). Cultural practices were done according to the needs, and the thinning at 15 days after sowing, resulting in two plants per hole (Pentecoste) and one plant per hole (Fortaleza), adding up to a population of 50,000 plants ha^{-1} and 66.666 plants ha^{-1}, respectively. Irrigations were undertaken by furrow in Pentecoste and by micro-sprinklers in Fortaleza.

Yield data (kg/ha) were subjected to analyses of variances (individually and jointly) to test the variability among genotypes, after performing the correct stand by the method of covariance, using the model defined by the equation $Y_{ij}=\mu + g_i + b_j + \beta\left(X_{ij} - \bar{X}\right) + \varepsilon_{ij}$, where Y_{ij} = observation of the genotype *i* of the repetition *j*, μ= overall mean of the experiment, g_i = effect of the genotype *i*, b_j = effect of the block *j*, $(X_{ij}-\bar{X})$ = deviation observed in the stand and ε_{ij}= random error, and the comparison of the means of the genotypes of each location was performed by the Scott-Knott's test, and between locations, by the Tukey's test.

In the joint analysis, the homogeneity of residual variances of the experiments (QMR) was verified by the ratio between the highest and the lowest mean-square residual of the tests. According to Gomes (1990), to be considered homogeneous, this ratio must be lower than seven.

The evaluation of the phenotypic adaptability and stability of the genotypes by the methods: TRADITIONAL, PLAISTED & PETERSON (1959), FINLAY & WILKINSON (1963), EBERHART & RUSSEL (1966), LIN & BINNS (1988), ANNICCHIARICO (1992) and WRICKE (1965). The statistical analyses were performed using the software Genes (CRUZ, 2006).

Table 1 - Means obtained by the genotypes (Kg ha^{-1}) in each evaluating location, mean of each environment, and coefficient of variation (CV) of the individual analyses

Genotype	Environment			
	Cascavel	Fortaleza	Pentecoste	Quixadá
CE-03	451.03 c* B**	637.63 b B	1760.03 a A	631.60 c B
CE-25	115.55 f C	833.85 a B	1179.89 b A	739.23 b B
CE-31	329.05 d C	863.82 a B	1724.24 a A	872.37 a B
CE-46	228.35 e B	605.96 b AB	974.00 b A	830.67 b A
CE-73	262.90 e C	747.03 b BC	1850.08 a A	997.70 a B
CE-77	231.61 e C	826.17 a B	1970.18 a A	979.04 a B
CE-104	221.59 e C	1152.17 a AB	1623.78 a A	556.32 c BC
CE-113	86.88 f C	716.66 b B	1265.53 b A	615.36 c B
CE-946	77.97 f B	393.58 b AB	643.97 b A	448.69 c AB
CE-947	218.68 e B	667.34 b B	1400.22 a A	593.58 c B
CE-949	561.07 b B	755.27 b B	1984.09 a A	716.88 b B
CE-956	340.60 d C	962.00 a B	1794.42 a A	605.59 c BC
CE-957	680.01 a B	656.49 b B	1535.65 a A	556.32 c B
CE-596	245.36 e C	967.53 a AB	1527.85 a A	795.48 b BC
CE-790	73.18 f B	758.71 b A	726.78 b A	592.31 c A
CE-796	443.67 c C	1022.30 a B	1584.37 a A	564.06 c BC
CE-798	191.62 e B	609.89 b B	1305.38 b A	409.83 c B
CE-930	229.42 e B	766.07 b A	975.89 b A	729.42 b AB
CE-933	218.01 e B	657.94 b AB	1033.88 b A	723.13 b A
CE-937	189.68 e B	642.99 b A	855.02 b A	719.51 b A
CE-939	247.07 e C	1018.31 a AB	1462.96 a A	818.66 b B
CE-940	410.16 c B	1045.78 a A	1247.77 b A	991.80 a A
Mean	275.16	786.71	1383.00	703.44
CV (%)	24.15	21.01	25.68	23.31

**Means followed by the same capital letter are not significantly different between the locations (row), by the Tukey's test at 5% probability. *Means followed by the same lower case are not significantly different within each location (column) by the Scott-Knott's test at 5% probability.

The order of adaptability and stability of each method was defined according to their concept of stability and number of parameters. The stability and adaptability parameters provided by each method were used with equal weight for defining the genotypes' classification.

Besides the classification of the genotypes according to the used methods, a classification considering the mean yield as one of the adaptability and stability parameters was also obtained. In this case, the genotypes were ranked in ascending order, from the highest average.

To compare the methods, a Spearman correlation was used between the rank orders obtained by the parameters of stability and adaptability for each pair of methods, as well as for the rank order of the genotypes in relation to the mean yield.

The overall mean of the genotypes in Fortaleza and Pentecoste was higher than in Cascavel and Quixadá (786.71 and 1,383 kg ha^{-1}, respectively), evidencing the superiority of those environments (Table 1). This result may be related to the use of irrigation in these locations, reducing considerably the risks, promoting thus a better control of the environment (MOUSINHO et al., 2008).

The yield in Pentecoste was different from the yield found in Fortaleza, but similar to the yield reported by SILVA & NEVES (2011), when reaching a mean yield of 1,436 kg ha^{-1} for the irrigated crop.

The mean yields in Cascavel and Quixadá were respectively 275.16 and 703.44 kg ha^{-1}. This reduction was probably due to the low water supply. RESENDE et al. (1981) reported that the water deficit reduces the turgor pressure and consequently the cell expansion, it also reduces the translocation of photoassimilates to the roots directly affecting the plant growth.

NASCIMENTO et al. (2004) found that the cowpea component most affected by water deficit is the number of pods per plant, the major responsible for the decreased yield, but consists in a defense mechanism of the plant. In this respect, LIMA et al. (2011) characterized this system as extreme annual variability of rainfall.

The significance of the interaction genotype x environment indicates the importance of evaluating genotypes in different environments. CARGNELUTTI FILHO et al. (2009) stated that the significance of that interaction emphasizes the inconsistent behavior of the genotypes in the different environments.

The techniques aim to identify genotypes with predictable behavior in diverse environments, which according to OLIVEIRA et al. (2006) reduce the errors of recommendation of genotypes, being indicated by CARGNELUTTI FILHO et al. (2009) as an adequate procedure.

Spearman correlations, in relation to the estimates obtained in the seven methods of analysis of adaptability and stability of grain yield of cowpea, ranged from -0.70 to 0.97, indicating distinct concordance levels in the genotypes classification (Table 2).

Table 2 - Spearman correlation applied to the orders of adaptability and stability of each pair of methods.

Method [(1)]	PeP	W	FeW	EeR	ANN	LeB	Média
TR	0.29	0.34	0.92**	0.69**	-0.47**	-0.70**	-0.70**
PeP		0.78**	0.04	0.45*	-0.48*	-0.44*	-0.49*
W			0.27	0.52*	-0.33	-0.38	-0.42*
FeW				0.67**	-0.39*	-0.65*	-0.63*
EeR					-0.55*	-0.68*	-0.69**
ANN						0.93**	0.92**
LeB							0.97**

[(1)]TR: Traditional; PeP: Plaisted & Peterson (1959); W: Wricke (1965); FeW: Finlay & Wilkinson (1963); EeR: Eberhart & Russell (1966); ANN: Annicchiarico (1992); LeB: Lin & Binns (1988). * and **Significant at 5 a 1% probability, respectively.

Nevertheless, the methods Traditional and Finlay & Wilkinson, and the methods Plaisted & Peterson and Wricke, presented positive correlation to each other, evidencing concordance in the indication of genotypes. The similarity between the methods Traditional and Finlay & Wilkinson may be explained by the fact that both assess the adaptability and stability through the minimum variance between environments. On the other hand, the similarity between methods Plaisted & Peterson and Wricke, is because both use the decomposition of the sum of squares, of the interaction genotype x environment in the derivation of their stability parameters (CRUZ et al., 2012). These methods presented negative correlations with the mean yield (Table 2), indicating that genotypes identified as the most stable and adapted are not necessarily the most productive. The genotypes with highest mean of yield (CE-77 and CE-949) were ranked respectively as 22nd and 21th in stability and adaptability by the Traditional method, 22nd and 18th by Finlay & Wilkinson, 19th and 21st by Plaisted & Peterson, and 20st and 22nd by Wricke (Table 3).

The Traditional method identified the genotypes CE-946 and CE-930 as the most adapted and stable. Nevertheless, they were ranked 22nd and 16th in yield (Table 3) respectively. The genotypes CE-946 and CE-790, identified as the most adapted and stable by Finlay and Wilkinson, were those ranked 22nd and 21st in yield. The genotypes CE-930 and CE-947, identified as the most adapted and stable by Plaisted & Peterson, were those at 16th and 15rd in yield. For the Wricke method, the genotypes CE-596 and CE-947, identified as the most adapted and stable, were those ranked 11th and 15rd in yield.

The methods of Annicchiarico and Lin & Binns were highly correlated between themselves and to the mean yield (Table 2), indicating that genotypes rated by these methods were the most adapted and stable, and should be considered as the most productive. The two methods identified the most productive genotypes (CE-31, CE-77 and CE-949) among the most adapted and stable in the average of all environments.

With regard to the methods of Annicchiarico and Lin & Binns, Pereira et al. (2009), found high relationship between them and with the mean yield, indicating the use of these methods. These same authors emphasized the practical advantages of using these methods, since besides identifying the most adapted and stable genotypes among the most productive, they also have ease of application and interpretation of the parameter that measures the stability and adaptability.

The method of Eberhart & Russell featured high positive correlation with the methods Traditional (r_s=0.69), Finlay & Wilkinson (r_s=0.67), Plaisted & Peterson (r_s=0.45) and Wricke (r_s=0.52), indicating similar responses between these methods. However, it had negative correlation with the methods Annicchiarico, Lin & Binns and with the average.

Among the available methodologies, the method of Eberhart & Russell, according to ROCHA et al. (2010), gives details of the genotypes behavior, by estimating the adaptability, stability and the coefficient of predictability of each genotype. Therefore this method can be used to add information to the methods of Annicchiarico and Lin & Binns. But attention should be given to the negative correlation with the mean yield.

In order to estimate the adaptability and stability of the genotypes the method of LIN & BINNS (1988) with the aid of EBERHART & RUSSELL (1966) was used. The LIN & BINNS method (1988) analyzes the adaptability and stability of genotypes through the Pi statistics, which measures the performance of a given genotype in relation to the genotype with best performance, in each environment evaluated, considering as the most promising, the genotype with the lowest estimate of Pi.

The model of Eberhart & Russell, uses the regression of the mean of each genotype in each environment in relation to an environmental index, and the slope indicates the genotype adaptability. When β_1>1 the genotype is more adapted to favorable environments, with β_1<1, the genotype is adapted to unfavorable environments. The genotypes with β_1=1 have wide adaptability to environments.

Table 3 - Estimates of adaptability and stability of 22 cowpea genotypes evaluated in four environments

Genotype	TR	PeP	W	FeW	EeR			ANN	LeB	Mean
	$QM_{(A/Gi)}$	θ_i	w_i	β'_i	β'_i	σ^2_{di}	R^2	Ii	Pi	(Kg ha^{-1})
CE-03	28.72^{19}	6.72^{20}	7.7^{21}	1.17^{17}	1.17	8676.33	79.84^{17,5}	108.44^{7}	30170.14^{3}	665.13^{6}
CE-25	20.28^{13}	3.05^{8}	2.33^{9}	1.25^{13}	1.05	-3669.33	90.89^{9,5}	76.67^{18}	81839.25^{16}	524.85^{14}
CE-31	28.10^{17}	2.81^{6}	1.98^{7}	1.29^{21}	1.29	23353.29	99.40^{11,0}	116.56^{3}	23166.13^{2}	696.88^{3}
CE-46	15.78^{8}	5.01^{16}	5.24^{17}	0.84^{7}	0.84	16774.12	75.64^{10,5}	85.93^{14}	81572.93^{15}	530.08^{13}
CE-73	30.55^{20}	5.08^{17}	5.33^{18}	1.28^{20}	1.28	963.81	90.35^{15,5}	104.70^{9}	37361.22^{7}	666.24^{5}
CE-77	39.68^{22}	6.00^{19}	6.70^{20}	1.52^{22}	1.52	24191.15	97.98^{22}	106.17^{8}	30716.99^{4}	700.46^{2}
CE-104	20.84^{14}	4.78^{12}	4.89^{13}	1.00^{11}	1.00	-509.44	81.01^{13}	94.22^{12}	61849.19^{12}	591.66^{12}
CE-113	23.24^{16}	2.35^{4}	1.29^{5}	1.16^{16}	1.16	-2264.90	97.43^{10,5}	68.34^{20}	89437.56^{18}	492.18^{18}
CE-596	21.05^{15}	1.95^{2}	0.70^{2}	1.11^{15}	1.11	16318.13	98.29^{9}	102.77^{11}	43655.97^{10}	625.44^{11}
CE-790	11.50^{3}	4.99^{15}	5.20^{16}	0.71^{3}	0.71	20096.64	74.91^{6}	58.56^{21}	139489.51^{21}	407.45^{21}
CE-796	14.52^{6}	4.78^{13}	4.90^{14}	0.81^{6}	0.81	15802.34	76.59^{9}	111.29^{4}	39437.79^{8}	645.91^{9}
CE-798	18.58^{11}	3.83^{10}	3.50^{11}	0.97^{10}	0.97	7813.82	84.84^{9}	71.82^{19}	101879.93^{19}	457.67^{20}
CE-930	11.29^{2}	3.74^{9}	3.36^{10}	0.75^{5}	0.75	2684.52	84.68^{13}	86.14^{13}	86112.63^{17}	513.40^{16}
CE-933	14.06^{5}	2.52^{5}	1.55^{6}	0.88^{9}	0.88	14648.25	92.66^{13}	84.47^{16}	81034.85^{14}	512.65^{17}
CE-937	11.65^{4}	4.68^{11}	4.74^{12}	0.73^{4}	0.73	1643.04	77.19^{5,5}	76.9^{17}	104652.34^{20}	473.47^{19}
CE-939	19.35^{12}	2.25^{3}	1.15^{4}	1.05^{14}	1.05	21935.16	95.40^{12}	103.57^{10}	45237.66^{11}	628.84^{10}
CE-940	15.75^{7}	4.83^{14}	4.97^{15}	0.85^{8}	0.85	37663.04	76.82^{10,5}	119.60^{2}	33806.48^{5}	694.08^{4}
CE-946	8.66^{1}	3.01^{7}	2.27^{8}	0.70^{2}	0.70	-2091.48	95.58^{3}	49.43^{22}	166433.34^{22}	336.94^{22}
CE-947	17.85^{10}	1.71^{1}	0.21^{1}	1.02^{12}	1.02	26196.68	98.46^{18,5}	84.84^{15}	73675.99^{13}	518.38^{15}
CE-949	31.21^{21}	8.25^{21}	10.03^{22}	1.19^{18}	1.19	50234.76	75.96^{7}	122.43^{1}	15689.18^{1}	746.52^{1}
CE-956	28.67^{18}	5.62^{18}	6.14^{19}	1.21^{19}	1.21	-2884.33	85.24^{17,5}	109.14^{6}	35963.50^{6}	660.34^{7}
CE-957	16.65^{9}	11.93^{22}	15.48^{3}	0.62^{1}	0.62	69781.03	39.00^{10,5}	109.315^{5}	40651.30^{9}	656.27^{8}

$^{(1)}$TR: Traditional; PeP: Plaisted & Peterson (1959); W: Wricke (1965); FeW: Finlay & Wilkinson (1963); EeR: Eberhart & Russell (1966); ANN: Annicchiarico (1992); LeB: Lin & Binns (1988)

In the evaluation of adaptability and stability of cowpea genotypes, considering the Lin & Binns method, in general, the genotypes CE-31, CE-73, CE-77, CE-949 and CE-956 were the most productive, and with lowest values of Pi. The genotypes CE-46, CE-946, CE-790, CE-930 and CE-937 had the lowest averages of yield and lower performance for adaptability.

The Eberhart & Russell model was complementary, used to add information to indicate genotypes. In general, the genotypes had good predictability, since the coefficients of determination (R^2) were above 80%.

The genotypes classified as the most adapted and stable are indicated by Eberhart & Russell for favorable environments ($\beta i>1$). However, only CE-31 was considered as the most stable, since it presented the lowest variance. Those less adapted and stable were best suited to harsh environments ($\beta i<1$).

The genotypes considered as less adapted and stable were those that responded less to the favorable environmental conditions, corroborating the methodology proposed by Eberhart & Russell. In this context, highlight the CE-946 (Table 1) that had no significant results under irrigation.

The genotypes CE-949 and CE-957 may be indicated to those farmers that invest in favorable environmental conditions by using farm inputs. And the CE-173 may be indicated to traditional farmers that do not employ or make little use of inputs in the crop.

Therefore is recommended using the evaluation method of Lin and Binns with the aid of the method proposed by Eberhart and Russel. The genotypes CE-31, CE-73, CE-77, CE-949 and CE-956 are the most adapted and stable to the studied environments, the latter two the most responsive to favorable environmental conditions.

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