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Adaptability and stability parameters for potassium and calcium contents and grain yield in cowpea lines

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The aim of the present study is to estimate the adaptability and stability of K and Ca contents, and grain yield in cowpea lines for release as new cultivars. Forty-four inbred lines and cultivars were assessed in seven sites of the Brazilian semi-arid region. Significant statistical differences were observed in the treatment, environments and environment treatment interaction mean squares for all variables. The methods by Eberhart and Russell (1966), Lin and Binns (1988), and the additive main effects and multiplicative interaction (AMMI) showed similar results in the selection of superior materials. The C4I and C3O lines showed grain yield equal to or greater than the overall mean of 1050 kg ha^{-1} in the experiments, with mean of K and Ca higher than the values of the assessed cultivars, as well as wide stability and good predictability in the assessed environment series. The lines showed great potential to be released as new cultivars in the Brazilian semiarid region.

Key words: *Vigna unguiculata*, additive main effects and multiplicative interaction (AMMI), biofortification, genotype×environment interaction.

INTRODUCTION

In Brazil, cowpea cultivation has become a major social and economic alternative for rural populations in the North and Northeast regions, and its cultivation has expanded to other regions in the country (Oliveira et al., 2010). Besides that, the nutritional and functional benefits of cowpea have gained industrial importance for use as a potential ingredient for food formulations (Hamid et al., 2014). Currently, introduction of biofortified agricultural products containing high protein and mineral levels is considered an important component in breeding programs focused on eliminating human malnutrition (Santos and Boiteux, 2013).

The nutritional deficiency in food has affected many poor families, particularly in developing countries (Bouis and Welch, 2010). According to FAO (2014), it is estimated that approximately 805 million people were chronically undernourished and that they did not have access to daily protein and carbohydrate intake recommended by the World Health Organization (WHO). According to Nutti et al. (2009), biofortification is a strategy used in agriculture to improve the health of the poor populations and it is an additional tool to combat nutrient deficiency.

Cowpea presents great variability in the chemical composition of the grains and it enables the selection of

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genotypes with high nutritional contents. Singh (2007) evaluated fifty cowpea lines and noted that the potassium content ranged from 12.7 to 16.2 g kg^{-1} and calcium content from 0.54 to 1.33 g kg^{-1}. Santos and Boiteux (2013) studying eighty-seven cowpea lines found K content from 21 to 27 g kg^{-1} and Ca content from 0.41 to 6.26 g kg^{-1}. These minerals are of great importance for human health. Ca is essential for muscle contraction, nervous system function, blood vessel expansion and contraction, and secretion of hormones and enzymes (McDowell, 1992). Potassium is the third most abundant mineral in the human body and is essential to human life (COMA, 1991).

In the selection phase of cowpea lines, the same line may have different behavior according to the year and place of cultivation. According to Cruz et al. (2012), this difference is often influenced by various environmental conditions treated as genotype×environment interaction (G×E). An alternative to minimize the influence of this interaction is to evaluate genotypes in many environments and apply methods to classify and select them according to their adaptability and stability.

The methods of adaptability and stability analysis are very helpful to identify stable and predictably genotypes in the presence of G×E (Silva and Duarte, 2006). Several adaptability and stability methods used to estimate the contribution of each genotype to the interaction stand out in the literature. Methods based on linear regression (Eberhart and Russell, 1966), non-parametric analysis (Lin and Binns, 1988) and the multiplicative based on principal components of additive main effects and multiplicative interaction (AMMI) have been the most used in the selection of cowpea genotypes with high productivity (Barros et al., 2013; Mano, 2009; Nunes et al., 2014). Differently from studies on grain yield, adaptability and stability studies related to the mineral content in cowpea are still scarce in the literature.

The aim of the current study was to estimate the adaptability and stability parameters of grain yield and mineral production in cowpea seeds, in two experiments assessed in seven irrigated or rainfed environments, in order to enable the recommendation and registration of new cultivars for São Francisco Valley region.

MATERIALS AND METHODS

Plant material

Cowpea lines selected due to their high mineral content and grain yield were assessed. The lines resulted from the crossing between three introduced accessions of the International Institute for Tropical Agriculture (IITA) and three cultivars adapted to the Brazilian semiarid region, according to the procedures described by Santos and Boiteux (2013). The selected lines composed of two experiments, according to the plant size type: I) semi-climbing habit and indeterminate growth (SCH), with 23 treatments - 20 lines (C2R, C3S, C3M, C3Q, C3B, C6P, C1M, C3F, C3L, C2C, C1T, C3R, C4G, C6A, C2T, C3P, C6D, C1V, C4I and T16_2R) and three control cultivars (BRS Acauã, BRS Pujante and Canapu landrace), and II) upright cowpea plants with determinate growth (UDG), with 21 treatments - 18 lines (C1N, C1R, C3O, C2I, C1G, C1S, C2J, C1J, C1F, C2O, C2S, C2B, C2A, C2Q, C1O, C1I, C2M and Marrom) and three control cultivars (BRS Carijó, BRS Tapaihum and Canapu landrace).

The experiments were conducted in the Brazilian States of Bahia, Ceará, Pernambuco and Piauí. The study adopted a randomized block experimental design with three replications in three irrigated environments, in the second half of the year, and four rainfed environments, in the first half of the year. Each plot had 3.0×2.0 m dimension. The experimental plot of the SCH experiment was formed by two rows, with 1.0 m space between rows and 0.1 m between plants, and it resulted in the population density of 100,000 plants per hectare. On the other hand, the experimental plot of the UDG experiment was formed by four rows, with 0.5 m space between rows and 0.1 m between plants, and it led to the population density of 200,000 plants per hectare.

Mineral quantification

Approximately 10 g of seeds from 924 plants were ground in a MA 630/1 mill (Marconi, Brazil) in order to obtain fine flour from each sample. The samples were analyzed in duplicate, according to the standard procedures of the Association of Official Analytical Chemists (AOAC, 1995). Five milliliters of nitric acid and 1 ml perchloric acid were added to each 500 mg of cowpea sample for acid digestion, which was carried out in a block digester. One milliliter of extract was transferred to a 50 ml beaker, identified by the sample protocol number, and 49 ml lanthanum oxide was added. The quantification samples were subjected to reading in flame atomic absorption spectrophotometer (Varian). The results were expressed in g kg^{-1} for potassium and calcium of grain dry matter. All the analyses were carried out in the soil laboratory of Semi-Arid Embrapa.

Statistical analyses

The statistical analyses of the experimental designs were performed in the SAS software (SAS, 1989), according to the GLM procedure (SAS, 1989). The grain yield was corrected in the SAS (1989) software, through covariance method, using the average plant stand of the plots in each experiment, as it was described by Vencovsky and Barriga (1992). Scott and Knott's (1974) clustering was applied at 5% of significance. The adaptability and stability of genotypes were assessed through the methods developed by Eberhart and Russell (1966) and Lin and Binns (1988) in the Genes software (Cruz, 2006), as well as by the multiplicative method based on principal components (AMMI), using the SAS software (1989) as described by Duarte and Vencovsky (1999).

According to the method by Eberhart and Russell (1966), the regression coefficient is associated with the linear component, and it indicates genotype adaptability: genotypes with index $\beta i = 1$ has wide adaptability; deviations from the regression equal to zero ($\sigma^2_{di} = 0$) indicate good stability. According to the method by Lin and Binns (1988), the Pi parameter defines the genotype stability as the mean square of the distance between the mean of a genotype and the maximum mean response of all locations. Genotypes with lower Pi values correspond to those with better performance.

The AMMI methodology stands out because it best describes the G×E interaction through the disposal of additional noises found in traditional interaction estimates. It uses together the variance analysis of the main effects of genotypes and environments and the principal component analysis (PCA) of the interaction. It also identifies the most stable and adaptable genotypes and performs the agronomic zoning of the environments (Duarte and Vencovsky, 1999).

Table 1. Treatment mean squares (TMS), residual mean squares (RMS), means and coefficient of variation (CV) related to yield, and potassium and calcium contents in 20 lines and three control cultivars (SCH experiment – semi-climbing habit) and in 17 lines and four cowpea cultivars (UDG experiment – upright cowpea plants with determined growth) assessed in seven irrigated and rainfed environments.

Locality	Yield				Potassium				Calcium			
	TMS	RMS	Mean	CV	TMS	RMS	Mean	CV	TMS	RMS	Mean	CV
	SCH Experiment											
Acauã	87189**	42345	684	30.0	3.5**	1.4	15.1[b]	7.8	0.2	0.11	1.3[a]	25.9
Petrolina A	306194**	57712	1322	18.1	7.9**	3.1	14.8[b]	11.9	0.0*	0.02	0.8[c]	17.2
Petrolina B	90050**	32140	727	24.6	3.2	3.7	14.9[b]	12.9	0.1	0.06	1.1[b]	22.1
Dormentes	355248**	60272	689	35.6	19.6**	5.4	14.7[b]	15.8	0.1**	0.04	0.9[c]	21.3
Limoeiro	278796**	114883	2192	15.4	15.0**	3.1	14.9[b]	11.8	0.4*	0.15	1.1[b]	33.6
Juazeiro	202060*	97575	729	42.8	5.5*	2.7	14.9[b]	11.0	0.7**	0.07	1.3[a]	20.7
Petrolândia	259048**	81818	897	31.8	5.9**	1.5	15.7[a]	7.9	0.1**	0.03	1.2[a]	14.9
	UDG Experiment											
Acauã	86308	78306	1087	25.7	1.6*	0.7	14.5[b]	6.0	0.03	0.02	0.9[b]	18.8
Petrolina A	121491*	62900	1697	14.7	5.3*	2.3	16.2[a]	9.4	0.04*	0.02	0.8[b]	16.8
Petrolina B	52592*	28273	734	22.9	3.4	3.4	14.1[c]	13.1	2.20*	0.01	0.8[b]	16.1
Dormentes	653413**	75526	887	30.9	2.5	1.8	14.0[c]	9.6	0.05	0.03	0.9[b]	21.5
Limoeiro	398371**	102030	2057	15.5	11.4**	4.3	14.8[b]	14.0	0.24	0.04	0.8[b]	24.5
Juazeiro	116106	83516	806	35.8	3.7*	1.9	14.6[b]	9.5	0.75**	0.08	1.1[b]	26.3
Petrolândia	98114	71214	692	38.5	5.2	3.9	16.4[a]	12.1	0.16**	0.05	1.2[a]	19.2

Values followed by the same letter in the column belong to the same group, according to the Scott and Knott test (1974) at 5% probability; **, * Significant at 1 and 5%, respectively, according to the F test.

RESULTS AND DISCUSSION

Cowpea lines of semi-climbing habit (SCH)

Statistically significant differences were observed in the mean squares of the treatments, for the grain yield and the potassium and calcium contents in most environments, except for the potassium and calcium contents in the Bebedouro environment, and for calcium content in the Acauã environment. The experiments in Acauã, Dormentes, Limoeiro and Petrolândia were conducted on farming properties. Such fact did not compromise the assessments as the variation coefficients were below 43% (Table 1) and allowed making the assessments in environments that represent the cowpea cultivation.

The Limoeiro environment showed the highest mean grain yield (Table 1), indicating the yield potential of the assessed lines. As it was observed in Limoeiro, some of them may exceed 3,000 kg ha^{-1} grain yield under high technology conditions. As for the minerals, the Petrolândia environment showed the highest mean potassium and calcium content.

The relations between the largest and smallest mean squared residuals observed in experiment were below or close to seven for all variables, and it indicated homogeneity in the residual variances, which is a required condition for the joint analysis of experiment (Cruz and Regazzi, 1997). The grain yield means in the three irrigated environments was 84% higher than the means found in the four rainfed environments (Table 1). This result corroborated those reported by Santos et al. (2008). However, the means of the assessed minerals showed similar values, regardless of the adopted handling, whether with or without irrigation.

The BRS Acauã cultivar showed the highest grain yield (Table 2). This cultivar was previously assessed in the same locations the lines of the current research were done (except for Limoeiro) and was selected exclusively for grain yield and earliness (Santos et al., 2008). The C3R and C3B lines presented grain yield close to that of the BRS Acauã control cultivar, as well as wide adaptability and good stability parameters through both the Eberhart and Russell (1966) and the Lin and Binns (1988) methods (Table 2).

The C2C, C3P, C6D, C1V, C4I e T16_2R lines showed the highest mean K contents. The Eberhart and Russell (1966) method highlighted the C6D and C1V lines with wide adaptability and stability. The Lin and Binns (1988) method highlighted the C41, C6D and C1V lines with the lowest Pi values. C1T, C6A, C2T and C4I lines showed the highest mean Ca contents and all showed unpredictable stability and only C1T presented broad adaptability by the Eberhart and Russell (1966) method. The Lin and Binns (1988) method were very different from Eberhart and Russell (1966) results, highlighting C4I

Table 2. Yield, potassium and calcium stability and adaptability in 20 lines and three cowpea control cultivars -semi-climbing habit (SCH) - assessed in seven irrigated and rainfed environments using the methods by Eberhart and Russell (1966) and Lin and Binns (1988).

Genotype	Yield				Potassium				Calcium			
	E&R			L&B	E&R			L&B	E&R			L&B
	βo	βi	σdii	Pi	βo	βi	σdii	Pi	βo	βi	σdii	Pi
C2R	886	1.3*	37767*	344349 (23)	13.4^{c}	-2.1*	0.90	18.4 (23)	0.9^{c}	0.6	-0.01	0.7 (23)
C3S	904	1.0	16770	305069 (19)	13.9^{c}	-2.5**	5.35**	17.0 (22)	1.2^{b}	0.4	0.14**	0.5 (13)
C3M	1150	0.9	-10959	152055 (5)	14.7^{b}	0.0	0.32	12.1 (16)	1.0^{c}	0.9	0.01	0.5 (15)
C3Q	1021	1.2	40905*	219184 (8)	13.5^{c}	1.4	-0.07	16.0 (21)	1.2^{b}	0.5	-0.01	0.5 (12)
C3B	1214	0.9	21638	144688 (4)	15.2^{b}	3.8*	2.22**	13.4 (19)	1.1^{b}	0.8	-0.00	0.5 (14)
C6P	101 I	0.9	-2161	224767 (9)	14.6^{b}	2.6	2.90**	11.7(15)	1.1^{b}	0.4	-0.00	0.6 (20)
C1M	959	1.4**	58313**	301820 (18)	15.3^{b}	2.0	0.93	8.3 (6)	1.2^{b}	1.5	0.00	0.4 (4)
C3F	883	0.8	1281	315024 (21)	15.1^{b}	1.9	0.24	10.1 (10)	1.2^{b}	0.8	0.01	0.5 (8)
C3L	950	1.0	-22570	249086 (13)	15.0^{b}	2.4	-0.12	10.8 (12)	1.1^{b}	0.5	-0.01	0.5 (16)
C2C	968	1.3*	29413	287946 (16)	16.0^{a}	1.6	0.21	6.4 (3)	1.1^{b}	1.0	-0.01	0.5 (9)
C1T	901	1.1	50964*	331871 (22)	14.4^{b}	2.1	0.69	14.0 (20)	1.3^{a}	0.9	0.06**	0.4 (5)
C3R	1228	0.8	-6056	125105 (2)	14.8^{b}	2.9	1.31*	11.2 (13)	1.1^{b}	1.1	0.01	0.5 (11)
C4G	1023	0.7*	27058	251814 (14)	14.6^{b}	2.4	2.21**	12.6 (18)	1.0^{c}	0.8	0.01	0.7 (21)
C6A	883	0.8	30778*	310255 (13)	14.9^{b}	1.8	0.12	9.0 (9)	1.4^{a}	1.9**	0.09**	0.2 (3)
C2T	934	0.9	6603	293622 (17)	15.2^{b}	1.4	0.07	8.6 (7)	1.5^{a}	1.5	0.11**	0.2 (2)
C3P	1055	0.7*	27301	239393 (11)	16.0^{a}	-0.7	-0.75	6.7 (4)	1.1^{b}	1.3	0.02	0.5 (7)
C6D	990	0.9	43453*	256330 (15)	15.9^{a}	1.0	-0.51	6.0 (2)	1.2^{b}	1.0	0.04*	0.5 (17)
C1V	1019	1.2	64770**	243650 (12)	15.8^{a}	-0.3	-0.67	7.0 (5)	1.1^{b}	1.7*	0.01	0.4 (6)
C4I	1102	1.0	-4448	171894 (6)	17.1^{a}	-4.3**	11.77**	1.1 (1)	1.7^{a}	3.5**	0.20**	0.1 (1)
T16_2R	1171	1.0	69547**	131728 (3)	15.8^{a}	1.2	1.94*	10.2 (11)	1.0^{c}	-0.8**	0.06**	0.6 (20)
Acauã	1341	1.0	112508**	63731 (1)	15.5^{b}	1.7	1.24	11.4 (14)	1.3^{a}	0.6	0.03	0.5 (10)
Pujante	1050	0.8	185586**	226464 (11)	15.4^{b}	1.0	-0.81	8.8 (8)	1.1^{b}	0.6	-0.01	0.5 (18)
Canapu	1153	0.5**	175495**	184265 (7)	14.8^{b}	1.7	1.17	12.4 (17)	0.9^{c}	0.5	-0.00	0.7 (22)
Mean			1034				15.08				1.15	

Values followed by the same letter in the column belong to the same group, according to the Scott and Knott test (1974) at 5% probability; **, * significant at 1 and 5%, respectively, according to the F-test.

line with the lowest Pi values, with better performance for calcium content (Table 2).

The genotype×environment interaction was decomposed in six principal components of the interaction (PCI) using the multivariate AMMI method. However, only the first axis (PCI1) showed significant residuals in the F_r test ($p<0.01$). Thus, the graphic interpretation of adaptability and stability was performed through the PCI1 alone, via AMMI1 biplot. Similar results were found by Barros et al. (2013) who assessed cowpea yield.

The first principal component of the interaction explained 49.78, 36.12 and 45.50% of grain yield and of K and Ca contents respectively in the SCH experiment (Table 4). BRS Acauã was the most stable environment and Limoeiro was the most productive for grain, although with high instability. The C3M and C3R were the most stable genotypes for grain yield (Figure 1). Petrolândia showed the lowest mean K content and was the most stable environment. The C3B, C4I and C3R genotype showed high stability and mean K content higher than that of the assessed cultivars. The Acauã environment was the most favorable to Ca content and the C4I, C2T and C6A, which showed the highest means, were also the most stable genotypes (Figure 1).

Cowpea lines of upright with determined growth (UDG)

Statistical significant differences were observed in the mean squares of the treatments for the grain yield, and the potassium and calcium contents. Three environments for each variable showed no statistical differences in mean squares of the treatments (Table 1). The experiments in Acauã, Dormentes, Limoeiro and Petrolândia were conducted in farming properties. Such fact did not compromise the assessments as the variation coefficients were below 39% (Table 1), which allowed making the assessments in environments that represented the species cultivation. The Limoeiro environment showed the highest mean grain yield (Table1).

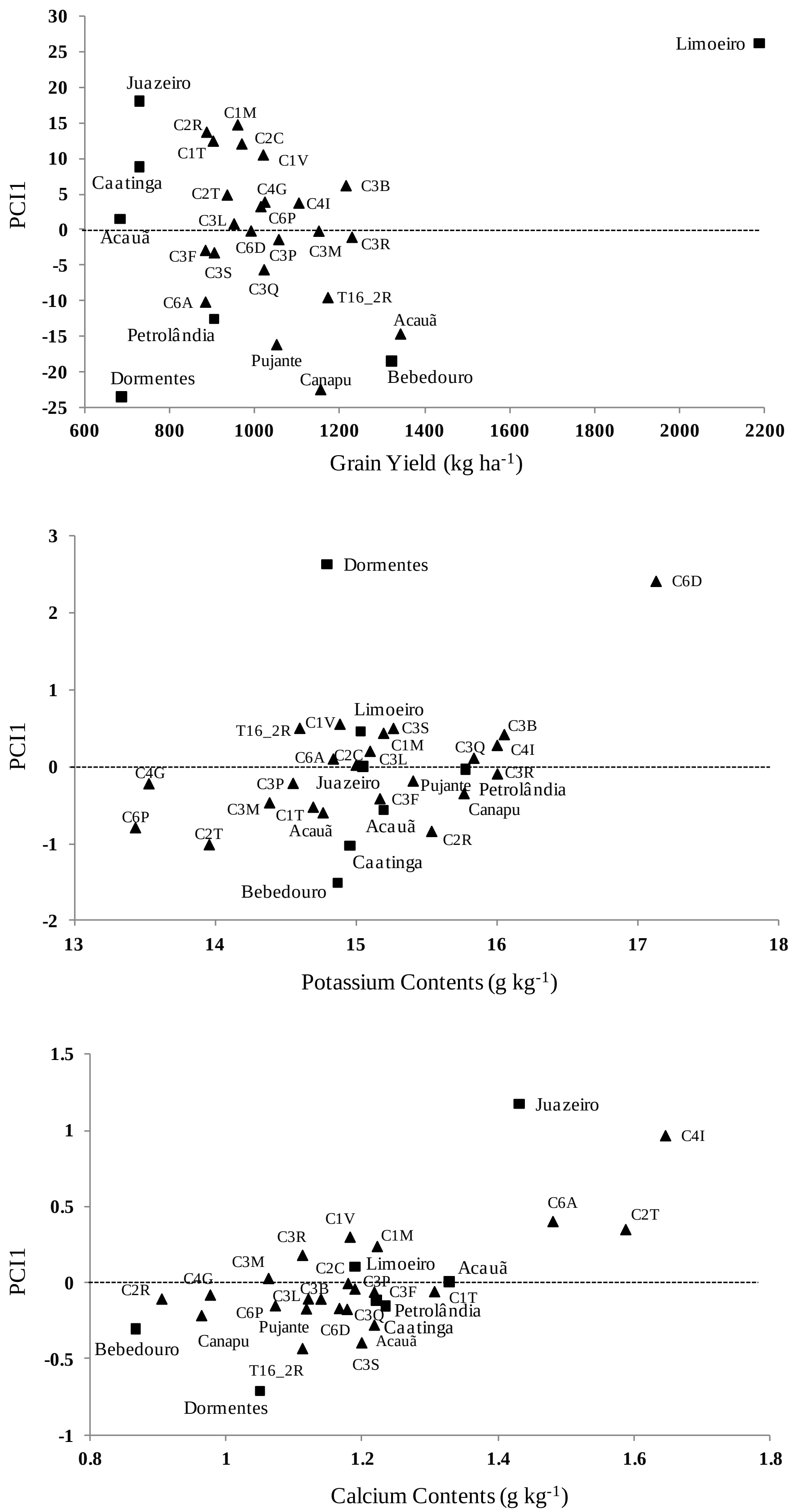


Figure 1. AMMI biplot for grain yield, potassium and calcium contents in 20 lines and three (▲) cowpea cultivars (*Vigna unguiculata*) with semi-climbing habit assessed in seven (■) irrigated and rainfed environments.

Table 3. Yield, potassium and calcium stability and adaptability in 17 lines and four cowpea cultivars – upright cowpea plants with determined growth (UDG) - assessed in seven irrigated and rainfed environments using the methods by Eberhart and Russell (1966) and Lin and Binns (1988).

Genotype	Yield				Potassium				Calcium			
	βo	E&R		L&B	βo	E&R		L&B	βo	E&R		L&B
		βi	σdii	Pi		βi	σdii	Pi		βi	σdii	Pi
C1N	1170	1.2	-55352	269488 (9)	14.7^b	0.9	-0.55	4.7 (11)	0.9^b	0.4	0.00	0.4 (14)
C1R	1044	0.9	-3561	372225 (18)	14.6^b	0.6	-0.08	5.4 (17)	1.0^b	1.2	0.02*	0.2 (4)
C3O	1203	0.4*	-5183	235209 (7)	16.6^a	1.7	0.33	0.7 (1)	1.1^a	2.4**	0.09**	0.1 (2)
C2I	953	0.9	-53143	404583 (19)	14.4^b	0.9	0.42	5.7 (19)	1.3^a	2.7**	0.33**	0.1 (1)
C1G	1129	1.0	-42325	304343 (11)	14.8^b	1.1	1.54*	5.0 (15)	0.9^b	0.8	-0.01	0.3 (11)
C1S	1107	0.9	-28073	344578 (14)	14.2^b	0.6	0.21	6.6 (20)	0.8^c	0.7	-0.01	0.4 (20)
C2J	1129	1.2	43212	202587 (4)	14.3^b	0.7	-0.31	5.5 (18)	0.9^b	0.9	-0.00	0.3 (12)
C1J	1121	1.0	-38895	249457 (8)	14.7^b	0.9	-0.27	4.7 (12)	1.0^b	0.7	0.01	0.2 (5)
C1F	1111	1.1	-45872	322260 (12)	14.8^b	1.6	0.79	5.1 (16)	0.8^c	0.4	0.01	0.4 (19)
C2O	1243	1.1	-46357	232238 (6)	14.5^b	1.2	-0.57	4.7 (10)	1.1^a	1.2	0.01	0.2 (3)
C2S	1196	0.9	-45261	276386 (10)	15.4^a	1.1	2.48**	3.7 (8)	1.0^b	1.5	0.00	0.3 (7)
C2B	1009	0.6	71955	496665 (21)	14.0^b	1.1	1.80*	8.1 (21)	1.0^b	-0.4**	0.11**	0.3 (8)
C2A	1111	1.2	-25378	329596 (13)	15.4^a	1.4	0.03	2.7 (4)	1.0^b	2.3**	0.09**	0.4 (13)
C2Q	1032	1.0	-46745	364971 (16)	15.6^a	1.5	0.42	2.4 (2)	0.9^b	1.2	0.02*	0.4 (15)
C1O	1022	0.8	-57381	367170 (17)	15.2^a	0.4	0.04	3.8 (9)	0.9^b	0.6	0.02*	0.4 (18)
C1I	1078	0.8	-26876	353772 (15)	15.1^a	1.1	1.32*	3.6 (7)	0.8^c	1.0	0.02*	0.3 (9)
C2M	893	0.9	-35771	479205 (20)	15.4^a	1.2	-0.14	2.7 (3)	1.0^b	-0.0**	0.09**	0.3 (6)
Marrom	1307	1.4	6935	185480 (3)	15.1^a	0.5	-0.27	3.6 (6)	0.8^c	0.4	0.00	0.5 (21)
Carijó	1344	0.9	-893	135731 (2)	14.5^b	0.8	-0.18	4.9 (14)	0.8^c	0.8	-0.01	0.4 (16)
Tapaihum	1323	1.4	-15169	123155 (1)	15.2^a	0.1*	3.17**	4.8 (13)	0.9^b	0.7	0.00	0.4 (17)
Canapu	1211	0.5*	493790	228627 (5)	15.4^a	1.1	0.92**	3.3 (5)	0.9^b	1.2	0.02*	0.3 (10)
Mean			1130				14.96				0.95	

Values followed by the same letter in the column belong to the same group, according to the Scott and Knott test (1974) at 5% probability; **, * Significant at 1 and 5, respectively, according to the F-test.

As in the previous experiment, relations between larger and smaller squares of the residues observed were below or close to seven in all variables. The grain yield means in the three irrigated environments was 45% higher than the means found in the four rainfed environments (Table 1). This result corroborated those reported by Santos et al. (2008). However, the means of the assessed minerals showed similar values, regardless of the adopted handling, whether with or without irrigation.

The BRS Carijo and BRS Tapaihum cultivars showed the highest grain yields (Table 3). This cultivars were previously assessed in the same locations the lines of the current research were (except for Limoeiro) and were selected exclusively for grain yield and earliness (Santos et al., 2008). The C2O line presented grain yield close to that of the BRS Carijo e BRS Tapaihum control cultivar, as well as wide adaptability and good stability parameters, through both the Eberhart and Russell (1966) and the Lin and Binns (1988) methods (Table 3).

The C3O showed the highest K content, with wide adaptability by Eberhart and Russell method (1966). Lin and Binns (1988) highlighted the C3O line with the lowest Pi value for K (Table 3). For the Ca content, the C20 showed average greater than experiment mean and wide adaptability and good stability by Eberhart and Russell (1966). By the Lin and Binns (1988) method C3 and C2I presented the lowest Pi values for Ca content (Table 3).

The genotype×environment interaction was decomposed in six principal components of the interaction (PCI) using the multivariate AMMI method. However, only the first axis (PCI1) showed significant residuals in the F_r test ($p < 0.01$). Thus, the graphic interpretation of adaptability and stability was performed through the PCI1 alone, via AMMI1 biplot.

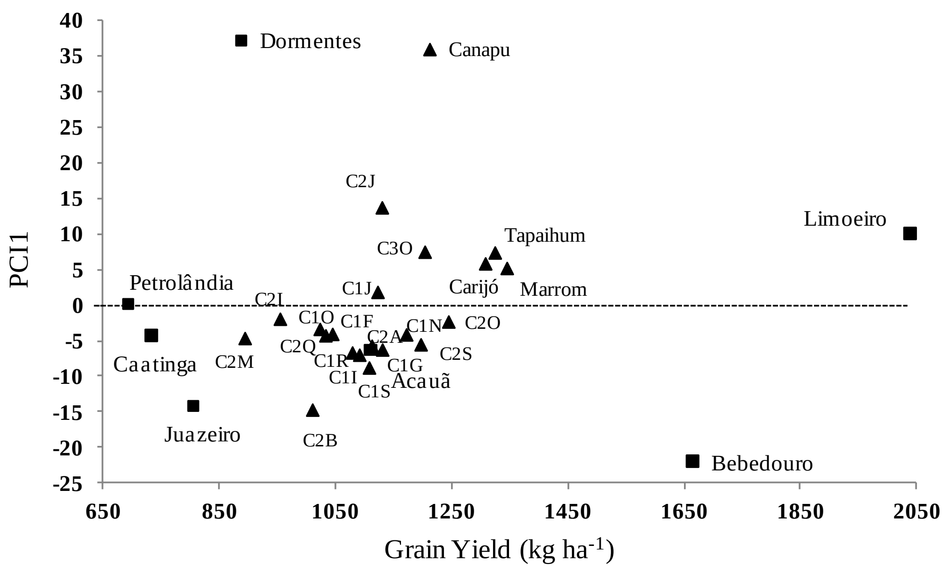
The first principal component of the interaction explained 54.46% grain yield, as well as 39.80% K and 46.96% Ca contents (Table 4). Petrolândia was the most stable environment and showed the lowest mean yield. The C2O stood out among the lines in the AMMI method due to high stability and mean yield close to that of the cultivars. The C3O line showed high K content stability. Bebedouro and Petrolândia were the most favorable environments. The C2I, C2A and C3O lines showed the highest mean Ca contents and good stability (Figure 2).

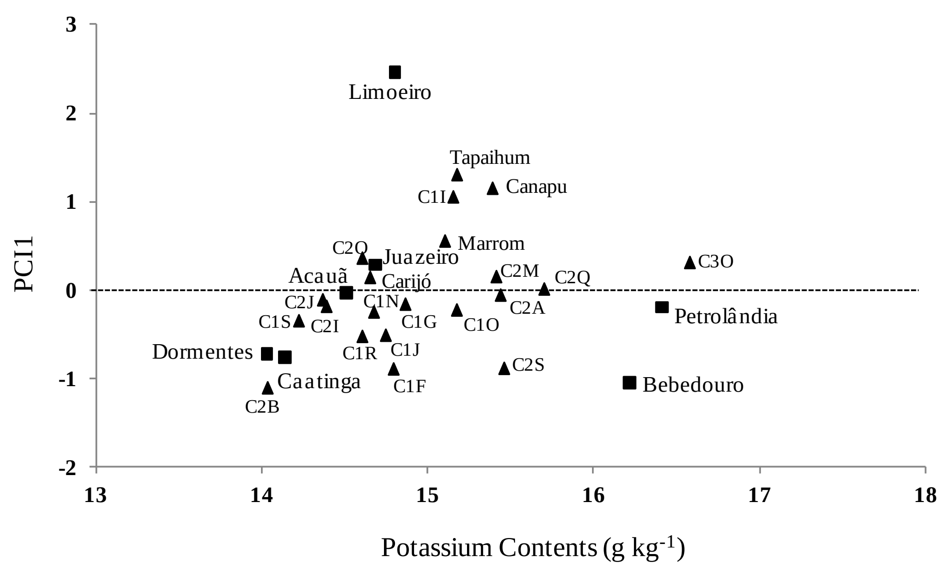
The methods by Eberhart and Russell (1966), Lin and

Table 4. Joint analysis of variance related to grain yield, and potassium and calcium levels in 20 lines and three cultivars (SCH Experiment –semi-climbing habit) and in 17 lines and four cowpea cultivars (UDG experiment – upright cowpea plants with determined growth) assessed in seven irrigated and rainfed environments.

Source of variation	Mean square							
	SCH Experiment				SCH Experiment			
	df	Yield	Potassium	Calcium	df	Yield	Potassium	Calcium
Genotype (G)	22	328825*	15.14**	0.64**	20	366806*	7.11**	0.29**
Environment (A)	6	20986713*	7.47*	2.07**	6	17240794*	58.08**	1.26**
G x A	132	209439**	7.54**	0.19**	120	200801**	4.38**	0.17**
PCI1	27	517149**	12.92*	0.45**	25	599283**	8.37*	0.61**
$Residual_{AMMI1}$	105	134136	5.87	0.14	95	131874	3.33	0.18
PCI1%		49.78	36.12	45.50		54.46	39.80	46.96
CV(%)		26.2	11.59	23.44		27.6	11.08	22.00

**,*, Significant at 1 and 5%, respectively, according to the F test.





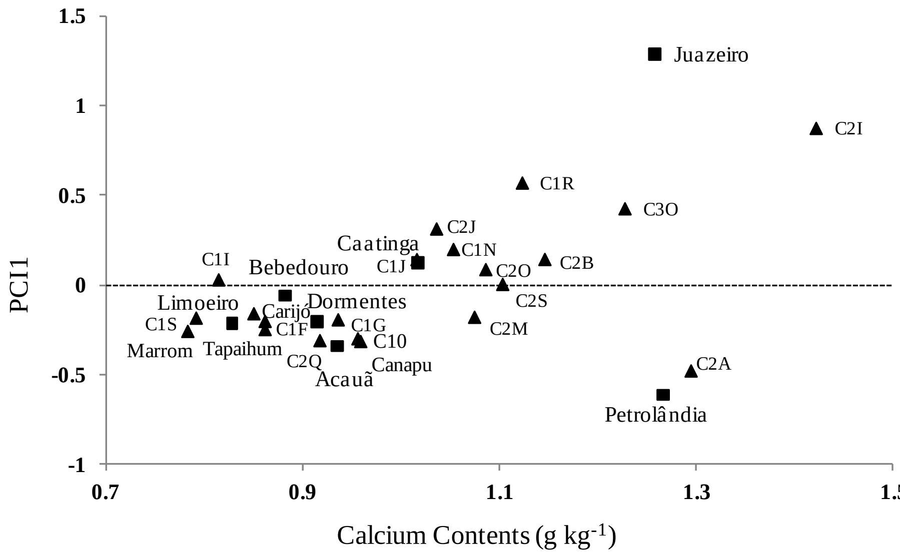


Figure 2. AMMI biplot for grain yield, potassium and calcium contents in 17 lines and four (▲) cowpea cultivars (*Vigna unguiculata*) of upright and determined growth assessed in seven (■) irrigated and rainfed environments.

Binns (1988), and the AMMI method showed similar results in the selection of superior materials, except for Ca content. Polizel et al. (2012) used seven methods to test 16 soybean genotypes in different environments. They found that the studied methods showed consistent and complementary results. Nunes et al. (2014), using parametric and non-parametric methods in 20 genotypes of cowpea found that some methods should not be used simultaneously, and those others should be complementary.

Cowpea is broadly grown in semi-arid regions due to its tolerance to water stress and substantial grain yield in comparison to other legumes such as common beans, lentils and chickpeas. Accordingly, the selection of superior cultivars through the combination of high yield and seed mineral content, and good adaptability and stability under different environmental conditions will have a huge positive impact on cowpea production-market chains, mainly in semi-arid regions.

Selection approaches have been being applied in many crop plants aiming to biofortify food crops with essential mineral elements most commonly lacking in human diets (White and Broadly, 2009). However, current efforts to select and release cowpea cultivars with high mineral content associated with good agronomic performance based on adaptability and stability parameters are still very restricted, even for important commodities, such as soybean. To our knowledge, the present study is the first one conducted to estimate adaptability and stability parameters for K and Ca contents in cowpea lines.

The C4I and C3O lines showed grain yields equal to or greater than the means of the experiments, high potassium and calcium means, wide stability and good predictability in the series of assessed environments, by the Eberhart and Russell (1966), Lin and Binns (1988) and the AMMI methods. The BRS Acauã, BRS Tapaihum and BRS Carijó, with the highest grain yield, should be used for crossing with C4I, C3O, C2I and C2T for selection of lines with higher grain yield, potassium and calcium contents, simultaneously.

Conclusion

The C4I lines cowpea, with semi-climbing habit, and C3O lines cowpea, with upright and determinate growth, identified in representative environments in the Brazilian semiarid region, both irrigated and rainfed conditions, have great potential to be recommended as new cultivars for the region, as grain yields were close to commercial cultivars, as well as potassium and calcium contents were greater than the average of the cowpea cultivar experiments.

Conflict of Interests

The authors have not declared any conflict of interests.

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Abbreviations

DSUG, Genotypes with determinate and semi upright growth; **ISCG,** genotypes with indeterminate and semi-climbing growth; **G×E,** genotype×environment interaction.

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