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Genotype x environment interaction and stability in landraces of cowpea under dryland conditions

Interação genótipo x ambiente e estabilidade em variedades crioulas de feijão de corda em terras secas

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ABSTRACT - Cowpea (*Vigna unguiculata* (L.) Walp.) is an excellent crop for research in semi-arid regions, due to its tolerance to high temperatures and water deficit, with satisfactory yields in rain-fed cultivation. The objective this work was to evaluate the genotype x environment (G x E) interaction, adaptability and stability of cowpea landraces used in the Cariri, Paraíba, in the semi-arid region of Northeast Brazil. The experiment was carried out under rain-fed conditions in two locations of this region. For all traits evaluated, the G x E interaction was simple, which means that the evaluated landraces can be recommended for the different environments tested. The results also suggest that phenotypic selection can be efficient to enhance the yield of cowpea landraces and, therefore, can be practiced by the farmers themselves. The most advantageous landraces were ranked with good stability (qi <5%). Although the performance standards between the cowpea landraces were similar in the different environments, the best values were obtained on the farm with the best environmental conservation history and with higher precipitation. Therefore, the integration between the yield of cowpea landraces, environmental conservation in agricultural landscapes, and strategic planning that considers possible variations in local precipitation is essential in models of sustainable agricultural development in semi-arid zones of Northeast Brazil.

Keywords: *Vigna unguiculata*. Local varieties. Semiarid. Phenotypic selection. Sustainability.

RESUMO - O feijão-de-corda (*Vigna unguiculata* (L.) Walp.) é uma cultura de grande importância nas regiões semiáridas, devido à sua tolerância a altas temperaturas e déficit hídrico, com rendimentos satisfatórios no cultivo de sequeiro. O objetivo deste trabalho foi avaliar a interação genótipo x ambiente (G x A), a adaptabilidade e a estabilidade de variedades crioulas de feijão-de-corda utilizadas no Cariri paraibano, zona semiárida do Nordeste brasileiro. O experimento foi conduzido em regime de sequeiro em duas localidades desta região. Para todas as características avaliadas, a interação foi simples, o que significa que os genótipos avaliados podem ser recomendados para os diferentes ambientes testados. Os resultados também sugerem que a seleção fenotípica pode ser eficiente para aumentar o rendimento de variedades crioulas de feijão-de-corda e esta pode ser praticada pelos próprios agricultores. As variedades crioulas mais vantajosas foram classificadas com boa estabilidade (i <5%). Embora os padrões de desempenho entre as variedades crioulas de feijão-de-corda tenham sido semelhantes nos diferentes ambientes, os melhores valores foram obtidos na fazenda com melhor histórico de conservação ambiental e com menor déficit hídrico. Portanto, a integração entre a produtividade de variedades crioulas de feijão-de-corda, a conservação ambiental nas paisagens agrícolas e um planejamento estratégico que considere possíveis variações nas precipitações locais é fundamental em modelos de desenvolvimento agrícola sustentável em zonas semiáridas do Nordeste brasileiro.

Palavras-chave: *Vigna unguiculata*. Variedades locais. Semiárido. Seleção fenotípica. Sustentabilidade.

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INTRODUCTION

Dryland regions correspond to approximately 41.5% of the continent and are classified as arid, semi-arid (SAR'S), or dry sub-humid regions, with more than 38% of the world population living in these areas (HUANG et al., 2016; BASTIN et al., 2017). With a history of continuous inadequate agricultural use, several areas of these regions have become susceptible to desertification with consequences on climate change, loss of biodiversity, soil degradation, cyclical reduction of agricultural areas, decrease in agricultural production, increase in economic losses, and poverty (SÁ et al., 2010; DANTAS et al., 2019). Although the history of inappropriate land use for agriculture has been one of the main threats to sustainability in these regions, agriculture also plays an essential role in economic development in dry regions around the world (STEWART, 2016).

The success of SAR'S agriculture relies on the water stored in the soil, efficient use of water, prevention of soil degradation, and use of cultivars tolerant to semi-arid conditions (STEWART, 2016). Therefore, the selection of cultivars that profitably meets the universal objective of environmental resources protection is essential in SAR'S.

Cowpea is one of the main food sources in arid, semi-arid, and tropical regions of the world (DIAS; BERTINI; FREIRE FILHO, 2016; GERRANO et al., 2020). This crop is considered an excellent example in SAR'S research due to its tolerance to abiotic factors, such as high temperatures and water deficit, with a minimum precipitation requirement of 300 mm for satisfactory yield in rainfed cultivation (SILVA et al., 2018; DANTAS et al., 2019).

Brazil is the fourth largest world producer of cowpea, according to the cowpea world production of 2020 (FAOSTAT, 2020), with a yield of 530 kg ha^{-1} in 2021/2022 agricultural year, and the northeast region yield is 409 kg ha^{-1} (CONAB, 2022), with most of this area located in SAR'S. Despite its great socioeconomic importance in the country, this crop is cultivated in a rudimentary way and the average yield in the semi-arid region is still low, 289 kg ha^{-1} (CONAB, 2022). Although the Northeast is the region responsible for about 61.4% of the national production, the highest yields (>800 kg ha^{-1}) are recorded in the Midwest and Southeast regions (CONAB, 2022). Some factors limit this production, such as the occurrence of biotic and abiotic stresses, low use of technology by farmers, and the cultivation of landraces with low yield potential (RODRIGUES et al., 2018; OWUSU et al., 2018; SOUSA et al., 2019). However, landraces can maintain a diversity of genotypes that respond favorably to local environmental variations and can contribute to increased yield, if varieties suitable for the regions' environment and production system are selected. In the selection process for an appropriate genotype for a given environment, it is necessary to understand that the phenotype is the result of the response of the genotype to the influence of the environment. However, environmental variations can promote different interactions between the environment and the genotype (OWUSU et al., 2020). An interaction can be complex when it generates different responses in the performance of genotypes in different environments, influencing the selection progress and the recommendation of cultivars with wide adaptability (TORRES et al., 2015). A simple interaction is observed when a genotype shows the same pattern of responses, although it is influenced by the environment (CRUZ; REGAZZI; CARNEIRO, 2012; SOUSA et al., 2018). This type of interaction does not interfere in breeding programs or in the recommendation of cultivars.

The objective of this work was to evaluate the genotype x environment interaction, adaptability and stability of cowpea landraces on the cultivation under different conditions of land use and precipitation in Cariri, Paraíba, situated in the semi-arid zone of Northeast Brazil.

MATERIALS AND METHODS

Area of the experiment

Planting was carried out in Cariri, Paraíba, situated in the semi-arid zone of Northeast Brazil (Figure 1). The region occupies an area of 11.233 km², composed of 30 municipalities, with an estimated population of 199.728, a demographic density of 17.78 habitants / km², and a GDP per capita/year per municipality of R$ 8,022.8181 (IBGE, 2017). The regional climate is classified as "Bsh" Semi-arid hot with summer rains, characterized by high temperatures (annual averages around 26 ºC) and annual precipitation of approximately 400 mm.

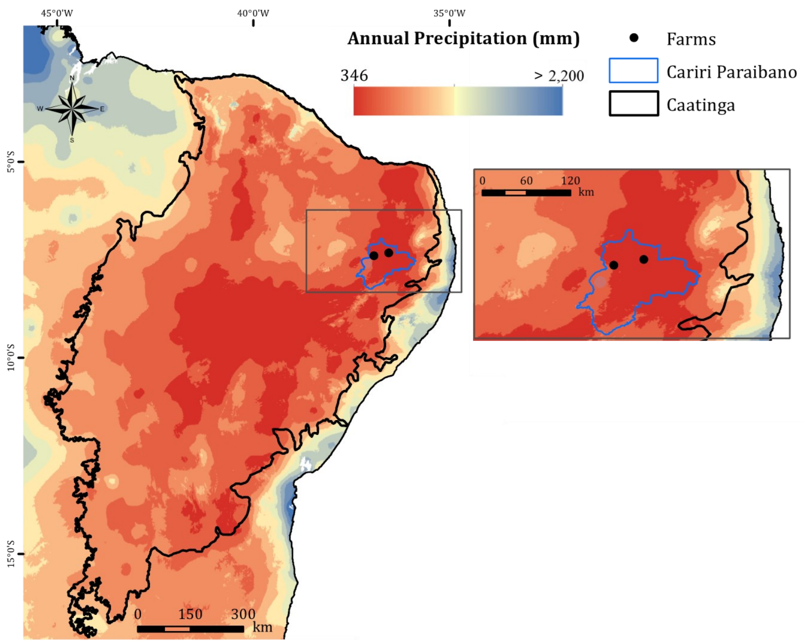

Figure 1. Location of the area under study in the Northeast Brazil. Black dots represent the locations of the farms where the experiment was conducted in Cariri, PB, Brazil (Adapted, (VELLOSO et al. 2002)).

The experiment was carried out in two areas of different municipalities to show productive indicators under the influence of different environmental conservation and local precipitation conditions: 1) São João do Cariri (SJC), where the vegetation is characterized by a long period of selective or shallow cutting for the production of firewood and native pasture for goats, a region that is one of the desertification hotspots of the Brazilian Semi-arid Region (PEREZ et al., 2012; TRAVASSOS; SOUZA, 2014); 2) São José dos Cordeiros, precisely at Almas Farm (ALMAS), where there is a private preserved environment, with conservation initiatives practiced for over forty years. Planting was performed in February of 2019 and harvest was carried out in May of the same year under total precipitation of 231 mm in São João do Cariri and 426 mm in São José dos Cordeiros (Real-Time Climate Monitoring Program of the Northeast Region-PROCLIMA and pluviometer).

Plant material

Ten cowpea genotypes were pre-selected based on characteristics such as water stress tolerance, grain yield, market value, and use in the region under study (Table 1). They were collected from communities and open markets in the semi-arid region of the Paraíba and Ceará States.

The preparation for planting was carried out conventionally, with plowing harrow two weeks before sowing in a soil classified as Luvisol, on both locations. Chemical, physical and mineralogical analyses of the soils were made. Mineral fertilization consisted of the application of 350 kg ha^{-1} of ammonium sulfate 30 days after sowing.

Table 1. Passport data of cowpea accessions collected from different sites in Paraíba and Ceará States, Brazil.

Landrace	City	State	Geographic coordinates	Class[1]	Subclass[2]	Grain shape
Canapu	Aurora	CE	6° 56' 4"S 38° 57' 51"W	Colors	Canapu	Round
Cariri	Remígio	PB	6° 53' 30"S 35° 49' 51"W	White	Fradinho	Oval
Corujinha	Prata	PB	7° 42' 4" S 37° 6' 33"W	Colors	Corujinha	Round
Macaíba	Alagoa Grande	PB	7° 4' 56"S 35° 35' 57"W	White	Fradinho	Oval
Manteiguinha	Pocinhos	PB	7° 4' 26"S 36° 3' 40"W	White	Manteiga	Oval
Quebra Cadeira	Areia	PB	6° 57' 42"S 35° 41' 43"W	White	Fradinho	Reniform
Pata De Vaca	Areia	PB	6° 57' 42"S 35° 41' 43"W	White	Olho Marrom	Reniform
Rabo De Tatu	Pocinhos	PB	7° 4' 26"S 36° 3' 40"W	Colors	Mulato Liso	Rhomboid
Roxinho	Prata	PB	7° 42' 4" S 37° 6' 33"W	Colors	Mulato Liso	Oval
Sempre Verde	Alagoa Grande	PB	7° 4' 56"S 35° 35' 57"W	Colors	Sempre-verde	Rhomboid

[1]Technical Regulation for Beans, Normative Instruction Nº 12, of 03/28/2008, MAPA (BRASIL, 2008); [2]Subdivision of commercial classes by Freire Filho et al. (2005).

Preparation of the experimental area

Sowing was performed manually with three seeds per hole, and after 15 days thinning was performed. Harvest was carried out approximately 65 days after planting. A randomized block experimental design with three replications was used in the two locations. The experimental plot consisted of four rows of four meters, with a typical spacing of 0.4 m between plants and 0.7 m between rows, with ten plants per experimental unit to be analyzed.

Evaluated traits

The varieties were evaluated for growth, flowering, yield, and environmental adaptation. The quantitative traits evaluated were: number of days to flowering and maturity days after sowing taken until more than 50% of the plot showed inflorescence and green pods, respectively; plant height (cm): measured from the plant collar to the apical bud of the highest branch or greatest distance from the plant collar; stem diameter (cm): measured two centimeters above the plant collar; number of leaves: count of all leaves with a minimum length of 3.0 cm; leaf water content (%): determined from the weight of fresh leaves (FW) and their weight after drying (DW) in an oven at 45 ºC until they reached a constant weight. With these values, the following formula was applied:

$$LWC(\%) = \frac{FW - DW}{FW} x\,100$$

Number of pods per plant: determined by counting all pods of an individual plant; number of grains per pod: determined by counting the number of grains in three pods for each individual; pod length (cm): mean of three pods of each plant in the stage that allows manual threshing to obtain green grains; weight of 100 green grains (g): after manually threshing the pods, 100 grains were counted and weighed on a precision scale; green (approximately 60 to 70% moisture) and dry (moisture content around 13%) (kg ha^{-1}) grain yield: determined from the production of grains per plant, per m² and estimated for ha, with eight replicates per plot collected for each grain type; aerial part biomass (g): eight replicates per plot were collected, cut close to the soil surface, weighed on a precision scale, and then the value per ha was estimated.

Individual and joint analysis of variance

Before the G x E interaction study, it is essential to perform the analysis of variance for each location to assess the existence of genetic variability between the genotypes under study. The relative production of each experiment and the homogeneity of the residual variances should also be investigated (CRUZ; REGAZZI; CARNEIRO, 2012). After conducting the individual analysis of variance for each location and checking the existence of the above-mentioned assumptions, a joint analysis was carried out. The joint analysis aimed to analyze the effects of genotypes, environments, and G x E interaction, considering the two locations. The variation component of the G x E interaction was quantified considering genotypes and environments as fixed effects (CRUZ; REGAZZI; CARNEIRO, 2012).

Estimates of genetic parameters

Based on the means and variances values, estimates of variance components were obtained to assess the potential of populations for breeding purposes and to establish effective selection strategies. The mathematical formula proposed by Cruz, Regazzi and Carneiro (2012) was used to estimate the phenotypic (*rf*) and genotypic (*rg*) correlation coefficients between environments.

Phenotypic correlation coefficient (r_f)

$$r_f = \frac{COV\ f(x,y)}{\sqrt{\sigma^2{}_{fx} \cdot \sigma^2{}_{fy}}}$$

Genotypic correlation coefficient (r_g)

$$r_g = \frac{COV\ g(x,y)}{\sqrt{\sigma^2{}_{gx} \cdot \sigma^2{}_{gy}}}$$

Where: COV f (X, Y) and COV g (X, Y) correspond to the estimates of phenotypic and genotypic covariance between environments, respectively;

σ^2_{fx} and σ^2_{gx} correspond to the estimates of phenotypic and genotypic variances in environment 1;

σ^2_{fy} and σ^2_{gy} correspond to the estimates of phenotypic and genotypic variances in environment 2;

The significance of the phenotypic, genotypic, and environment correlation coefficients was assessed by the t-test ($p < 0.05$).

When the significant G x E interaction was observed, the decomposition of the mean square of the interaction into simple parts (provided by the difference in variance between genotypes in the environments) and complex parts (generated by the low correlation between locations, due to the irregular performance of the genotypes) was estimated using the formula proposed by Cruz and Castoldi (1991):

$$C = \sqrt{(1-r)^3 Q_1 Q_2}$$

Where *r* is the correlation between the means of genotypes in the two environments; and *Q1* and *Q2* are the mean squares between genotypes in environments 1 and 2, respectively.

Another relevant aspect, depending on the G x E interaction, is the gain prediction to be obtained by a given improvement strategy. In this study, the genetic gains were predicted for each environment using, for the selection differential, an intensity of 30% of the individuals with the best performance and the coefficient of genotypic determination of the target trait.

Adaptability and stability analysis

To obtain information on the performance of each genotype under the variations in both locations, adaptability and stability were estimated using the method proposed by Plaisted and Perterson (1959). Subsequently, a ranking of genotypes was carried out based on the genotype-ideotype distance selection index proposed by Wricke and Weber (1986). All statistical analyses were performed using the computer software Genes (CRUZ, 2013).

RESULTS AND DISCUSSION

It was possible to verify a significant effect of genotypes, environments, and of the G x E interaction (Table 2). The estimates and the significance of the genotypes mean squares showed significant effects ($p < 0.01$) for the following traits: number of days to flowering, plant height, stem diameter, number of leaves, number of days to maturity, pod length, number of grains per pod, weight of 100 grains, green and dry grain yield, and aerial part biomass. The experimental variation coefficients of the analyzed traits provided good data confidence.

The success in the development of high-yielding varieties is a consequence of the genetic variability level and diversity of the breeding population (DIAS et al., 2015; MEENA et al., 2017). Cowpea landraces exhibit a wide range of phenotypic variability, which has enabled their production under different climatic and soil conditions (GERRANO et al., 2020) attributed to inherent genetic properties and/or environmental influence, which can be exploited for improvement through selection and/or hybridization of individuals with desired traits (ALIYU et al., 2019).

Table 2. Summary of the joint analysis of variance for 13 traits observed in 10 cowpea landraces, evaluated in two regions of Cariri, PB, in Northeast Brazil.

		Mean Squares						
SV	DFr	DF	PH	SD	NL	LWC	DM	NPP
Block	2	9.86	0.76	0.08	277.48	136.81	0.81	2.10
Genotype	9	59.97**	365.52**	0.08**	537.77**	207.55^{ns}	124.65**	11.19^{ns}
Environment	1	1075.23**	5192.19**	0.53**	8450.25**	218.30^{ns}	160.06**	488.26**
G x E	9	36.22**	159.14**	0.02^{ns}	273.98*	188.41^{ns}	111.88**	12.83*
CV (%)		4.63	18.50	16.33	24.82	19.22	2.80	22.57
Error		0.78	1.82	0.02	2.42	0.78	0.82	0.51
Mean		50.06	38.35	0.89	43.75	83.58	65.46	10.50

	DFr	PL	NGP	W100G	GGY	APB	DGY
Block	2	1.87	2.06	36.62	64.371.53	5051.15	38.648.40
Genotype	9	11.08 **	33.16**	236.95**	247555.75**	24942.07**	65526.51**
Environment	1	126.81**	201.41**	51.18^{ns}	2982812.39**	514500.41**	3589108.77**
G x E	9	4.90**	5.32*	67.88^{ns}	75033.49*	6513.22^{ns}	62.47.76**
CV(%)		7.02	14.05	22.70	33.27	34.94	28.91
Error		0.30	0.42	1.16	45.17	16.48	38.70
Mean		16.81	10.57	31.16	536.47	182.26	388.83

SV: Source of variation; DFr: degrees of freedom; DF: number of days to flowering; PH (cm): plant height; SD (cm): stem diameter; NL: number of leaves; LWC (%): leaf water content; DM: number of days to maturity; NPP: number of pods per plant; PL (cm): pod length; NGP: number of grains per pod; W100G (g): weight of 100 grains; GGY (kg ha^{-1}): green grain yield; APB (g): aerial part biomass; DGY (kg ha^{-1}): dry grain yield. ns, not significant. ^{ns} Not significant; *,** Significant at 5% and 1% probability level, respectively.

Considering the source of variation in the environments, a significant difference at 1% probability level by the F test was observed, for most of the traits evaluated, which indicates the existence of variability for the environment's conditions between the test locations, except for the weight of 100 grains and leaf water content, for which no significant variation was observed (Table 2). The existence of G x E interaction also demonstrated significant differences for the relative performance of the cowpea landraces for each descriptor in the two environments: number of days to flowering, plant height, number of leaves, number of days to maturity, number of pods per plant, pod length, number of grains per pod, and green and dry grain yield (Table 2).

This interaction indicates that the performance of the genotypes was not consistent in the two locations evaluated, which reflects the different behaviors of the genotypes under the environmental conditions to which they were subjected (GUERRA et al., 2017). In Brazil and more seriously in the Northeast region, genetically improved cultivars that showed good performance in other regions are recommended for cultivation without considering the edaphoclimatic peculiarities of the semi-arid region (TEIXEIRA et al., 2010). This problem occurs with several crops and is aggravated in situations where cultivation occurs under weather conditions, e.g., in cowpea cultivation. It is known that water deficit in some stages of the plant causes a loss of cell turgor that causes physiological changes, restricting cell elongation and division, causing disturbances in photosynthesis that affect development and yield (FREITAS et al., 2017).

Estimate of genetic parameters

The magnitudes of the genotypic variability ($ø^2G$) were higher than the estimates of the interaction quadratic component ($ø^2_{G\,x\,E}$). The only traits that did not show similar results were earliness (days to flowering and maturity) and yield (number of pods per plant) (Table 3). The coefficient of genotypic determination for the traits evaluated in study is considered of high magnitude (> 75%), which indicates greater confidence when performing phenotypic selection based on these traits (Table 3). This estimate was below 75% only for the number of pods per plant (49.81%). High values of h² are extremely important for confidence in the selection of genotypes (SOUZA et al., 2018), but it should not be considered alone when the objective is to assess the potential of genotypes.

Table 3. Estimation of the quadratic, genotypic ($ø^2G$) and genotype x environment ($ø^2GE$) interaction components; genotypic determination (h²) and genetic (CVg) and environmental (CVe) coefficients; intraclass (r), phenotypic (r_F) and genotypic (r_G) correlation among environments, percentages of the simple (% S) and complex part of the interaction (% C) in cowpea landraces, in two regions of Cariri, PB, in Northeast Brazil.

Traits	$ø^2_G$	$ø^2_{GE}$	r	h^2	GS(%)[1]	GS(%)[2]	CVg/CVe	r_F	r_G	%S	%C
DF	9.09	10.27	62.77	91.00	-10.39	-3.7	1.29	0.31	0.40	57.45	42.54
PH	52.52	36.25	51.03	86.21	22.25	21	1.02	0.39	0.48	77.74	22.25
NL	69.96	51.99	37.22	78.06	39.57	10.04	0.77	0.32	0.47	82.02	17.97
DM	20.21	36.16	85.68	97.29	-8.09	-10.47	2.44	0.05	0.05	95.93	4.06
NPP	0.92	2.40	14.19	49.81	15.39	8.71	0.40	-0.07	-0.13	93.37	6.62
PL	1.61	1.17	53.66	87.42	7.71	6.95	1.07	0.38	0.46	78.02	21.97
NGP	5.15	1.03	70.01	93.33	24.4	13.72	1.52	0.72*	0.80*	52.51	47.48
GGY	35948.79	14390.16	53.01	87.12	56.77	26.27	1.06	0.58	0.72*	51.76	48.23
DGY	8813.75	16.734	41.07	80.70	61.37	23.4	0.83	0.02	0.03	79.06	20.93

DF: number of days to flowering; PH (cm); NL: number of leaves; DM: number of days to maturity; NPP: number of pods per plant; PL (cm): pod length; NGP: number of grains per pod; GGY (kg ha^{-1}): green grain yield; DGY (kg ha^{-1}): dry grain yield. [1]São João do Cariri; [2]Almas Farm; * Significant by t-test ($p<0.05$).

Intraclass correlation coefficients above 50% were observed for the number of days to flowering, number of days to maturity, plant height, pod length, number of grains per pod, and green grain yield (Table 3), which indicates the stability of the phenotypic superiority of the cowpea landraces, in the different evaluated environments (CRUZ; REGAZZI; CARNEIRO, 2012).

These same traits also showed a ratio between the coefficients of genetic and environmental variation (CVg/CVe) above one, which confirms that the selection can be made based on the phenotype. In this study, earliness and yield of green grains had the highest h² and CVg/CVe ratio above one, which indicates that the additive gene action was predominant (RODRIGUES et al., 2018), and with experimental quality, as well as safety and reliability in the selection of superior genotypes (SOUSA et al., 2019) for these traits. Therefore, the phenotypic selection is efficient to enhance the yield of cowpea landrace, and this can be practiced by farmers, under rainfed conditions. Aramendiz-Tatis, Espitia and Cardona (2019) highlight that the successful selection and development of new cultivars is associated with the participation of farmers in breeding programs, helping to choose new genotypes that respond to their conditions and meet their requirements and needs.

The phenotypic and genotypic correlation coefficients among environments was estimated. The number of grains per pod showed high and significant ($p<0.05$) phenotypic and genotypic correlations among evaluated environments (Table 3), which means that, for this trait, the performance of the superior genotypes did not change according to the evaluated environment. Although the grain yield trait is not suitable for phenotypic selection, as it is considered quantitative, controlled by several genes, with a strong influence of the environment on their expression, the results obtained here indicate genes with an additive effect and h² above 80%. In this case, phenotypic selection can be made, and we can advantageously indicate the use of the most productive genotypes with acceptable stability (ALVES et al., 2019).

The estimates of the G x E interaction showed a preponderance of the simple type (Table 3). This confirms the influence of the environment on the phenotypic response of cowpea landraces, with no changes in the genotype performance pattern between environments, which does not imply major selection problems (GUERRA et al., 2017). In this case, the same genotype can be recommended for different environments (GERRANO et al., 2020), with no need for regionalization of breeding programs, and it reduces costs associated with breeding.

The gains of selection (GS) were satisfactory in both environments and ranged from -10.39 to 61.37% (Table 3). However, the largest GS was observed in the SJC environment. The expected gain from selection is related to the difference between the phenotypic means of a trait and expresses the advancement of the next generation relative to the original population, resulting from the selection performed (BALDISSERA et al., 2014). In this location, the cowpea landraces had the highest mean variation for the traits analyzed, where some genotypes had very good mean values and others very low, which leads to a greater selection differential and, consequently, a high estimate in the GS.

When the two environments are compared, the genotypes developed better in Almas Farm (Figure 2), except for the number of days to maturity. In the SJC, the Manteiguinha and Roxinho genotypes did not reach dry grain yield due to plant attack by ants. Cowpea landraces showed a better response pattern in the location with a better environmental history of land use and higher precipitation. Producers and plant breeders are interested in selecting genotypes that show an ideotype of interest (SILVA et al., 2018), that is, highly productive, resilient to current climatic challenges (OWUSU et al., 2020), early with good grain quality, resistance to water deficit, in addition to stable yield. According to the traits analyzed, the genotypes Cariri, Canapu, Corujinha, Macaíba, and Roxinho are superiority in terms of earliness, plant architecture, and yield (Figure 2).

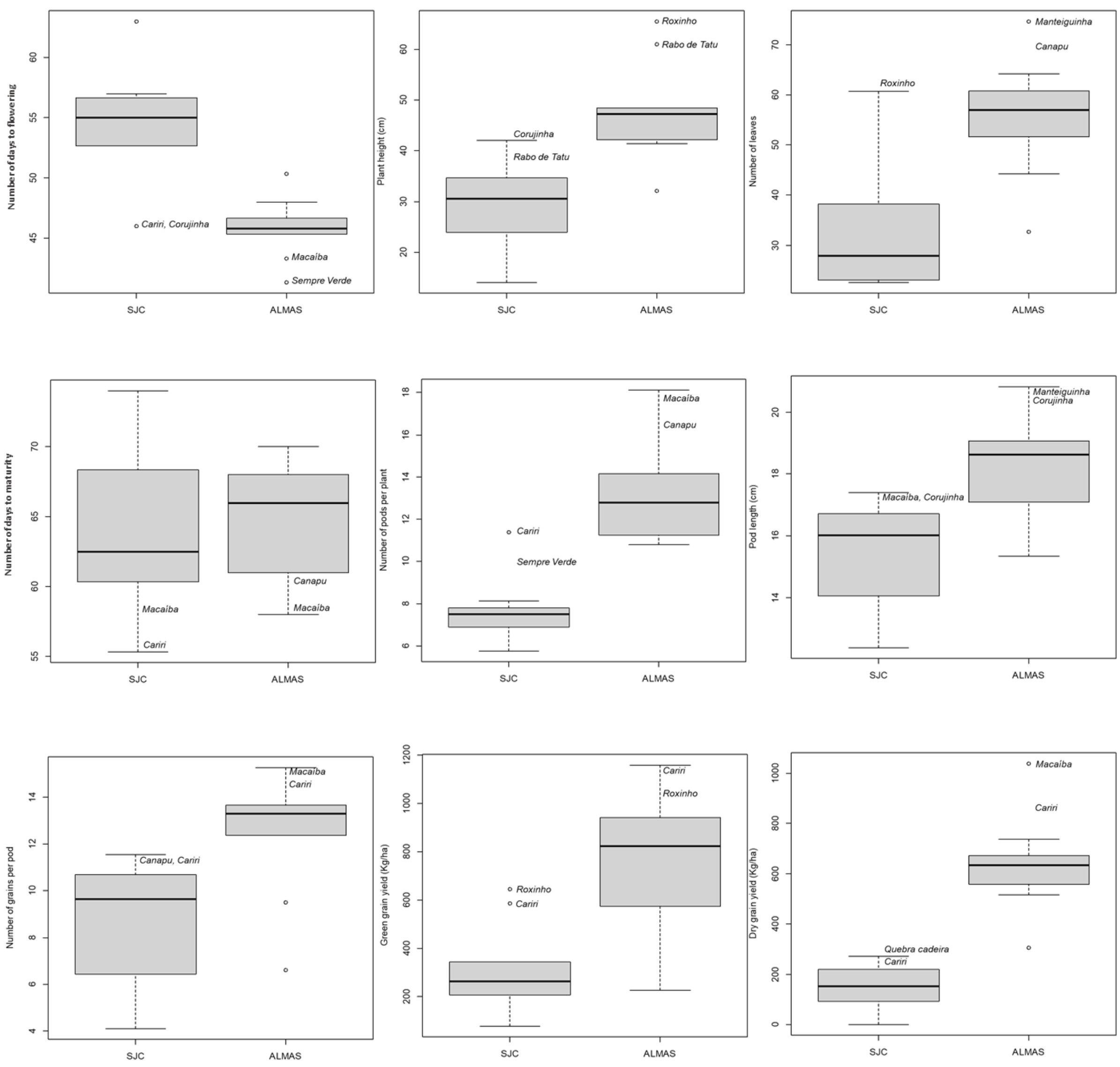

Figure 2. Performance of 10 cowpea landraces, for production and earliness traits evaluated in two locations (SJC and ALMAS) in the Cariri, Paraíba State, Northeast Brazil. The cowpea landraces that stood out according to trait performance are cited and positioned in the respective graph.

Adaptability and stability

The most stable cowpea landraces were not the earliest and most productive, according to the lowest values for the estimate θi (%) (Table 4). Among the evaluated cowpea landraces, with satisfactory stability (<5%) and high yield, Cariri and Roxinho, with green grain yields above 800 kg ha^{-1}, and Cariri, Canapu, and Macaíba, with dry grain yields above 420 kg ha^{-1} are indicated. These values are above the average dry grain yield recorded in the state of Paraíba (289 kg ha^{-1}) and throughout the Northeast region of Brazil (409 kg ha^{-1}) (CONAB, 2022).

Among the ten cowpea landraces used in our study, the ranking through the selection index based on the distance between the genotype and the ideotype indicated the top five varieties: Canapu, Cariri, Macaíba, Rabo de Tatu, and Roxinho (Table 4). For selection, it would be more advantageous to use the most productive genotypes for which stability is acceptable and that are in a good position in the Rank (ALVES et al., 2019). Thus, the landraces Canapu, Cariri, and Macaíba are the most suitable, with the highest green and dry grain yields. Cowpea landraces need to be valued and used to maintain local diversity, strengthen small-farm agriculture in the Brazilian semi-arid region and guarantee food sovereignty in this region (FERNANDES, 2017). One way to increase grain yield in cowpea landraces is through selection (DIAS; BERTINI; FREIRE-FILHO, 2016) and adaptation to environmental conditions. Based on our results, it is possible to invest in cowpea landraces research with a focus on yield and water deficit (DANTAS et al., 2019).

Table 4. Estimates of adaptability and stability parameters according to the Plaisted and Peterson (1959) and Wricke and Weber (1986) methodologies, obtained in analysis with 10 cowpea landraces, in two locations in the Cariri, PB State, Northeast Brazil.

Genotypes	DF	PH	NL	DM	NPP	PL	NGP	PGY	DGY	Rank
	θi(%)	θi(%)	θi(%)	θi(%)	θi(%)	θi(%)	θi(%)	θi(%)	θi(%)	GI
Canapu	4.32	3.36	6.12	7.86	20.41	7.30	11.12	5.56	5.94	2º
Cariri	26.66	11.16	1.71	14.82	18.84	3.75	6.63	4.39	5.16	3º
Corujinha	22.00	16.07	1.55	17.29	6.94	3.46	1.50	9.25	3.85	6º
Macaíba	4.32	6.79	10.83	6.46	36.66	4.87	3.66	1.91	38.19	1º
Manteguinha	8.89	2.69	19.82	11.43	1.60	44.54	21.64	1.39	8.18	9º
Quebra Cadeira	4.70	2.70	4.78	5.28	1.81	9.25	2.38	8.69	13.85	7º
Pata De Vaca	6.34	5.67	4.30	19.04	2.09	3.44	4.95	4.04	7.49	10º
Rabo De Tatu	5.85	3.75	1.36	4.84	2.45	10.78	36.40	17.34	3.78	4º
Roxinho	5.43	43.31	38.38	7.99	3.78	4.36	9.97	4.86	9.38	5º
Sempre Verde	11.43	4.45	11.10	4.93	5.37	8.22	1.70	42.52	4.13	8º

DF: number of days to flowering; PH (cm): plant height; NL: number of leaves; DM: number of days to maturity; NPP: number of pods per plant; PL (cm): pod length; NGP: number of grains per pod; PGV (kg ha^{-1}): green grain yield; DGY (kg ha^{-1}): dry grain yield.
θ: Stability parameter proposed by Plaisted and Peterson (1959); GI - Genotype-Ideotype Index proposed by Wricke and Weber (1986).

CONCLUSIONS

Phenotypic selection can be efficient to enhance the yield of cowpea landraces and this selection can be practiced by the farmers themselves, for the landraces Cariri, Canapu, Macaíba, and Roxinho for use and development in the production of dry or green grains, and for the landraces Canapu, Manteguinha, and Roxinho to produce aerial biomass, regardless of the conservation history or even the precipitation variation.

Although the performance standards between the cowpea landraces were similar in the different environments, the best values were obtained on the farm with the best environmental conservation history and with higher precipitation during the cultivation. Therefore, the integration among yield, environment conservation in agricultural landscapes, and strategic planning that considers possible variations in local precipitation is essential in sustainable agricultural development models in the semi-arid region of Northeast Brazil, mainly to assist in the eradication of current and future desertification problems.

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