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Adaptability, stability, and agronomic performance of cowpea lines in Mato Grosso, Brazil

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ABSTRACT: This work was carried out to evaluate adaptability and stability, agronomic performance, and phenotypic correlation between the characters of erect/semi-erect cowpea lines in Mato Grosso, Brazil. The trials were conducted in the municipalities of Nova Ubiratã-MT, Primavera do Leste-MT and Sinop-MT in 2014 and 2015. A total of 15 lines and five commercial controls were evaluated using a randomized complete block design (RBD) with four replications. Cultivation value, plant lodging, pod mass, pod length, number of grains per pod, grain mass, mass of 100 grains, grain index and grain yield were evaluated. Data were subjected to analysis of variance and yield adaptability and stability were estimated. Phenotypic correlations among characters were also estimated. The L22, L24, L25, L27, L31, L34 and L35 lines presented good performance for the evaluated characters and good yield adaptability and stability. Estimates of phenotypic correlations indicated that upright plants with smaller lodging presented smaller and lighter pods, with fewer grains per pod and heavier grains.

Key words: plant breeding; selection of lines; *Vigna unguiculata* L.

Adaptabilidade, estabilidade e desempenho agronômico de linhagens de feijão-caupi em Mato Grosso

RESUMO: Este trabalho foi realizado com o objetivo de avaliar a adaptabilidade e estabilidade, o desempenho agronômico e a correlação fenotípica entre caracteres de linhagens de feijão-caupi de porte ereto/semiereto em Mato Grosso. Os ensaios foram conduzidos nos municípios de Nova Ubiratã-MT, Primavera do Leste-MT e Sinop-MT nos anos de 2014 e 2015. Foram avaliadas 15 linhagens e 5 testemunhas comerciais, utilizando-se o delineamento de blocos completos casualizados (DBC) com quatro repetições. Foram avaliados o valor de cultivo, acamamento das plantas, massa da vagem, comprimento da vagem, número de grãos por vagem, massa do grão, massa de 100 grãos, índice de grãos e a produtividade de grãos. Os dados foram submetidos a análises de variância e estimada a adaptabilidade e estabilidade de produção. Também foram estimadas as correlações fenotípicas entre os caracteres. As linhagens L22, L24, L25, L27, L31, L34 e L35 apresentaram fenótipos favoráveis para as características avaliadas e boa adaptabilidade e estabilidade de produção. As estimativas de correlações fenotípicas indicaram que plantas de porte ereto e menor acamamento apresentaram vagens menores, mais leves, com menor número de grãos por vagem e grãos mais pesados.

Palavras-chave: melhoramento de plantas; seleção de linhagens; *Vigna unguiculata* L.

Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.] cultivation in the Center-West region of Brazil, mainly in Mato Grosso, has proven to be a good option for cultivation in the second crop, allowing to sow areas after the end of the ideal sowing period for off-season corn (Delmondes et al., 2017; Menezes Júnior et al., 2019). The crop has shown good adaptation in Mato Grosso, reaching 142.4 thousand tons of grains produced in the 2018/2019 harvest, with an average yield of 1094 kg ha^{-1} (Conab, 2020), which qualifies the state as the largest national producer. This scenario is a reflection of realized research which has developed cultivars through genetic breeding, in addition to being more productive along with modern plant architecture to enable mechanized harvesting (Freire Filho et al., 2011), thus stimulating large-scale cowpea production.

The grains produced by farmers in Mato Grosso have mainly attended the internal market demands of the North and Northeast regions, which are the main consuming cowpea regions in Brazil, and have also been involved in external trade through exportation. In 2019, cowpeas contributed to the export of Brazilian beans exceeding 112 thousand tons (Brazil, 2020). This is due to the fact that cowpeas are consumed in several countries (Singh, 2007).

Selecting lines with good adaptability and production stability in the different grain producing regions is one of the main objectives of the breeding programs in order to continue to meet the demands of the internal market and expand exportation. These assessments demand a lot of dedication, investment and organization due to the need to conduct them in different locations, in addition to being fundamental to identify potential parents and support decision-making on promising lines for recommendation to farmers (Ramalho et al., 2012).

In addition to assessing the yield adaptability and stability among other estimates, it is also very important to know the correlation among the characters in the breeding process (Cruz et al., 2012), as it is then possible to define the best selecting alternatives for the development of lines which gather most of the phenotypes in a favorable condition.

Considering that there is a demand for new technologies for cowpea cultivation, there is a lack of cultivars with different commercial grain types and difficulty in bringing together several phenotypes of interest in a lines such as high yield, resistance to the main biotic and abiotic stresses, modern plant architecture and with commercially accepted grains, investments in research activities are fundamental for the sustainability of the cowpea production chain. In this scenario, this work was carried out with the objective to evaluate adaptability and stability, agronomic performance and phenotypic correlation among characters of cowpea lines with different commercial grain types in the state of Mato Grosso, Brazil.

Materials and Methods

The experiments were conducted in five environments in the field. In 2014, the trials were carried out in three environments: one in Primavera do Leste-MT (Cerrado) in the off-season, without irrigation; and two in Nova Ubiratã-MT (transition from Cerrado and Amazon), one in the off-season period without irrigation, and another after the rainy season with sprinkler irrigation. In 2015, the trials were carried out in two environments: Primavera do Leste-MT and Sinop-MT (transition from Cerrado and Amazon), both in the off-season without irrigation. Sowing was carried out at the end of the rainy season (sowing between 02/15 to 03/10) in the trials conducted in the off-season, with the harvest being carried out in May. The sowing for the irrigated trial was carried out in May and harvesting in September.

A total of 15 erect/semi-erect cowpea lines from the Embrapa Meio-Norte breeding program were evaluated, three from the white commercial class (L21 and L22 from the white smooth subclass and L35 from the white rough subclass), and 12 from the colors commercial class (L23, L24, L25, L26, L28, L30, L31, L33 and L34 from the smooth mulatto subclass, and L27, L29 and L32 from the evergreen subclass), as well as five commercial cultivars (BRS Guariba, BRS Tumucumaque, BRS Novaera, BRS Itaim and BRS Cauamé), totaling 20 treatments.

A randomized complete block design (RBD) with four replications and plots of four lines of 5 m in length with a spacing of 0.45 meters between rows was used. The two central rows of the plot were considered as useful area, and these were harvested to obtain grain yield data.

Before harvesting the pods in the five environments, the cultivation value (CV) was evaluated using a grading scale (scores 1 to 5), taking into account the general aspect of the plant (size, architecture, amount of pods, grain appearance and phytosanitary aspect), in which a score of 1 refers to a plant without adequate characteristics for commercial cultivation; score 2 to a plant with only a few characteristics suitable for commercial cultivation; score 3 to a plant with most of the characteristics suitable for commercial cultivation; score 4 to a plant with all the characteristics suitable for commercial cultivation; and score 5 to a plant with excellent characteristics for commercial cultivation and plant lodging (LOD); also, through a score scale (scores 1 to 5), taking into account the percentage of plant lodging and/or with the main branch broken, in which score 1 refers to the absence of plant lodging; score 2 from 1 to 5% of plant lodging; score 3 from 6 to 10% plant lodging; score 4 from 11 to 20% plant lodging; and score 5 over 20% plant lodging.

Next, five pods were randomly sampled in each plot to obtain the correlation estimates among characters in two environments (Nova Ubiratã-MT and Primavera do Leste-MT, both in the off-season 2014), and the following production components were evaluated: pod mass (PM), pod length (PL), grain mass (GM), number of grains per pod (NGP), grain index (GI) [(GI = grain mass/pod mass) x 100] and the mass of 100 grains (M100G). Grain yield (PROD) was evaluated in the five environments.

Analysis of variance was performed for each characters and then joint analysis of variance considering all the locations where the characters were evaluated. The observed data met the assumptions for carrying out the analysis of variance. The Cochran (1954) method was used to include all environments in the joint analysis for the characters in which there was diversity among the evaluated environments and the presence of heterogeneity among the error variances. In these cases, the degrees of freedom (Df) of the error and the interaction were adjusted to minimize the possible effect of heterogeneity on the significance to be obtained. The treatment means were grouped by the Scott & Knott (1974) test at 5% probability.

The yield adaptability and stability analysis for the lines was carried out using the methodology of Lin & Binns (1988) modified by Carneiro (1998). The general recommendation was made based on the estimate of general P_i obtained by the method of Lin & Binns (1988), and the recommendation for favorable and unfavorable environments was made based on the estimates of P_{if} (favorable environments) and P_{iu} (unfavorable environments), obtained by the decomposition of the general P_i by the methodology of Carneiro (1998).

The means of the two environments in which all production components were evaluated were used to obtain the estimates of phenotypic correlation among the characters. The significance of the correlation coefficients was assessed by the t-test (Cruz et al., 2012). All statistical analyzes were performed using the GENES program (Cruz, 2013).

Results and Discussion

A significant effect was observed for treatments for all characters in all environments, indicating that there is a difference among the means of treatments and the possibility of selecting lines with better performance (Table 1). No significant difference was observed among the means of treatments only regarding lodging in the irrigated environment, as all lines showed less than 5% of plant lodging in this environment. The means of the lodging scores ranged from 1.05 in the irrigated environment to 4.57 in Primavera do Leste 2014, indicating a lot of influence of the environment (Table 1).

The environmental effect for grain yield was also remarkable, as the means ranged from 524.98 kg ha^{-1} in Nova Ubiratã 2014 (irrigated) to 3323.16 kg ha^{-1} in Primavera do Leste 2014 (Table 1). There were no other crops close to the experiment in the irrigated environment which resulted in a high incidence of pest insects and difficulty in control, in addition to an abortion of flowers and an increase in the cycle.

There was a lot of rain during the crop cycle in Sinop 2015 and so the plants became overgrown, showed uneven maturation, and rain during the harvest caused pod rot. The edaphoclimatic conditions in the other environments were favorable for good plant development without the occurrence of rain in the harvest and excellent grain yield averages.

A significant effect was also observed for treatments in the joint analysis (Table 2), indicating that a significant difference was detected in the average of the environments among the treatment averages and the possibility of selecting lines with better performance. A significant effect was also detected for environments, highlighting the divergence between them.

Table 1. Summary of individual analysis of variance for cultivation value (VC), lodging (LOD), grain yield in kg ha^{-1} (PROD), pod mass (PM), pod length (PL), number of grains per pod (NGP), grain mass (MG), grain index (GI) and mass of 100 grains (M100G) of erect and semi-erect cowpea lines evaluated in Primavera do Leste-MT, Nova Ubiratã-MT and Sinop-MT, Brazil.

	CV	LOD	PROD	PM	PL	NGP	MG	GI	M100G
Primavera do Leste-MT - 2014									
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mean	3.24	4.57	3323	3.06	19.58	12.93	0.18	76.58	18.30
CV (%)	11.78	13.50	13.04	14.42	7.38	10.08	9.95	4.89	9.94
Nova Ubiratã-MT - 2014									
p	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000
Mean	3.55	2.46	2082	3.08	19.75	12.97	0.18	77.75	18.76
CV (%)	7.99	18.79	14.29	11.68	6.29	10.66	7.62	3.81	7.35

	CV	LOD	PROD
Nova Ubiratã-MT - Irrigated - 2014			
p	0.000	0.081	0.000
Mean	2.85	1.05	525
CV (%)	25.70	19.54	25.27
Primavera do Leste-MT - 2015			
p	0.006	0.000	0.000
Mean	3.19	3.97	2404
CV (%)	9.43	20.00	13.05
Sinop-MT - 2015			
p	0.009	0.000	0.000
Mean	3.25	3.40	589
CV (%)	17.29	29.28	25.28

p: Probability by the F-test; CV (%): Coefficient of variation in percentage.

Table 2. Summary of joint analysis of variance for cultivation value (CV), lodging (LOD) and grain yield (PROD, in kg ha^{-1}) of erect and semi-erect cowpea lines evaluated in the state of Mato Grosso, Brazil, in 2014 and 2015.

SV	Mean square								
	CV			LOD			PROD		
	Df	QM	p	Df	MS	p	Df	MS	p
Block/environments	3	0.682		3	1.262		3	174330.32	
Environments (E)	4	5.042	0.000	4	152.797	0.000	4	117093521.94	0.000
Treatments (T)	19	0.687	0.000	19	6.938	0.000	19	1009879.995	0.000
T x A	76	1.020	0.000	54(*)	1.848	0.000	54(*)	728138.604	0.000
Mean error	285	0.234		185	0.696		183	129188.477	
Overall average		3.21			3.09			1784.68	
Mean for the lines		3.18			3.30			1802.18	
Control mean		3.31			2.46			1732.2	
CV (%)		15.03			26.99			20.14	

SV: Source of Variation; Df: Degrees of Freedom; MS: Medium Square; p: Probability by the F-test; CV (%): Coefficient of variation in percentage; (*) Degrees of Freedom adjusted by the methodology proposed by Cochran (1954).

The interaction between treatments and environments was significant for the three characters (Table 2), indicating that the treatments showed different performance in the evaluated environments and the need to evaluate the adaptability and stability of the lines. An occurrence of genotype x environment interaction has been common in cowpea culture (Shiringani & Shimelis, 2011; Torres et al., 2016; Kamara et al., 2017; Souza et al., 2018).

In the mean of the five evaluated environments, the cultivation value scores ranged from 2.98 (L23) to 3.58 (L22) (Table 3). All lines proved to be suitable by visual evaluation, considering that a score of 3 refers to plants with most characteristics suitable for commercial cultivation. According to the Scott & Knott (1974) test, two distinct groups were formed with six lines showing higher scores than the control BRS Tumucumaque, which is the most used cultivar in the state of Mato Grosso, Brazil.

Table 3. Mean cultivation value, lodging and grain yield (kg ha^{-1}) of erect and semi-erect cowpea lines evaluated in the state of Mato Grosso, Brazil, in 2014 and 2015.

Treatment (1)	Cultivation value	Lodging	Grain yield
L31	3.05 b	3.75 a	2033 a
L25	3.15 b	3.90 a	2032 a
L34	3.20 b	3.45 a	2018 a
L27	3.43 a	3.55 a	1988 a
L24	3.03 b	3.65 a	1971 a
L33	3.30 a	3.30 b	1916 b
L32	3.00 b	3.25 b	1885 b
Cauamé	3.38 a	2.30 d	1846 b
L28	2.98 b	3.55 a	1843 b
BRS Guariba	3.15 b	3.10 b	1820 b
BRS Itaim	3.43 a	2.00 d	1808 b
L26	3.10 b	3.55 a	1805 b
L35	3.35 a	2.20 d	1762 c
L22	3.58 a	2.60 c	1761 c
L30	2.98 b	3.60 a	1688 c
L29	3.33 a	3.20 b	1678 c
BRS Tumucumaque	3.20 b	2.85 c	1608 c
L21	3.40 a	2.80 c	1606 c
BRS Novaera	3.40 a	2.05 d	1579 c
L23	2.98 b	3.20 b	1048 d

(1) Means followed by the same letter in the column do not differ by the Scott & Knott test at 5% probability.

The L35 line had the lowest lodging score (2.2) and was grouped together with the BRS Itaim, BRS Novaera and BRS Cauamé control (Table 3). Considering that a score of 4 corresponds to the range of 11 to 20% plant lodging, all lines showed an average of 10% or less plant lodging. Plants with an erect size and low lodging are essential for mechanized harvesting (Machado et al., 2008; Matos Filho et al., 2009), which is the main system used by farmers in the state of Mato Grosso, Brazil.

Grain yield averages ranged from 1048 kg ha^{-1} to 2033 kg ha^{-1}, with five lines forming a group superior to all controls (Table 3). These results show the potential of this group of lines considering as reference the mean of cowpea cultivars recommended for the Brazil midwest region (1350 kg ha^{-1}) (Rocha et al., 2017).

In addition to presenting phenotypes of agronomic interest (Table 3), the L24, L25, L27, L31 and L34 lines also had the lowest general P_i estimates (Table 4). These lines also showed the highest grain yield averages, confirming the association between high mean and lowest P_i estimates (Lin & Binns, 1988). Therefore, these lines showed good adaptability and general stability for cultivation in Mato Grosso.

From the decomposition of the general P_i estimates, it was observed that most of the estimates were generally due to genetic deviations (Table 4). The contribution of genetic deviations for the five lines with the lowest general P_i estimates was greater than 69%, in addition to a low contribution to the interaction, all of which were less than 3% (Table 4). Considering that the most suitable line is the one with the lowest P_i value and has the greatest share of the genetic deviation component (Cruz et al., 2014), these five lines are promising for cultivation in Mato Grosso and also to be used as parents in the breeding program.

A good coincidence was observed between the lines most suitable for favorable environments (Table 5) with those of better adaptability and general stability (Table 4). The L26 line was the most indicated for unfavorable environments with the lowest P_{iu} estimate (Table 5). However, it is noted

Table 4. Grain yield adaptability and stability estimates of erect and semi-erect cowpea lines in the state of Mato Grosso, Brazil, based on the methodology of Lin & Binns (1988).

Treatment	General P_i/1000	Deviation / 1000		% of genetic deviation	Contribution to the interaction (%)
		Genetics	Interaction		
L31	77.24	62.38	14.87	80.75	1.06
L25	89.22	62.85	26.36	70.44	1.88
L34	95.01	67.84	27.17	71.40	1.94
L24	101.67	86.09	15.58	84.67	1.11
L27	113.51	79.44	34.06	69.98	2.43
L33	146.06	110.76	35.30	75.83	2.51
L32	165.15	125.38	39.77	75.91	2.83
L28	186.32	147.72	38.59	79.28	2.75
BRS Guariba	196.14	160.26	35.87	81.71	2.56
BRS Cauamé	213.95	145.88	68.07	68.18	4.85
L22	223.47	195.50	27.97	87.48	1.99
BRS Itaim	251.53	166.90	84.64	66.35	6.03
L30	272.33	243.67	28.66	89.47	2.04
L29	306.86	250.60	56.27	81.66	4.01
L35	314.77	195.03	119.73	61.96	8.53
L26	332.90	168.84	164.06	50.71	11.69
L21	358.90	304.08	54.30	84.84	3.87
BRS Tumucumaque	412.90	302.95	109.95	73.37	7.83
BRS Novaera	461.27	325.87	135.40	70.64	9.65
L23	1182.34	895.26	287.09	75.71	20.45

Table 5. Decomposition of grain yield adaptability and stability (P_i) estimates of erect and semi-erect cowpea lines in the state of Mato Grosso, Brazil, based on the methodology of Carneiro (1998) in favorable (P_{if}) and unfavorable (P_{iu}) environments.

Treatment	P_{if} - favorable / 1000	Treatment	P_{iu} - unfavorable / 1000
L31	24.58	L26	75.14
L32	47.12	L25	125.90
L27	47.55	L31	156.25
L34	49.88	L34	162.70
L24	53.36	L24	174.13
L25	64.76	L33	180.99
L33	122.77	L35	182.54
L28	123.33	BRS Cauamé	203.07
L22	144.14	BRS Tumucumaque	204.31
BRS Guariba	149.62	L27	212.43
L30	216.66	BRS Guariba	265.91
BRS Cauamé	221.20	L28	280.80
BRS Itaim	222.22	BRS Itaim	295.51
L29	314.42	L29	295.54
L21	383.23	BRS Novaera	314.75
L35	402.91	L21	321.11
L26	504.74	L32	342.19
BRS Tumucumaque	551.96	L22	342.45
BRS Novaera	558.95	L30	355.84
L23	1672.49	L23	447.12

that this line had a low genetic deviation value (50.71%) and a high estimate of the contribution to the interaction (11.69%) (Table 4). Thus, the indication of the L26 line is restricted to unfavorable environments, since it presented oscillation in the means in the different environments.

The L31 line deserves mention among the lines of the commercial group cores for having the lowest estimates of P_i (general and favorable) and the third lowest estimate of P_{iu}, a high contribution of genetic deviations (80.75%) and a low contribution to the interaction (1.06%), showing that this line performed well in most environments. Therefore, this line can be considered of general adaptation and of good predictability. Among the lines of the smooth and rough white commercial class, L22 and L35, respectively, presented the best adaptability and stability estimates, evidencing their good potential to be used as parents in the breeding program and utilization in the state of Mato Grosso, Brazil.

The correlation estimates between the characters were generally significant (Table 6), in these cases indicating the possibility of association among the characters and implications in the selection process. Estimating significant correlations among characters has been common in cowpea

Table 6. Estimates of phenotypic correlation coefficients for cultivation value (CV), lodging (LOD), pod mass (PM), pod length (CV), number of grains per pod (NGP), grain mass (GM), grain index (GI), mass of 100 grains (M100G) and grain yield (PROD) of erect and semi-erect cowpea lines evaluated in Nova Ubiratã and Primavera do Leste, Mato Grosso, Brazil, 2014.

	LOD	PM	PL	NGP	GM	GI	M100G	PROD
CV	-0.860**	-0.554*	-0.406	-0.635**	0.635**	0.452*	0.638**	0.154
LOD		0.580**	0.489*	0.748**	-0.799**	-0.525*	-0.806**	0.154
PM			0.791**	0.892**	-0.575**	-0.552*	-0.588**	-0.125
PL				0.748**	-0.528*	-0.384	-0.550*	0.040
NGP					-0.841**	-0.485*	-0.853**	0.089
GM						0.579**	0.998**	-0.031
GI							0.566**	0.544*
M100G								-0.053

(**, *): Significant at 1 and 5% of probability by the t-test.

cultivation (Lopes et al., 2001; Rocha et al., 2009; Silva & Neves, 2011; Correa et al., 2012).

The lodging scores did not show significant correlation with grain yield (Table 6), however the correlation between lodging and cultivation value was negative and significant (-0.860), indicating that the selection based on the cultivation value score can reduce the lodging score, which is desirable since the higher the cultivation value score, the lower the lodging.

The cultivation value scores did not correlate with grain yield (Table 6). This fact implies that the cultivation value scores were more influenced by plant lodging than by grain yield. It is worth mentioning that the scores were visually assigned in the field, and the perception of plant lodging by the evaluator is more evident than the grain yield, in which it is possible to only observe the loading of pods.

A positive correlation was observed between lodging scores with pod mass, pod length and number of grains per pod, indicating that plants with lower lodging scores had smaller, lighter pods and fewer grains per pod (Table 6). On the other hand, lodging presented a negative correlation with the grain mass, with the grain index and with the mass of 100 grains, indicating that less lodging lines had heavier grains and a higher grain index. This is an indication that the selection of erect and low lodging lines should consider plants with smaller, lighter pods, with fewer grains per pod and with heavier grains.

The pod length was shown to be positively correlated with the number of grains per pod and negatively with the grain mass and with the mass of 100 grains (Table 6), which means that it can be inferred that larger pods had a higher number of grains, but with smaller and lighter grains. However, it is desirable for most commercial classes that the grains are larger (Freire Filho et al., 2011) and, in this case, the correlation estimates indicated a selection of shorter pods. The pod length did not correlate with grain yield, indicating that productive lines can be obtained by simultaneously selecting plants with low lodging, as well as shorter and lighter pods.

There was a negative correlation between the number of grains per pod with the grain mass, with the mass of 100 grains and with the grain index (Table 6). This indicates that lines with a lower number of grains per pod presented larger and heavier grains and with a higher grain index. The grain index is an estimate of the percentage of grains in relation to the total weight of the pod and the higher the index, the straw is expected to be thinner and lighter. The grain index also showed a positive correlation with grain yield (Table 6), indicating that the most productive lines had a higher percentage of grains in relation to the total pod weight.

Conclusions

The L24, L25, L27, L31 and L34 lines of the color commercial class, L22 of the white smooth commercial class and L35 of the white rough commercial class, showed good agronomic performance and good adaptability and stability for cultivation in Mato Grosso.

The phenotypic correlation estimates indicated that plants of erect size and less lodging also had smaller and lighter pods with less number of grains per pod, but with heavier grains.

Erect/semi-erect lines with different commercial types of promising grains were identified for use as parents in the breeding program.

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