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Agronomic and commercial potential of compound-inflorescence cowpea lines

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Abstract – The objective of this work was to select cowpea lines with compound inflorescences that show a high potential to generate the first commercial cultivar with this characteristic in Brazil. Thirty-seven lines were evaluated in a randomized complete block design, with two replicates, in 2021, in the municipality of Teresina, in the state of Piauí. The following traits were evaluated: number of days to the onset of flowering, plant size, commercial grain quality, number of grains per pod, weight of 100 grains, and grain yield. Deviance analyzes were performed by the restricted maximum likelihood/ best unbiased linear predictor methodology, and the values and genetic parameters necessary to carry out simultaneous selection were estimated based on the rank sum index. A statistical difference was detected between the lines evaluated by the likelihood ratio test (LRT). In general, genetic variance was the largest component of phenotypic variance for the evaluated traits. The ten most promising cowpea lines with compound inflorescences are: MNC15-33E-123, MNC15-33E-178, MNC15-33E-222, MNC15-33E-171, MNC15-33E-232, MNC15-33E-223, MNC15-33E-219, MNC15-33E-183, MNC15-33E-91, and MNC15-33E-165. These lines were selected for the next selection stages and show a high potential to generate the first commercial cowpea cultivar with compound inflorescences in Brazil.

Index terms: *Vigna unguiculata*, branched peduncle, grain yield.

Potencial agronômico e comercial de linhagens de feijão-caupi de inflorescência composta

Resumo – O objetivo deste trabalho foi selecionar linhagens de feijão-caupi de inflorescência composta que apresentam alto potencial para gerar a primeira cultivar comercial com esta característica no Brasil. Trinta e sete linhagens foram avaliadas em delineamento de blocos ao acaso, com duas repetições, em 2021, no município de Teresina, no estado do Piauí. Foram avaliados os seguintes caracteres: número de dias para o início do florescimento, porte da planta, qualidade comercial do grão, número de grãos por vagem, peso de 100 grãos e rendimento de grãos. Foram realizadas análises de deviance pela metodologia da máxima verossimilhança restrita/melhor preditor linear não viesado, e estimados os valores e os parâmetros genéticos necessários para realização da seleção simultânea com base no índice de soma de postos. Foi detectada diferença estatística entre as linhagens avaliadas por meio do teste de razão de verossimilhança. Em geral, a variância genética foi o maior componente da variância fenotípica para os caracteres avaliados. As dez linhagens de feijão-caupi de inflorescência composta mais promissoras são: MNC15-33E-123, MNC15-33E-178, MNC15-33E-222, MNC15-33E-171, MNC15-33E-232, MNC15-33E-223, MNC15-33E-219, MNC15-33E-183, MNC15-33E-91 e MNC15-33E-165. Essas linhagens foram selecionadas para as próximas etapas de seleção e apresentam grande potencial para gerar a primeira cultivar comercial de feijão-caupi de inflorescência composta no Brasil.

Termos para indexação: *Vigna unguiculata*, pedúnculo ramificado, rendimento de grãos.

Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.] is a legume adapted to the dry regions of the globe and the marginal areas of the tropics and subtropics (Gondwe et al., 2019), where it has a great socioeconomic importance, as it produces satisfactorily in soils with a low fertility and under a reduced average annual precipitation, being used to generate employment and income for needy communities in these locations.

In 2019, more than 90% of the 8.9 million tons of dry cowpea pulses produced worldwide, in 15.06 million hectares, with an average yield of 591.2 kg ha^{-1}, came from the African continent (FAO, 2020). According to Companhia Nacional de Abastecimento (CONAB) (Acompanhamento…, 2022), Brazil was not included in these estimates, although it ranked as the fourth largest grain producer in the 2020/2021 harvest, with 625,800 tons of cowpea produced in 1,349.600 hectares, with a mean yield of 462.11 kg ha^{-1}.

In Brazil, cowpea is cultivated mainly in the Northern and Northeastern regions, where it stands out for its relevant contribution to the income of the population who commercializes grains from several of the cultivars that have been launched up to now in the market (Freire Filho, 2011). Although this type of bean is the second most consumed in the country, its national grain yield is lower than that of common bean (*Phaseolus vulgaris* L.) due to unfavorable edaphoclimatic conditions and to the low crop-management technological level in both of those regions that cover a significant portion of the planted area (Acompanhamento…, 2022).

The cowpea crop has also been expanding to other regions of Brazil, such as the Midwest, especially the state of Mato Grosso, which is attributed to the increased demand of the consumer market of the Northeastern region, the export potential of the product, and the possibility of implementing crop rotation using cowpea, which is a viable crop in the off-season (Delmondes et al., 2017).

Since cowpea is mainly consumed by the population in the form of grain, during the registration, protection, and/or release process of a new cultivar, some parameters related to grain quality must be defined (Almeida et al., 2020). Among them, grain size and color can be crucial for the acceptance of cultivars by farmers, the market, and consumers in different regions of Brazil and the world (Freire Filho, 2011). In this context, it is equally important to evaluate both the technological quality and yield potential of the grain of elite lines to be released (Gonçalves et al., 2020).

Breeders have adopted specific methodologies to decompose phenotypic variation into environmental and genetic components for a given trait, particularly the restricted maximum likelihood/best linear unbiased predictor (REML/BLUP) methodology via mixed models, which has been frequently used to obtain variance components, and, through them, the genetic values and parameters that are of paramount importance for the improvement and understanding of the genetic variability among the evaluated genotypes (Resende, 2016). The tool helps the breeder in the decision-making process to choose the best selection strategy and, consequently, to obtain superior genotypes, either through direct or indirect selection (Correa et al., 2012), also improving the accuracy of the prediction of genetic gains even for traits with a low heritability (Preisigke et al., 2020).

In Brazil, the released cowpea cultivars present predominantly a simple inflorescence, although an accession with a branched peduncle was collected in the mid-1970s in the Northeastern region (Freire Filho, 2011). Since some crops with compound inflorescences have a relatively higher yield than cowpea, the following hypothesis has been raised: that the introduction of the gene that controls the compound inflorescence trait can increase crop yield. Several annual leguminous crops, such as soybean [*Glycine max* (L.) Merr.] (Perini et al., 2012) and common bean (Martins et al., 2017), have already been subjected to the improvement process for the insertion of genes that confer compound inflorescences.

In the case of cowpea, compound inflorescences have a recessive monogenic inheritance (Machado et al., 2007), which facilitates the selection of individuals in the first generations of populations inbred for the trait. Initially, progenies were generated from crosses and backcrosses between the branched cultivar and commercial cultivars of cowpea with a single inflorescence (Barros et al., 2011; Sousa et al., 2016; Bernardo et al., 2018). However, the commercial quality of the grains from these crosses is still low compared with that of the cowpea cultivars with a single inflorescence currently on the market.

The objective of this work was to select cowpea lines with compound inflorescences that present a

high potential to generate the first commercial cultivar with this characteristic in Brazil.

Materials and Methods

The genetic material used for the experiment was composed of 35 cowpea lines with compound inflorescences (L1 to L35) and their parents (L36 and L37), totaling the following 37 lines: MNC15-33E-10 (L1), MNC15-33E-53 (L2), MNC15-33E-69 (L3), MNC15-33E-91 (L4), MNC15-33E-94 (L5), MNC15-33E-119 (L6), MNC15-33E-123 (L7), MNC15-33E-163 (L8), MNC15-33E-165 (L9), MNC15-33E-169 (L10), MNC15-33E-171 (L11), MNC15-33E-178 (L12), MNC15-33E-181 (L13), MNC15-33E-182 (L14), MNC15-33E-183 (L15), MNC15-33E-197 (L16), MNC15-33E-199 (L17), MNC15-33E-200 (L18), MNC15-33E-201 (L19), MNC15-33E-206 (L20), MNC15-33E-211 (L21), MNC15-33E-214 (L22), MNC15-33E-215 (L23), MNC15-33E-219 (L24), MNC15-33E-222 (L25), MNC15-33E-223 (L26), MNC15-33E-226 (L27), MNC15-33E-228 (L28), MNC15-33E-230 (L29), MNC15-33E-231 (L30), MNC15-33E-232 (L31), MNC15-33E-234 (L32), MNC15-33E-237 (L33), MNC15-33E-239 (L34), MNC15-33E-240 (L35), and MNC04-795F-168 (L36) x MNC11-1076B-131-1-22 (L37).

All lines used in the experiment were obtained by the cowpea genetic breeding program of Embrapa Meio-Norte, headquartered in the municipality of Teresina, in the state of Piauí, Brazil (05º05'21"S, 42º48'07"W, at 72 m altitude), where the average annual rainfall is of 1,378 mm.

The cowpea lines with compound inflorescences, resulting from the MNC04-795F-168 (parent 1, P_1) x MNC11-1076B-131-1-22 (parent 2, P_2) cross, were selected in a preliminary yield trial carried out in the breeding program after the advancement of generations and the opening of the inflorescences of the lines in the third cycle of crossings in 2015. The main characteristics of the parental lines are: simple inflorescence, early maturity cycle, semi-erect plant size, and high commercial grain quality for MNC04-795F-168; and early maturity cycle, compound inflorescences, semi-erect plant size, and low commercial grain quality for MNC11-1076B-131-1-22, which was developed from two cycles of previous crossings (Barros et al., 2011; Bernardo et al., 2018).

In the cowpea breeding program of Embrapa Meio-Norte, the intermediate trial, which succeeds the preliminary trial and precedes the value for cultivation and use (VCU) trial, was carried out in a randomized complete block design, with two replicates, in the first semester of 2021, between April and June, in the experimental field of the company. The experimental unit (plot) consisted of a 3.0 m row, containing ten plants per linear meter. The spacing was 0.5 m between rows and 0.25 m between plants within the row; the useful area of the plot was the row itself (1.5 m²).

After planting, thinning was carried out 15 days after sowing, leaving a stand of eight plants per linear meter. Two manual weeding were performed, respectively, 20 and 35 days after sowing. Pesticides were used to control insect pests and diseases according to the recommendations for the crop (Freire Filho, 2011), aiming to stabilize the plant stand. Harvesting was done manually at approximately 65 to 75 days after planting.

The evaluated traits were: number of days to the onset of flowering (OF), equivalent to the number of days from planting until 50% of the plants in the useful area of the plot opened flowers; plant size, determined visually, using a scale of scores (1 to 4), in the useful area of the plot; commercial grain quality (CGQ), classified through a visual grade scale (1 to 5), considering color, shape, size, hilum aspect, and presence/absence of grain defects (Table 1); number of grains per pod (NGP), obtained as the mean of the number of grains (units) from five pods collected randomly in the useful area of the plot; weight of 100 grains (W100G), considered the mean weight of 100 grains (g) from the pods in the useful area of the sampled plot; and grain yield, calculated as the total weight of the grains in the useful area of the plot (g m⁻²), extrapolated to kg ha⁻¹. The data involving visual scores were transformed to √(x+0.5) to perform statistical analyses.

The residual analysis was carried out to check for the presence of outliers and estimate possible data from lost plots, which were then replaced by their respective predicted phenotypic values with the aid of the SAS statistical software (SAS Institute Inc., Cary, NC, USA).

The estimators of the variance components, values, and genetic parameters were obtained by the REML/BLUP approach using the following model: $Y = Xr + Zg + e$, where Y is the data vector; r is the

vector of the repeat effects (assumed to be fixed) plus the overall average; g is the vector of genotypic effects (assumed to be random); e is the vector of errors or residuals (assumed to be random); and X and Z represent the incidence matrices for the aforementioned effects.

The genetic parameters estimated via REML were: phenotypic variance (σ^2_p); environmental variance (σ^2_e); genotypic variance (σ^2_g); broad-sense heritability (h^2_g); broad-sense heritability at the level of genotype means (h^2_{mg}); selective accuracy of the lines ($\hat{r}_{\hat{g}\hat{g}}$); and relative coefficient of variation calculated by the (CV_g/CV_e) ratio, where CV_g and CV_e are the coefficients of genetic and experimental variation, respectively. The significance of the random effects of the model was evaluated using the likelihood ratio test (LRT) and the generated table, with the analysis of deviance (Resende, 2016).

The genotypic values were predicted through the BLUP of each individual evaluated for the traits under analysis. The selection intensity adopted was 27.03%, corresponding to the ten lines that presented the highest genetic values.

Table 1. Visual grade scales used to classify plant size and commercial grain quality of the evaluated cowpea (*Vigna unguiculata*) lines.

Grade	Plant size
1	Erect: the main and secondary branches of the plant are short; the main branch is erect and the secondary branches usually form an acute angle with it.
2	Semi-erect: the main and secondary branches can vary from short to medium; the main branch is erect and the secondary branches form a right angle with it, without touching the ground.
3	Semi-prostrate: the main and secondary branches are medium; the main branch is erect and the inferior secondary branches touch the ground.
4	Prostrate: the secondary and main branches are long; the main branch is contorted and, regardless of its position, the secondary branches touch the ground.

Grade	Commercial grain quality
1	Very bad: less than 400 or more than 500 grains per 100 g with a high postharvest color loss, non-reniform shape, and presence of defects (cracks in the tegument and/or split ends).
2	Bad: less than 400 or more than 500 grains per 100 g with a high postharvest color loss, non-reniform shape, and no defects.
3	Regular: from 400 to 500 grains per 100 g with a small postharvest color loss, non-reniform shape, and no defects.
4	Good: from 400 to 500 grains per 100 g with a small postharvest color loss, reniform shape, and no defects.
5	Excellent: from 400 to 500 grains per 100 g with no or small postharvest color loss, reniform shape, and no defects.

In addition, the selection index (MMI) proposed by Mulamba & Mock (Mulamba & Mock, 1978), based on the sum of ranks, was adopted when selection was performed considering the classification or ordering of the lines for multiple traits. The calculation of the index depended only on the genotypic means obtained via the mixed model; no economic weight was adopted. The MMI was determined through the following equation: MMI = Rxu, where R is the v × n matrix of the ranks associated with the adjusted genotypic means of v relative genotypes to n traits; and u is the n × 1 vector of economic weights.

The mean values of four traits – NGP, W100G, grain yield, and CGQ – were increased and of one – plant size – decreased in the population of selected individuals.

Results and Discussion

The LRT identified a significant difference at 1 and 5% probability among genotypes for most studied traits, except for OF (Table 2). This indicates the presence of genetic variability in the group of genotypes evaluated, and consequently, the probability of success in the selection process of superior individuals with erect plants that allow mechanized cultivation and a satisfactory grain yield and quality.

While evaluating 60 F_4 cowpea progenies with compound inflorescences, Bernardo et al. (2018) observed genetic variability for grain yield and its components in the second cycle of crossings. However, Barros et al. (2011) found no significant difference between cowpea progenies with a simple inflorescence and those with compound inflorescences in the first cycle of crossings. Despite these results, the authors highlighted the productive potential of the obtained progenies, indicating the possibility of significant gains in grain yield with the introduction of compound inflorescences through the selection process.

The mean and individual heritability values obtained for plant size, NGP, W100G, grain yield, and CGQ were higher than those for OF (Table 2), which can be attributed to the high heritability and predominance of additive effects in early generations (Sousa et al., 2016), enabling the success in the selection and fixation process of early-cycle lines in the corresponding stage of the breeding program. The values for this parameter in the present work were higher than those of 0.21 for NGP and 0.43 for grain yield found by Bernardo

et al. (2018) and of 0.68 for NGP by Barros et al. (2011) when evaluating F_4 cowpea progenies with compound inflorescences in one of the conducted backcrosses. These results are indicative that cowpea lines can be selected based on relatively simple predicted values for NGP, W100G, grain yield, and CGQ when the proportion of genetic variation is much higher than that of environmental origin.

According to the classification of Resende & Duarte (2007), plant size, NGP, W100G, grain yield, and CGQ, respectively, showed a high, very high, high, very high, and very high experimental precision, respectively, due to their selective accuracies of 0.76, 0.91, 0.86, 0.93, and 0.94 (Table 2). These authors concluded that accuracy levels above 0.90 are only possible when the heritability obtained by the variable is above 0.60, as observed in the present study for most traits, among which grain yield stands out for being a quantitative trait and, therefore, an exception. This result is important since high experimental precisions make the selection process of superior individuals reliable. Barroso Neto et al. (2017) reported similar values while evaluating 62 cowpea genotypes with a simple inflorescence in the municipality of Marco, in the state of Ceará, Brazil.

The relative coefficient of determination, obtained from the relationship between the genotypic and experimental coefficient of variation, is another very important genetic parameter related to accuracy. Since there is a direct relationship between a given accuracy and the value of this coefficient plus the number of replicates used in the experiment, for a selective accuracy with values within the range considered "very high", the value of the coefficient must be equal to or greater than 1.5 in experiments with two replicates (Resende & Duarte, 2007). In the present study, values of 1.52, 1.76, and 1.9 were obtained for NGP, grain yield, and CGQ were, respectively, which are the traits that presented accuracy values above 0.90 (Table 2). However, since it is common to adopt a relative coefficient of determination with a value equal to or greater than 1.0 to proceed with the selection process, W100G, with a value of 1.18, can also provide significant genetic gains.

Although 37 lines were evaluated, in order to reduce the size of the tables and focus on the cowpea lines with compound inflorescences that show a greater agronomic and commercial potential, only the results of the best 10 lines in terms of predicted genetic values (overall average + BLUP of genotypic effects) were presented. According to the predicted genetic values,

Table 2. Analyses of deviance, chi-square (χ^2) test, and estimates of variance components for the traits number of days to onset of flowering (OF), plant size, number of grains per pod (NGP), weight of 100 grains (W100G), grain yield, and commercial grain quality (CGQ) of 37 cowpea (*Vigna unguiculata*) lines evaluated in the intermediate trial of the breeding program carried out in 2021, in the municipality of Teresina, in the state of Piauí, Brazil.

Effect	Analyses of deviance					
	OF	Plant size[1]	NGP	W100G	Grain yield	CGQ[1]
Complete model	94.57	-201.89	147.94	237.03	970.71	-136.16
Lines	94.59	-195.55	171.86	251.93	1001.28	-101.96
LRT[2] (χ^2)	0.02ns	6.34*	23.92**	14.90**	30.57**	34.20*
Parameter[3]	Estimates of variance components					
σ^2_g	0.0343	0.0088	2.5229	6.4088	275,727.7862	0.0632
σ^2_e	1.2039	0.0131	1.0979	4.6004	88,790.8003	0.0175
σ^2_p	1.2382	0.0219	3.6207	11.0092	364,518.5865	0.0808
h^2_g	0.0277	0.4019	0.6968	0.5821	0.7564	0.7831
h^2_{mg}	0.0539	0.5734	0.8213	0.7359	0.8613	0.8784
$\hat{r}_{\hat{g}g}$	0.2321	0.7572	0.9063	0.8578	0.9281	0.9372
CV_r	0.1687	0.8197	1.5159	1.1803	1.7622	1.9001
Overall average	31.51	1.49	11.06	22.30	1,485.75	1.63

[1]Data transformed to $\sqrt{(x+0.5)}$. [2]Likelihood ratio test. [3]Genetic parameters estimated for the evaluated cowpea lines: σ^2_g, genotypic variance; σ^2_e, residual variance; σ^2_p, phenotypic variance; h^2_g, broad-sense individual heritability; h^2_{mg}, broad-sense heritability at the level of genotype means; $\hat{r}_{\hat{g}g}$, selective accuracy; and CV_r, coefficient of relative variation. *and **χ^2 test at 5 and 1% probability, respectively.

the presence of variability caused significant gains and a shift from the overall average in plant size, NGP, W100G, grain yield, and CGQ (Table 3).

A genetic gain of 0.10 was obtained for plant size due to the predominance of negative deviations from the overall average and the individual BLUP of the selection interval between the selected lines (Table 3). In this case, the last member (L24) of the selection interval presented a genetic value of 1.44 and the first one (L16) of 1.34, with an overall average of 1.49 and a new average of 1.39 after the selection of the best lines for a more compact plant size. This is indicative that, after selection, lines with an erect plant type predominate, which is confirmed by the initial average value obtained for the trait by the visual scale of scores. This characteristic is the aim of cowpea genetic breeding, as upright genotypes allow mechanized harvesting and a more compact arrangement between the genotypes allocated to the field and, consequently, an increased grain yield (Hall, 2012).

Regarding NGP, the adopted selection intensity led to a significant genetic gain, ranging from 12.16 to 13.48 grains, respectively, for the last (L6) and first (L17) individuals of the group (Table 3), with an overall average of 11.06 grains and a new average of 12.64 grains after selection for a larger number of grains per pod,

representing a gain of 1.58 grains. Barros et al. (2011) obtained a lower indirect gain of 0.71 grains per pod when selecting five cowpea progenies with compound inflorescences for grain yield in the second backcross.

The possibility of increasing the number of grains per pod through genetic gain is promising for crop improvement, since cowpea genotypes with a single inflorescence show more seeds per pod than those with compound inflorescences, which present a shorter pod length (Sousa et al., 2016). Family farmers prefer larger pods, whereas business farmers, who mechanically grow large areas, prefer smaller pods, which facilitate mechanized harvesting, also increasing the number of pods per plant and yield per hectare (Silva et al., 2016).

For W100G, the positive deviations of the individual BLUPs generated by the selected lines and the L36 parental line (P_1) also caused a significant shift from the overall average, with minimum and maximum predicted genetic values in the selection interval of 23.80 and 27.95 g for L12 and L35, respectively, and an overall average of 22.30 g (Table 3). The new average of the lines after selection for an increased grain size was 24.79 g, corresponding to a genetic gain of 2.49 g, which is higher than the indirect gain of 0.5 g found by Barros et al. (2011) for W100G when selecting ten cowpea progenies with compound inflorescences for productive

Table 3. Predicted genetic values ($\mu + g$) for the traits plant size, number of grains per pod (NGP), weight of 100 grains (W100G), grain yield, and commercial grain quality (CGQ) of the 10 best cowpea (*Vigna unguiculata*) lines evaluated in the intermediate trial of the breeding program carried out in 2021, in the municipality of Teresina, in the state of Piauí, Brazil.

Plant size[1]		NGP		W100G (g)		Grain yield (kg ha⁻¹)		CGQ[1]	
Nº	$\mu + g$	Nº	$\mu + g$	Nº	$\mu + g$	Nº	$\mu + g$	Nº	$\mu + g$
L24	1.44	L17	13.48	L35	27.95	L31	3,320.69	L36 (P₁)	2.26
L26	1.44	L26	13.39	L33	26.34	L16	2,340.82	L25	2.06
L28	1.44	L11	12.82	L25	24.83	L6	2,147.15	L4	1.84
L29	1.44	L15	12.74	L14	24.45	L15	2,013.09	L5	1.84
L32	1.44	L30	12.49	L19	24.16	L34	1,828.17	L11	1.84
L1	1.34	L24	12.45	L7	24.14	L20	1,753.83	L12	1.84
L2	1.34	L7	12.33	L18	24.12	L28	1,713.65	L13	1.84
L10	1.34	L22	12.33	L3	24.10	L9	1,687.69	L14	1.84
L12	1.34	L25	12.20	L36 (P₁)	24.02	L26	1,686.82	L24	1.84
L16	1.34	L6	12.16	L12	23.80	L27	1,664.56	L31	1.84
Overall average[2]	1.49	-	11.06	-	22.30	-	1,485.75	-	1.63
New average[3]	1.39	-	12.64	-	24.79	-	2,015.65	-	1.90
Initial average[4]	1.73	-	-	-	-	-	-	-	2.24
General[5] gain (%)	-6.71		14.29		11.17		35.66		16.56

[1]Data transformed to $\sqrt{(x+0.5)}$. [2]Calculated based on the data from 37 cowpea lines. [3]New average after the selection of the best lines. [4]Original average obtained before data transformation and genotype selection. [5]Genetic gain after selection.

potential. This shows the possibility of increasing the size of cowpea grains, which is fundamental for their commercialization and consumption in Brazil and worldwide (Freire Filho, 2011).

The displacement of the overall average through the averages predicted via the individual BLUPs for the selected lines was superior to that of the parental lines and the other evaluated lines, showing the greatest genetic gains in relation to the overall average (Table 3). The last and the first ranked individuals (L27 and L31, respectively) in the selection range showed a genetic value of 1,664.56 and 3,320.69 kg ha^{-1}. The overall average of the genetic value for grain yield was 1,485.75 kg ha^{-1}, which is higher than the national average yield of 462.11 kg ha^{-1} according to cowpea yield data of the 2020/2021 harvest (Acompanhamento…, 2022).

The new average after selection for an increased grain yield was 2,015.65 kg ha^{-1}, with a genetic gain of 529.90 kg ha^{-1} (Table 3). This gain is much higher than that reported in several works carried out with cowpea lines with a simple inflorescence, such as the one of Torres et al. (2016), who evaluated the grain yield of 20 cowpea genotypes in the Midwestern region of Brazil and found gain estimates of 18.79 and 18.04% for the two best lines, and of Rocha et al. (2017), who studied 20 cowpea genotypes in the Northeastern region of the country and obtained gains of 10.56, 8.52, and 7.76% for the three best cowpea lines. The high genetic gain obtained in the present study may have been due to the introduction of compound inflorescences to the lines, as speculated by Benlloch et al. (2015).

The cowpea lines with compound inflorescences that were selected for CGQ showed satisfactory genetic gains in relation to the overall average, with genetic values of 1.84 to 2.26 for the last (L31) and first (parental L36) lines, as well as an overall average of 1.63 for the selection range covered by the lines (Table 3). The new average after selection for an increased commercial grain quality was 1.90, with a genetic gain of 0.27. For that trait, the ranking of the cowpea lines with compound inflorescences, taking into account the original data to favor its interpretation, was as follows: L36 (P$_1$) in first place, with a score equal to 5 in both replicates; L25 in second, with a score equal to 4 in both replicates; L4, L5, L11, L12, L13, L14, L24, and L31 in third, with a score equal to 3 in both replicates.

Based on the predicted genetic values of the individuals, in general, it was possible to select lines superior to the L36 and L37 parents for all evaluated traits, except for CGQ (Table 3). Although only one cowpea line with compound inflorescences (L25) showed a score close to that of the best control (cowpea parental line with a simple inflorescence) already consolidated in the market, most of the studied cowpea lines with compound inflorescences present good traits that can be improved in the future using adequate strategies in the cowpea breeding program.

The obtained results are indicative of the possibility of the selection of cowpea lines with compound inflorescences that show a higher CGQ. In addition, the third cycle of crosses was efficient in improving the commercial quality of the grains of these lines, which increases the chance of acceptance by the producer and the commercial and consumer market at the end of the cowpea breeding process (Freire Filho, 2011; Almeida et al., 2020). CGQ is a key feature for the adoption of cowpea cultivars by farmers and for the consumption by consumers, which can, therefore, contribute to the expansion of the market and consumption of cowpea in Brazil.

The general genetic gain values obtained by the MMI were: 0, 1.24 grains, 0.48 g, and 0.14 for plant size, NGP, W100G, and CGQ, respectively; and 133.70 kg ha^{-1} for grain yield, representing percentages of 0, 11.27, 2.16, 8.72, and 9.00; simultaneously, the MMI gain for all traits (sum of gains of all evaluated traits) was 31.15% (Table 4). This evidences the high efficiency of the simultaneous selection of several traits through the MMI. Silva et al. (2018) also found high gains in cowpea through simultaneous selection via the MMI when evaluating 105 cowpea lines with a simple inflorescence.

The cowpea lines with compound inflorescences that were selected by the individual BLUPS showed genetic gains of -0.10 for plant size (-6.71%), 1.58 grains for NGP (14.29%), 2.49 g for W100G (11.17%), 0.27 for CGQ (16,56%), and 529.90 kg ha^{-1} for grain yield (35.66%) (Table 3). Although these values were higher than the general ones of individuals selected by the MMI, the gain values of the index remained within the minimum required for selection (Table 4). Oliveira et al. (2017), evaluating simultaneously 12 traits of F$_4$ cowpea progenies with a simple inflorescence, reported genetic gains from 5.0 to 31.25%, general gain range in which the present study is.

Table 4. Specific and general selection gains for the traits plant size, weight of 100 grains (W100G), number of grains per pod (NGP), grain yield, and commercial grain quality (CGQ) obtained through the rank sum index of Mulamba & Mock (1978) for the ten best cowpea (*Vigna unguiculata*) lines and their parents (P_1 and P_2) in the intermediate trial of the breeding program carried out in 2021, in the municipality of Teresina, in the state of Piauí, Brazil.

Line	Rank of Mulamba & Mock	Plant size[1]	NGP	W100G (g)	Grain yield (kg ha⁻¹)	CGQ[1]
		-- Specific gain (%)[2] --				
L7	1	0.36	11.42	8.27	5.04	6.22
L12	2	-10.15	6.96	6.75	12.83	-30.72
L25	3	3.57	10.30	11.36	26.31	-2.57
L11	4	3.57	15.87	1.59	12.83	-5.28
L31	5	3.57	6.22	5.43	12.83	123.50
L26	6	-3.29	21.07	-8.99	-2.76	13.53
L24	7	-3.29	12.53	0.12	12.83	-43.97
L15	8	3.57	15.13	-1.56	-2.76	35.49
L4	9	3.57	6.22	2.48	12.83	-19.81
L9	10	0.36	6.96	-3.78	-2.76	13.59
L36 (P_1)	21	3.57	-26.45	7.72	6.89	38.35
L37 (P_2)	29	-3.29	3.25	-5.21	0.28	-21.93
General gain[3]		0	11.27	2.16	8.72	9.00

[1]Data transformed to $\sqrt{(x+0.5)}$. [2]Specific gain of a line for a specific trait. [3]General gain obtained by the lines selected by the selection index.

According to the MMI, the best ten cowpea lines with compound inflorescences, which are also the most promising for the target traits of selection, were: MNC15-33E-123, MNC15-33E-178, MNC15-33E-222, MNC15-33E-171, MNC15-33E-232, MNC15-33E-223, MNC15-33E-219, MNC15-33E-183, MNC15-33E-91, and MNC15-33E-165 (Table 4). All these lines were superior to their parents (L36 and L37) based on the general genetic gain estimated through the rank sum index, which considers simultaneously all the evaluated traits.

Despite the positive results, it is necessary to confirm the superiority of the selected lines under different edaphoclimatic conditions (i.e., in VCU trials), which is the next stage of the cowpea breeding program. The aim is to promote a safe cultivation and also to obtain the first Brazilian cowpea cultivar with compound inflorescences, early development, erect plant, high grain yield, high commercial grain quality, and adaptability and stability in the several cultivation regions in Brazil.

Conclusion

The ten most promising cowpea (*Vigna unguiculata*) lines with compound inflorescences that were selected for the target traits – early maturity cycle, erect plant, high yield, and high commercial grain quality –

and, consequently, for the next selection stages are: MNC15-33E-123, MNC15-33E-178, MNC15-33E-222, MNC15-33E-171, MNC15-33E-232, MNC15-33E-223, MNC15-33E-219, MNC15-33E-183, MNC15-33E-91, and MNC15-33E-165, which, therefore, show a high potential to generate the first commercial cowpea cultivar with compound inflorescences in Brazil.

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