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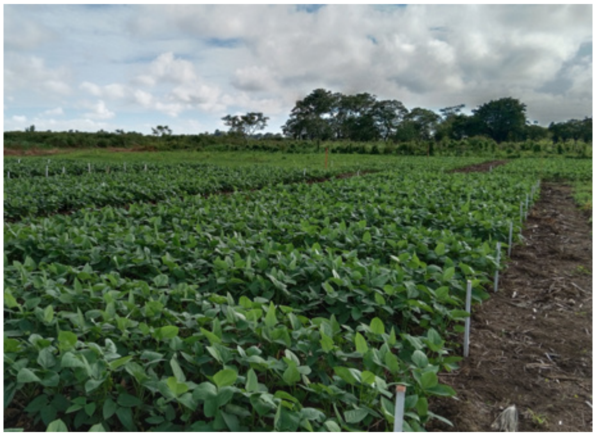
Variability, correlation, and path analysis in erect and prostrate cultivars of cowpea (*Vigna unguiculata* [L.] Walp.)

Análisis de variabilidad, correlación y sendero en cultivares erectos y postrados de caupí (*Vigna unguiculata* [L.] Walp.)



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Evaluation of cowpea cultivars.

Photo: L.A. Perneth

ABSTRACT

The cowpea bean (*Vigna unguiculata* [L.] Walp.) is the most important legume in the Colombian Caribbean, and is cultivated with genotypes having prostrate growth habit, with yields that do not exceed 700 kg ha^{-1}. Manual harvesting is very expensive for crop rotation in commercial agriculture, which is why cultivars with erect growth habit are required. The research was carried out in the first semester of 2022, in the experimental area of the Universidad de Córdoba (Monteria-Colombia). Sixteen erect genotypes and five prostrate genotypes, including the control, were evaluated under a randomized complete block design with five repetitions. Each experimental unit consisted of two rows of 5 m in length, with a distance between plants of 0.15 m and between rows of 0.40 m for a population density of 166.000 plants/ha. The results indicated genetic variability, which enables successful phenotypic selection, according to the estimated genetic parameters. Likewise, there was positive and significant correlations of performance components with yield. In addition, the unfolding of genotypic correlations by means of path analysis indicated that grain thickness is an important and easy to measure characteristic to increase yield.

Additional key words: legumes; grain quality; genetic variability; food security; nutritional composition.

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RESUMEN

El fríjol caupí (*Vigna unguiculata* [L.] Walp.) es la leguminosa más importante del Caribe colombiano, la cual es cultivada con genotipos de hábito de crecimiento postrado, con rendimientos que no superan los 700 kg ha^{-1}. La cosecha manual resulta muy costosa para la rotación de cultivos en la agricultura empresarial, por lo que se requiere de cultivares de hábito de crecimiento erecto. La investigación se realizó en el primer semestre de 2022, en el área experimental de la Universidad de Córdoba (Montería-Colombia). Se evaluaron 16 genotipos erectos y cinco postrados incluido el testigo, bajo el diseño de bloques completos al azar con cinco repeticiones; cada unidad experimental estuvo conformada por dos surcos de 5 m de longitud, con distancia entre plantas de 0,15 m y entre surcos de 0,40 m para una densidad de población de 166.000 plantas/ha. Los resultados indicaron variabilidad genética, la cual posibilita la selección fenotípica exitosa, de acuerdo con los parámetros genéticos estimados. Así mismo, la existencia de correlaciones positivas y significativas de los componentes del rendimiento con el rendimiento. Además, el desdoblamiento de las correlaciones genotípicas mediante análisis de sendero indica que, el espesor del grano es una característica importante y fácil de medir para incrementar el rendimiento.

Palabras clave adicionales: leguminosas; calidad de grano; variabilidad genética, seguridad alimentaria; composición nutricional.

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INTRODUCTION

The cowpea bean is a legume of African origin with great economic and nutritional importance, which is consumed as a fresh grain and mainly as a dry grain for its high protein and mineral content, iron being vital for the transport of oxygen in the blood, DNA synthesis, energy production and other metabolic processes; while the bioavailability of zinc is important in cell growth and replication, bone formation, strengthening of the immune system and sexual maturation (Singh *et al.*, 2016; Xiong *et al.*, 2016). In addition, in the USA, the demand for cowpea as an alternative to soy in the preparation of food for animal feed is expected to increase (Osipitan *et al.*, 2021).

In Colombia, it is cultivated mainly on the north coast of the country by small and medium producers, which benefit from their adaptation to the rainfall deficit and the incorporation of atmospheric nitrogen into the soil (Abaidoo *et al.*, 2017), the latter decreases the need for very expensive inorganic fertilizers. This production system has grown from 14,361 ha in 2007 to 17,199 ha in 2020 (Agronet, 2022), due to the release of new varieties with prostrate habit and greater yield potential, but with the difficulty of manual harvesting, which represents 44% of production costs (Martínez-Reina *et al.*, 2022), and the additional challenge of finding labour for such work. Likewise, these prostrate cultivars are affected by the microclimate, since the pods, when they come into contact with the soil, deteriorate, thereby affecting grain yield.

The native varieties of cowpea beans, 'Like tiger hand', 'Guajiro', 'Turkey quin', 'Quarantine' and 'Momposino', whose yield does not exceed 700 kg ha^{-1}, are planted in most of the cultivated area, which makes it necessary to select new cultivars with good agronomic and nutritional characteristics that allow improving the yield and quality of the crop grain, to contribute to an improvement in the quality of life of the producer, the nutrition of the consumer and open the possibilities of exporting to demanding markets, with problems of food insecurity, mainly in the Caribbean region.

In this sense, research based on estimates of genetic parameters are of great relevance in the genetic improvement of plants, since this allows knowing the genetic variability of a population (Cardona-Ayala *et al*., 2013) and the degree of expression of a characteristic from one generation to another and the possible gain through direct and indirect selection, and, likewise, the methods of genetic improvement according to the gene action in the control of quantitative characteristics (Silva *et al.*, 2014).

Characteristics such as grain yield and its components, being of a quantitative nature, are strongly influenced by the environment, therefore, knowledge of the existence of genetic variability indicates the path to follow to obtain greater profits through the selection process. The objective of this research was to estimate the genetic parameters of agronomic characteristics and the iron and zinc contents, the correlations between characteristics and the direct and indirect effects of a set of variables on yield, to select biofortified lines with high grain yield and erect growth.

MATERIALS AND METHODS

Location

The study was carried out in the first semester of 2022 at the Faculty of Agricultural Sciences of the Universidad de Córdoba, located at 8°48’ N 75°52’ W, with an elevation of 15 m a.s.l. The surrounding area has an average annual rainfall of 1,200 mm, average temperature of 28°C, solar brightness of 1,800 light h year^{-1} and a relative humidity of 84%.

Genotypes

Sixteen lines of erect growth were evaluated, and four were of prostrate growth, plus the commercial control ‘Caupicor 50’ also prostrate; with cream-colored grains and black hilium obtained by the plant breeding program of the Universidad de Córdoba. The 16 lines originated by individual selection of the Missouri genotype, while the prostrate ones originated from the cross between IT86×LCPM-35.

Experimental design

A randomized complete block design with five replications was used. Each experimental unit consisted of two rows of 2 m in length, with a distance between plants of 0.15 m and between rows of 0.40 m for a population density of 166.000 plants/ha.

Agronomic management

For the control of weeds, glyphosate was applied in pre-emergence at a rate of 15 mL L^{-1} and in post-emergence diuron 100 mL plus ammonium glufosinate-5 mL L^{-1}; for the management of Damping off, azoxystrobin + difenoconazole was applied at a rate of 1.0 mL L^{-1}, and, for sucking insects, cypermethrin 1.0 mL L^{-1}.

Response and measurement variables

The measurements were made on five competing plants in each experimental unit, apart from the yield that was made on the whole plot. The iron and zinc contents were determined in a sample of 20 g per plot. The characteristics studied were: days at flowering (DFL), plant height (PH), pod length (PL), number of pods per plant (NPPP), number of seeds per pod (NSPP), weight of 100 seeds (W100S), seed length (SL), seed width (SW), seed thickness (ST), dry grain yield (DGY), iron content (Fe) and zinc content (Zn) in the seed.

Analysis of variance was performed with the Genes v. 2016.6.0 software developed by Cruz (2016) and separation of means using Tukey’s test at 5% and 1%. Phenotypic, genotypic, and environmental variances were estimated with the formulas used by Prasad *et al.* (1981).

With the formulas proposed by Johnson *et al.* (1955) and Donkor *et al.* (2022), the following were estimated: phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), variability index (b), heritability in the broad sense (h^2) and genetic gain (GA).

The iron and zinc contents were determined with an energy dispersive X-ray fluorescence spectrometer (XRF-Bruker, S2 PUMA, Germany) for each material, as described by Paltridge *et al.* (2012).

Pearson’s correlation coefficients between pairs of characteristics were estimated with the standard procedure, and the coefficients of direct effects ($P_{x_i y} = \frac{\sigma_{x_i}}{\sigma_y}$) and indirect effects ($r_{i,j} P_{j,y}$) of the path analysis, according to the procedure described by Espinosa (2018). The Genes software version Windows Genes v. 2016.6.0 (Cruz, 2016) was used.

RESULTS AND DISCUSSION

Analysis of variance

The analysis of variance revealed significant differences for all the agronomic and nutritional characteristics (Tab. 1), so the existing genetic variability can be used for the selection of lines with excellent agronomic and nutritional attributes; similar results were reported by Donkor *et al.* (2022) in *Vigna subterranea*, Varanya *et al.* (2022) in *V. unguiculata* and Singh *et al.* (2018) in *V. unguiculata*.

The contrasts recorded in table 1, show significant differences in C1 (erect *vs*. prostrate) for all variables, while for C2 (erect *vs*. control), only highly significant differences were detected for DFL, PH, PL, NSPP and DGY and significant for Fe, corroborating the existence of genetic divergence between genotypes as previously detected in this species by Varanya *et al.* (2022).

The averages of the agronomic and nutritional characteristics indicate that the DFL, PH, NPPP, SL, ST and DGY in the erect cultivars were agronomically better than the prostrate ones and the control: they flowered at 30 d, that is, 5 d before the prostrate ones and the control, PH of 102.66 cm compared to 193.71 and 168.68 cm of the prostrate and control cultivars, NPPP of 10.59 cm in the erect cultivars compared to 6.96 and 8.02 cm of the prostrate and control, respectively, SL and ST slightly higher than the prostrate and control, and W100S larger than the prostrate and similar to the control. The SW was similar in erect, prostrate and control cultivars.

The average DGY of the erect cultivar (1,225 kg ha^{-1}) far exceeded the prostrate one and control; the LM-40 line stood out with yields of 1,719 kg ha^{-1} and LM-27 with Fe and Zn contents of 71.40 and 44.46 mg kg^{-1}, respectively. The iron contents were like those reported by Carvalho *et al.* (2012) and those of zinc. The PL was lower in the erect cultivar, with lower NSPP and larger seed dimensions (SL and ST). On the other hand, the control surpassed the erect and prostrate in terms of PL, NSPP, W100S and contents of Fe and Zn.

It was inferred that the selection of genotypes with good agronomic and nutritional characteristics is feasible due to the presence of genetic variability, considering attributes such as high grain yield, erect growing habit, determined growth pattern, earliness, and the location of pods above the plant canopy (Singh, 2007), which allows improving the food supply and the fight against hidden hunger (Dinesh *et al.*, 2017; Mafakheri *et al.*, 2017).

Estimation of genetic parameters

The most relevant genetic parameters in genetic improvement in the genus *Vigna* are: phenotypic coefficient of variation, genotypic coefficient of variation, phenotypic, genetic and environmental variances, variability index, heritability and genetic advance (Donkor *et al.*, 2022; Varanya *et al.*, 2022).

The decomposition of phenotypic variance (Tab. 2) registered a greater contribution of genetic variance than environmental variance, except for NPPP, SL and SW, which was due to environmental effects on the expression of these characteristics, as highlighted by Donkor *et al.* (2022).

In a broad sense, heritability estimates allow us to know the degree of expression of a characteristic in the following generations, being quantified as low when it is less than 30%, moderate from 30 to 60%,

Table 1. Mean squares of the analysis of variance and contrasts for agronomic characteristics and micronutrient content in cowpea beans.

FV	DF	DFL	PH	PL	NPPP	NSPP	W100S	SL	SW	ST	DGY	Fe	Zn
Block	4	3.65	1,978.93	1.36	26.58	1.64	2.57	0.51	0.49	0.34	255,062.25	3.84	0.92
Genotype	20	18.15**	8,966.75**	2.83**	18.59*	5.72**	14.67**	0.67*	0.33*	0.25**	771,515.38**	20.02**	7.06**
Error	80	2.05	700.11	0.46	9.48	0.75	0.7	0.41	0.17	0.09	140,476	3.54	1.14
Mean		31.8	124.34	15.03	9.72	10.03	16.09	8.37	5.94	4.67	1,038	64.84	42.19
C1	1	275.56**	151,491.43**	3.71**	243.40**	84.08**	211.42**	1.42*	2.14**	2.67**	11939,443.62**	71.67**	4.63*
C2	1	81.04**	20,506.12**	12.39**	31.21^{NS}	22.49**	1.80^{NS}	0.05^{NS}	0.26^{NS}	0.08^{NS}	1064,616.62**	16.92*	3.76^{NS}
CV (%)		4.5	21.27	4.52	31.64	8.65	5.19	7.68	6.96	6.42	36.08	2.9	2.53

FV = source of variation; DF = degrees of freedom; C1 = erect *vs*. prostrate; C2 = erect *vs*. control; DFL = days to flowering; PH = plant height; PL = pod length; NPPP = number of pods per plant; NSPP = number of seeds per pod; W100S = weight of 100 seeds; SL = seed length; SW = seed width; ST = seed thickness; DGY = dry grain yield; Fe = iron content; Zn = zinc content; CV = coefficient of variation. Means with ^{NS} was not significative, * significative $P<0.05$, ** significative $P<0.01$, for the Tukey test.

and high when it is greater than 60% (Donkor *et al.,* 2022). In this study, moderate values were found for NPPP, SL and SW, and high values in the remaining nine variables. Therefore, phenotypic selection can be efficient in identifying cultivars with better agronomic and nutritional characteristics, given the existence of genetic variability quantified through the genetic variability index, which when it is equal to or greater than unity, there are favorable conditions for selection (Jost *et al.*, 2013) and allows advances that result in cultivars with better performance and accumulation of iron and zinc, corroborating what was expressed by Donkor *et al.* (2022), who pointed out that high magnitudes of heritability and genotypic coefficient of variation generate reliable indicators of genetic progress, due to genes with additive action that favor phenotypic selection, especially for DFL, PH, W100S, DGY and Fe and Zn content. The results are consistent with Panchta *et al.* (2022) and Varanya *et al.* (2022).

Correlations

In this study, 40% of the phenotypic (rF) and 59% of the genotypic (rG) correlations were significant and of the same meaning, at 5 or 1% probability (Tab. 3). However, the genotypic correlations were of greater magnitude and importance than the phenotypic ones, which represents a greater genetic contribution and value in selection, as has been reported in several legumes (Bandi *et al.*, 2018; Tirkey *et al.*, 2022).

DFL presented negative and significant rG (-0.51 to 1.00) with NPPP, W100S, SL, SW, ST and DGY, suggesting that later flowering affected NPPP, biometric characteristics and DGY, possibly because by increasing the duration of the crop cycle, the genotypes were exposed to a greater competition between plants and intraplant, affecting the partition of assimilates, to which is added a longer exposure time to pests and diseases. Other studies have reported that nutrient uptake and nodule activity is affected by abiotic factors such as drought or excess water in the soil, which translates into lower yields in materials with longer days to flowering and harvest (Panchta *et al.*, 2020; Tirkey *et al.*, 2022).

On the other hand, DFL positively correlated (rG = 1.00**) with NSPP and PH, which suggests that by increasing the crop cycle, starting from a later flowering, plants of greater heights and NSPP are formed, possibly because their characteristics are controlled by genes with pleiotropic or linked effects, which from the physiological point of view allows the plant to produce photoassimilates that increase NSPP and PH; results consistent with those found in other studies (Panchta *et al.*, 2020; Tirkey *et al.*, 2022).

Table 2. Phenotypic variance (PV), genotypic variance (GV), environmental variance (EV), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), variability index (b), heritability in the broad sense (h^2), genetic advance (GA) and genetic advance as percent of mean (GAM) for 12 quantitative traits of cowpea (*Vigna unguiculata* (L.) Walp).

Variable	PV	GV	EV	GCV	PCV	b	h^2	GA	GAM (%)
DFL	3.63	3.21	0.41	5.63	5.98	1.25	88.66	3.47	10.9
PH	1793.35	1653.31	140.03	32.7	34.05	1.53	92.19	80.42	64.68
PL	0.56	0.47	0.09	4.58	4.97	1.01	83.71	1.29	8.58
NPPP	3.69	1.8	1.89	13.78	19.74	0.43	48.67	1.92	19.79
NSPP	1.14	0.99	0.15	9.93	10.64	1.14	86.8	1.9	19.03
W100S	2.93	2.79	0.14	10.38	10.63	1.99	95.22	3.35	20.82
SL	0.13	0.06	0.07	3	4.32	0.4	46.57	0.34	4.07
SW	0.066	0.031	0.034	3	4.32	0.43	48.17	0.25	4.29
ST	0.05	0.032	0.018	3.83	4.78	0.59	64.05	0.29	6.31
DGY	154,303	125,384.8	28,918.24	34.09	37.82	0.93	81.25	655.4	63.11
Fe	4	3.29	0.7	2.79	3.08	0.96	82.28	3.38	5.22
Zn	1.41	1.18	0.22	2.57	2.81	1.01	83.73	2.04	4.83

DFL = days to flowering; PH = plant height; PL = pod length; NPPP = number of pods per plant; NSPP = number of seeds per pod; W100S = weight of 100 seeds; SL = seed length; SW = seed width; ST = seed thickness; DGY = dry grain yield; Fe = iron content; Zn = zinc content.

The NPPP was negatively and significantly correlated (rG: -1.00**) with DFL, NSPP and PH, while with W100S, SL, SW, ST and DGY the correlation was positive (rG from 1.00** to 0.92). This indicates that the variables DFL, NSPP, PH, W100S, SL, SW, ST, DGY and NPPP have similar genetic control, so it can be inferred that it is possible to select plants with higher NPPP to improve yield and establish a physiological limit in this type of population that does not reduce the DGY; also valid for NSPP (Tirkey *et al.*, 2022).

The NSPP was negatively and significantly correlated with W100S, SL, SW, ST and DGY (rG from -0.57* to -0.89**), this suggests that the selection of plants with higher NSPP decreases the weight and the biometric characteristics of the grain and the DGY. Competition for photoassimilates during grain filling affects W100S, SL, SW and ST, which has been reported by Silva *et al.* (2014) and suggests that it is better to select pods with fewer seeds, but larger and heavier (Tirkey *et al.*, 2022).

Due to its importance and application in the selection, the correlations of W100S with SL, SW, ST and DGY were positive and significant (rG from 0.85** to 1.00**), but negative with PH (rG = -0.89**), which allows us to infer that the selection of plants with higher W100S, facilitates increase in the size and biomass of the grain, which is reflected in higher DGY, associated in turn with lower PH. Similar results have been reported by Lekshmanan and Vahab (2017) and Tirkey *et al.* (2022).

The three grain dimensions SL, SW and ST were positively correlated with each other (rG from 0.64** to 0.93**). On the other hand, SW and ST correlated positively with DGY (rG = 0.85** and 1.00**) and negatively with PH (rG from -0.48* to -0.88**), which confirms that the selection of plants by higher W100S, SL, SW, ST and NPPP, should be considered as criterion to increase the DGY, especially ST (rG = 1.00**) should be considered in a breeding program by selection to improve yield.

Table 3. Estimates of phenotypic (rF) and genotypic (rG) correlations (r's) among thirteen agronomic traits (Var's) in cowpea bean cultivars.

Var´s	r's	PL	NPPP	NSPP	W100S	SL	SW	ST	PH	DGY	Fe	Zn
DFL	rF	0.30	**-0.78**	**0.86**	**-0.73**	-0.33	-0.41	**-0.63**	**0.90**	**-0.81**	-0.18	-0.07
	rG	0.36	**-1.00**	**1.00**	**-0.79**	**-0.51**	**-0.61**	**-0.82**	**1.00**	**-0.89**	-0.21	-0.06
PL	rF		-0.18	**0.50**	0.17	0.38	0.21	-0.10	0.38	-0.16	0.01	0.42
	rG		-0.39	**0.49**	0.18	**0.48**	0.27	-0.18	0.39	-0.23	-0.02	0.49
NPPP	rF			-0.78	0.74	0.48	0.57	0.69	-0.83	0.75	0.25	0.26
	rG			**-1.00**	**1.00**	**0.92**	**1.00**	**1.00**	**-1.00**	**1.00**	0.36	0.33
NSPP	rF				**-0.65**	-0.35	-0.34	**-0.56**	**0.93**	**-0.71**	-0.13	0.01
	rG				**-0.73**	**-0.62**	**-0.57**	**-0.83**	**1.00**	**-0.89**	-0.18	-0.04
W100S	rF					0.57	**0.75**	**0.77**	**-0.76**	**0.81**	0.17	0.21
	rG					**0.85**	**1.00**	**0.97**	**-0.80**	**0.89**	0.19	0.22
SL	rF						0.69	**0.48**	-0.31	0.29	-0.01	0.20
	rG						**0.64**	0.40	**-0.48**	0.46	-0.05	0.26
SW	rF							0.83	-0.45	0.52	0.26	0.16
	rG							**0.93**	**-0.65**	**0.85**	0.33	0.18
ST	rF								**-0.67**	**0.78**	0.18	-0.01
	rG								**-0.88**	**1.00**	0.18	-0.09
PH	rF									**-0.81**	-0.19	-0.01
	rG									**-0.93**	-0.22	-0.01
DGY	rF										0.37	0.14
	rG										0.44	0.11
Fe	rF											0.61
	rG											0.65

DF = days to flowering; PL = length of the pod; NPPP = number of pods per plant; NSPP = number of seeds per pod; W100S = weight of 100 seeds; SL = grain length; SW = grain width; ST = grain thickness; PH = plant height; DGY = dry grain yield; Fe = iron content; Zn = zinc content. In bold the rF and rG correlations are significant at 5 or 1% probability.

The DGY presented negative and significant correlation (rG from -0.55* to -0.93**) with DFL, NSPP and PH; while with NPPP, W100S, SW and ST, the correlation was positive (rG from 0.85** to 1.00**). Due to their importance, these positive genetic correlations make the selection and improvement of the DGY much easier, since, by exerting selection pressure on one of these characteristics, the other is affected, due to the existence of a joint action of genes that govern them or by pleiotropic action between these characters (Bandi *et al.*, 2018; Tirkey *et al.*, 2022).

The Fe and Zn did not correlate significantly with the agronomic characteristics, however, between both elements the correlation was positive and significant (rG = 0.61**), which allows increase in the content of iron and zinc in the grain in this type of cultivars, while selecting plants with higher iron or zinc content.

Path analysis

Next, the relationship of several characteristics with the performance variable is explained, through the analysis of path coefficients (Tab. 4), a useful technique for determining cause-effect relationships and information from the direct and indirect effects of indicator variables (Espinosa, 2018).

At the phenotypic level, ST caused the greatest positive direct effect on performance ($P_{(ST)DGY}$= 0.61) (Tab. 4), this means that, with a higher ST, a higher performance is achieved. However, ST is associated with positive indirect effects via SW, W100S and NPPP, so performance is expected to increase with higher SW, W100S and NPPP. On the other hand, ST is associated with negative indirect effects with PH, NSPP and DFL, indicating that a higher yield is achieved with plants of lower height and lower NSPP and DFL. At the genotypic level, the result is similar, but with higher magnitudes of the path coefficients ($P_{(ST)DGY}$ = 3.84) and, in general, for all positive and negative indirect effects.

The variable W100S presented positive direct effect ($P_{(W100S)\ DGY}$ = 0.50) at the phenotypic level, this means higher yield with heavier seeds. Indirect effects via SW, W100S and NPPP, were also positive and contributed to increased yield indirectly. However, PH, DFL and NSPP exerted negative indirect effects, that is, heavier seeds were obtained with lower PH, DFL and NSPP. At the genotypic level, the magnitudes of path coefficients for the effects were smaller.

Table 4. Estimates of direct (diagonal in bold) and indirect effects of the seven-component correlation on cowpea yield at the phenotypic (rF) and genotypic (rG) levels.

VAR´s	DFL	NPPP	NSPP	W100S	SW	ST	PH	rF DGY
DFL	**-0.21**	-0.11	0.15	-0.36	0.21	-0.39	-0.10	**-0.81****
NPPP	0.16	**0.14**	-0.13	0.37	-0.29	0.42	0.09	**0.75****
NSPP	-0.18	-0.11	**0.17**	-0.32	0.17	-0.34	-0.10	**-0.71****
W100S	0.15	0.10	-0.11	**0.50**	-0.39	0.47	0.09	**0.81****
SW	0.08	0.08	-0.06	0.38	**-0.51**	0.50	0.05	**0.52***
ST	0.13	0.10	-0.10	0.39	-0.42	**0.61**	0.08	**0.78****
PH	-0.19	-0.12	0.16	-0.38	0.23	-0.41	**-0.11**	**-0.81****
R^2= 0.85	h = 0.15							
VAR´s	DFL	NPPP	NSPP	W100S	SW	ST	PH	rG DGY
DFL	**-1.58**	0.94	1.84	-0.18	1.13	-3.13	0.10	**-0.89****
NPPP	1.76	**-0.84**	-2.37	0.23	-2.17	4.52	-0.12	**1.00****
NSPP	-1.60	1.09	**1.82**	-0.16	1.05	-3.20	0.10	-0.89**
W100S	1.25	-0.86	-1.33	**0.22**	-2.05	3.73	-0.08	**0.89****
SW	0.97	-0.99	-1.05	0.25	**-1.84**	3.57	-0.06	**0.85****
ST	1.29	-0.99	-1.52	0.22	-1.70	**3.84**	-0.08	**1.00****
PH	-1.58	1.05	1.89	-0.18	1.19	-3.39	**0.10**	**-0.93****
R^2= 1.00	h = 0.00							

DFL = days to flowering; NPPP = number of pods per plant; NSPP = number of seeds per pod; W100S = weight of 100 seeds; SW = seed width; ST = seed thickness; PH = plant height; DGY = dry grain yield.

DFL, at the phenotypic level, exerted a negative direct effect on yield ($P_{(DFL)DGY}$= -0.21), which means that a higher yield was associated with earlier flowering, as evidenced in the comparisons of means and contrasts (Tab. 2). Complementarily, the indirect effects via NPPP, W100S, SW and ST were positive, that is, earlier flowering was associated with higher values of these four variables. At the genotypic level, the magnitudes of the path coefficients were higher.

NSPP presented a direct positive effect on performance ($P_{(NSPP)DGY}$= 0.17) and positive indirect effects via DFL and PH. It would then be expected that yield would increase with taller plants and later flowering, but experimental evidence has shown that the 16 erect cultivars, with lower PH and DFL, had higher yields than the five prostrate ones. At the genotypic level, the direct effect was greater ($P_{(NSPP)DGY}$= 1.82), as were the indirect effects on performance via DF and PH (Tab. 4).

CONCLUSION

The existence of genetic variability among the evaluated genotypes allows selection of phenotypes with good agronomic attributes and iron and zinc content, to improve yields and contribute to reducing the problems of hidden hunger.

The number of pods per plant, weight of 100 seeds, length, width, and thickness of the seeds showed a positive correlation with yield; while days to flowering, number of seeds per pod and plant height negatively correlated with yield.

Path analysis revealed that grain thickness is an important and easy to measure characteristics for increasing yield.

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