Biometric genetics in Cowpea beans (*Vigna unguiculata* (L.) Walp) II: estimates of genetic gains through selection indices

Genética biométrica en Caupí (*Vigna unguiculata* (L.) Walp) II: estimaciones de ganancias genéticas a través de índices de selección

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Abstract

Low cowpea productivity (*Vigna unguiculata* (L.) Walp) in the semi-arid region of Paraíba is due, among other factors, to poor-quality cultivars. This research tested biometric models intending to increase productivity of superior cultivars with the following objectives: i. Estimate genetic gains in production components; ii. Identify the selection index model providing the greatest gains through simultaneously selecting a set of variables, and iii. Select cultivars with higher productivity. The experiment was carried out in the experimental field of the Agrifood Science and Technology Center of the Federal University of Campina Grande. Eight cultivars and 13 variables were evaluated. Data were subjected to ANOVA and means were grouped using the Scott and Knott test. Genetic gains were estimated by correlated response, classic selection index, rank sum and index based on desired gains. Direct selection of the secondary pod yield component provides significant genetic gains in main grain yield. Among the methodologies used, the classic selection index provided greater distribution of genetic gains for main grain yield and primary production components. These results allow concluding that Costela de vaca, BRS Marataoã and Paulistinha cultivars should be selected for cultivation and commercial exploitation in the semiarid region of Paraíba.

Keywords

selection indices • genetic improvement • simultaneous selection • productivity • correlated response

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Resumen

En la región semiárida de Paraíba, el caupí (*Vigna unguiculata* (L.) Walp) es el principal producto de la agricultura familiar. El cultivo tiene baja productividad debido a lluvias irregulares y al uso de cultivares de baja productividad. Con el objetivo de superar estas limitaciones y aumentar la eficiencia de la selección de cultivares superiores, se llevó a cabo un extenso estudio utilizando modelos biométricos en caupí, con los siguientes objetivos: i. Estimar las ganancias genéticas de los componentes de la producción; ii. Identificar el modelo de índice de selección que proporciona las mayores ganancias mediante la selección simultánea de un conjunto de variables y iii. Seleccionar cultivares con mayor productividad. El experimento se llevó a cabo en el campo experimental del Centro de Ciencia y Tecnología Agroalimentaria de la Universidad Federal de Campina Grande. Se evaluaron 13 variables relacionadas con la productividad. Los datos se sometieron a ANOVA y las medias se agruparon según la prueba de Scott y Knott p≤ 0,05. También se estimó el coeficiente de heredabilidad de cada variable. Las ganancias genéticas se estimaron utilizando las siguientes metodologías: respuesta correlacionada, índice de selección clásico, suma de rango e índice basado en las ganancias deseadas. Se encontró que la selección directa del componente de rendimiento de la vaina secundaria proporciona ganancias genéticas significativas en rendimiento de grano. Entre las metodologías utilizadas, el índice de selección clásico proporcionó una mayor distribución de las ganancias genéticas para rendimiento de grano y para los componentes primarios de producción. Estos resultados permiten concluir que los cultivares Costela de vaca, BRS Marataoã y Paulistinha pueden seleccionarse para cultivo y explotación en la región semiárida de Paraíba.

Palabras clave

índices de selección • mejoramiento genético • selección simultánea • productividad • respuesta correlacionada

Introduction

Cowpea beans (*Vigna unguiculata* L. Walp) are one main product of family farming in Paraíba, and one major source of rural employment and income. As in other northeastern states, agricultural productivity is greatly affected by semi-arid conditions (37). However, according to Oliveira *et al.* (2001) low productivity is not only linked to unfavourable environmental conditions but also to the use of traditional, poor-quality cultivars.

Superior cultivars should meet a set of favourable agronomic and yield-related traits while satisfying both consumer and producer requirements (29). According to Cruz *et al*. (2012), selecting one or a few traits turns inefficient. While improving only a few selected variables, other undesired traits may be unintentionally selected. To overcome this limitation, breeders have used different selection methodologies (13, 16, 17).

Normally, selection indices are obtained from linear combinations of a set of variables, allowing a single value to perform an efficient selection with significant genetic gains (19). In other words, selection indices simultaneously combining several variables of economic importance, result in superior cultivars choices for this set of variables, regardless of any correlation among them (1, 17).

Existing literature mentions several Selection Index methodologies for cowpea (5, 33). However, there is strong need for new sets of variables with high heritability and ease of measurement. Additionally, these studies are still scarce in semiarid regions. Given the above, this work aimed to estimate genetic gains in production components, finding one selection index model providing greater gains through simultaneous selection of a set of variables for productive cultivars.

Material and methods

The experiment was carried out in an experimental field at the Center for Agrifood Science and Technology, Federal University of Campina Grande, CCTA/UFCG, Campus de Pombal - Paraíba, (06°46' South latitude, 37°48' West longitude) (4). According to Köppen's classification, the climate is Aw, semi-arid, with summer and autumn rains and average annual rainfall of 800 mm, with the rainiest period between February and April, concentrating 60 to 80% of the total annual precipitation (25).

For experimental set-up, ploughing was carried out 15 days before sowing, followed by cross harrowing 5 days before bean planting, providing weed control for germination. Soon after this procedure, the plots were marked and randomly distributed in the field.

Sowing was manual and holes were opened with a hoe, at approximately 5 cm depth, placing three seeds per hole. Spacing was 0.5 m with five plants per linear meter (41).

Fertilization was carried out according to Fernandes (1993). Thinning was close to the ground, about 15 days after emergence, keeping two plants per hole. Pest management involved two sprays with Dimethoate (1.0 litre/ha^{-1}) against aphids (*Apis cracyvora* Koch) and thrips (Order Thysanoptera), one spray with Methomyl (0.5 litre/ ha^{-1}) for armyworm (*Spodoptera frugiperda*) and one with Imidacloprid and Beta-cyfluthrin (270 g/ha^{-1}) for whitefly (Order Hemiptera).

The experimental design was randomized blocks (18) with eight treatments and four replications, totalling 32 experimental units, with 2.0 m spacing among blocks and plots. The treatments consisted of eight cowpea cultivars: Costela de Vaca (Control), BRS Marataoã, BRS Itaim, BR-17 Gurguéia, BRS Novaera, Paulistinha, Setentão and BRS Patativa.

Each experimental unit consisted of 9 m^2 with six rows of plants and a useful area of 4m^2. Spacing between rows was 0.5 meters, with fifteen holes and two plants per hole. Two lateral rows were considered borders. Data collection was carried out in the third and fifth rows.

Cultivar evaluation included phenology. The following characteristics related to precocity were evaluated: initial flowering (FL) and initial fruiting (DAFFF), determined by number of days between sowing and 50% of the plants with at least one flower or an open pod. Precocious plants were those reaching full flowering 70 days after sowing. This helped obtaining number of days between bloom and fruiting (DAFFH).

Manual harvest was performed with completely pale brown (dry) pods. During harvest, several yield components were measured. Total number of pods (TNP); pod unit mass (PUP, kg); pod length (PL, cm); pod diameter (PD, mm) obtained with a caliper; pod grain number (NGP), counting the grains of a sample of 10 pods; number of pods per plant (NPP), as the ratio between total pods in the usable area and number of plants; grain yield (GY, kg.) later transformed into tons per hectare; pod bark productivity (PDC, kg.), later transformed into tons per hectare; pod yield (PP, kg.), later transformed into tons per hectare, and seed/pod ratio (PSR), as the ratio between total mass of grains and pod number.

Data were submitted to ANOVA using linear additive model of randomized blocks, according to Cruz (2006a). Means were grouped by the Scott and Knott test (1974) at 5% probability.

Genetic gains were estimated through Correlated response, Classic selection index proposed by Smith (1936) and Hazel (1943), Rank-sum-based index proposed by Mulamba and Mock (1978) and the index based on gains proposed by Pesek and Baker (1969) and Cruz *et al.* (2012). For genetic gain calculation in the correlated response and classic selection index, k value was established at 0.3, according to Cruz (2006b) for multicollinearity, allowing a correlation of 0.90 between the index and the genotypic aggregate. The methodologies proposed by Mulamba and Mock (1978) and Pesek and Baker (1969) exclude multicollinear variables. All genetic-statistical analyzes were performed by Genes software (11).

Results and discussion

The ANOVA revealed significant differences between the evaluated variables, except for TNP, PUP and NPP. Means grouping allowed the establishment of superior groups regarding the variables PL, PD, NGP, GY, PP, PSR, FL, DAFFF and DAFFH (table 1, page 143).

Table 1. Mean grouping for evaluated in an experiment conducted in an experimental field at the Center for Food Science and Technology of the Federal University of Campina Grande in the city of Pombal - Paraíba.

Tabla 1. Agrupación de los promedios de los caracteres evaluados en el campo experimental del Centro de Ciencia y Tecnología de Alimentos de la Universidad Federal de Campina Grande en la ciudad de Pombal - Paraíba.

Cultivars	TNP	PUP(kg)	PL(cm)	PD(cm)	NGP	NPP	GY(t.ha^{-1})
Costela de vaca	277.5a	3.50a	22.28a	8.31a	16.30a	4.12a	2.40ª
BR-17 Gurguéia	267.2a	3.12a	18.07c	7.21b	15.85a	3.50a	1.65b
BRS Itaim	263.7a	3.00a	17.12c	7.15b	10.67b	3.42a	1.40b
BRS Patativa	228.7a	3.75a	18.91b	8.22a	15.67a	2.95a	2.12ª
Setentão	208.2a	3.50a	17.43c	9.05a	14.05a	2.75a	1.70b
BRS Marataoã	206.2a	3.62a	19.70b	7.47b	15.70a	3.13a	2.10ª
BRS Novaera	193.5a	2.50a	15.76c	8.34a	8.42b	2.95a	1.25b
Paulistinha	173.2a	3.50a	19.83b	8.01a	16.82a	2.58a	1.65b
F	1.26^{ns}	1.89^{ns}	6.80**	3.19*	13.67**	2.41^{ns}	4.36**
Cultivars	**PDC(t.ha^{-1})**	**PP(t.ha^{-1})**	**PSR(%)**	**FL**	**DAFFF**	**DAFFH**	-
Costela de vaca	0.57a	2.92a	80.60a	47.25b	7.00b	37.75c	-
BR-17 Gurguéia	0.60a	2.20b	74.85b	45.75b	4.00c	39.25c	-
BRS Itaim	0.40a	1.75b	77.93a	38.00d	6.50b	47.00a	-
BRS Patativa	0.65a	2.75a	76.91a	47.00b	5.25b	38.00c	-
Setentão	0.72a	2.42a	69.07b	46.25b	3.75c	38.75c	-
BRS Marataoã	0.75a	2.87a	73.51b	45.00b	4.00c	40.00c	-
BRS Novaera	0.47a	1.60b	72.62b	40.25c	6.25b	44.75b	-
Paulistinha	0.52a	1.82b	76.53a	49.75a	11.25a	35.25d	-
F	2.59*	4.04**	5.62**	50.70**	34.57**	50.71**	-

Total number of pods (TNP), pod unit mass (PUP, kg), pod length (PL, cm), pod diameter (PD, mm), pod grain number (NGP), number of pods per plant (NPP), grain yield (GY, kg.), pod bark productivity (PDC, kg.), pod yield (PP, kg.), seed/pod ratio (PSR), initial flowering (FL), initial fruiting (DAFFF) and number of days between bloom and fruiting (DAFFH).

Means followed by the same letter belong to the same group by the Scott and Knott test at 5% probability. ** and * show significance at 1 and 5% probability; respectively by the F test. ns non-significant by the F test.

Número total de cápsulas (TNP); masa unitaria de la vaina (PUP, kg); longitud de la vaina (PL, cm); diámetro de la vaina (DP, mm); grano de vaina número (NGP); vainas por planta (NPP), grano rendimiento (GY, kg.); corteza de vaina productividad (PDC, kg.), rendimiento de vaina (PP, kg.), semilla/proporción de cápsulas (PSR), inicial floración (FL), inicial fructificación (DAFFF) y número de días entre florecer y fructificar (DAFH).

Las medias seguidas de la misma letra pertenecen al mismo grupo según la prueba de Scott y Knott al 5% de probabilidad. ** y * muestran significancia al 1 y 5% de probabilidad; respectivamente; por la prueba de F. ns no significativa; por prueba F.

The ANOVA showed great genetic variability among cultivars, as verified by Rocha *et al.* (2003) and Silva and Neves (2011), who also detected significant cultivar effect on grain yield (39). This result allows the application of different selection index methods with favourable perspectives of simultaneous gains in a set of variables (24). Rodrigues *et al.* (2017), verified the existence of genetic variability in cowpea cultivars under water stress conditions and successfully applied different selection index methodologies, identifying superior genotypes.

Regarding mean grouping, three groups were established for PL, emphasizing cultivar Costela de vaca, with the greatest pod length and separately allocated in group 'a'. According to Araújo (2019), pod length varies from 15 to 20 cm. This author emphasizes the importance of smaller pods for mechanized harvesting and larger pods for manual harvesting. In the present work, the results were diverse with smaller pod cultivars for mechanized harvesting and larger pods (> 18cm) for manual harvesting, suitable for small farmers without financial and technological resources to implement mechanized harvesting.

For PD, two groups are observed. Group "a" comprises cultivars Costela de vaca, BRS Patativa, Setentão, BRS Novaera and Paulistinha. For Costa *et al.* (2021), larger diameter pods would contain heavier seeds.

Two groups were also established for NGP. Cultivars Costela de vaca, BRS Marataoã, BR-17 Gurguéia, Paulistinha, Setentão and BRS patativa were allocated to group 'a'. This variable has already been stated as one primary component of production (40), Andrade *et al.* (2010) estimated genetic parameters and correlations in cowpea demonstrating that this variable must be carefully studied in selection indices models, since it is related to other primary components, including PL.

Regarding GY variables, cultivars Costela de vaca, BRS Marataoã and BRS Patativa were allocated to group 'a' while cultivars Costela de vaca, BRS Marataoã, Setentão and BRS

Patativa were allocated to group 'a' for GY and PP. According to Freire Filho *et al.* (2007), grain yield constitutes an important commercial trait for expanding consumption, industrial processing and commercialization of seeds among farmers. These authors also emphasize that high off-season production reaches high market prices. Cultivars Costela de vaca, BRS Marataoã and BRS Patativa showed better GY performance than the other cultivars due to gene recombination and possible transgressive segregation (31). However, before effectively selecting these cultivars, it must be considered that GY is determined by several genes and correlated with several other primary components. Therefore, to truly obtain superior cultivars, evaluating models of selection indices simultaneously gathering several favourable attributes, becomes necessary (5, 12).

For PSR, Costela de vaca, BRS Itaim, Paulistinha and BRS Patativa were placed in group 'a'. Regarding FL, four groups were found and Paulistinha was separately allocated to group 'a'. Noteworthy is that BRS Itaim showed higher precocity in relation to the others. As to DAFFF, three groups resulted with Paulistinha separately allocated to group 'a'.

Finally, for DAFFH, four groups separately allocated BRS Itaim in group 'a' and cultivar Paulistinha in group 'd'.

Genetic gains obtained by correlated responses, that is, by direct and indirect selection, are shown in table 2.

Table 2. Estimates of original means ($\overline{X}_0$), selected cultivars ($\overline{X}_s$), broad sense heritability (h^2) and direct and indirect selection gains (GS) for 13 traits, evaluated in 8 cowpea cultivars.

Tabla 2. Estimaciones de medias originales ($\overline{X}_0$), cultivares seleccionados ($\overline{X}_s$), heredabilidad en sentido amplio (h^2) y ganancias de selección directa e indirecta (GS) para 13 caracteres, evaluados en 8 cultivares de caupí.

Variables	$\overline{X}_0$	$\overline{X}_s$	h^2%	GS	GS%
TNP	227.31	241.87	21.00	3.05	1.34
PUP	3.31	3.56	46.49	0.12	3.51
PL	18.64	20.99	85.30	2.01	10.76
PD	7.97	7.89	68.68	-0.05	-0.7
NGP	14.18	16.0	92.69	1.68	11.84
NPP	3.17	3.63	58.52	0.26	8.31
GY	**1.78**	**2.25**	**77.10**	**0.36**	**20.12**
PDC	0.59	0.66	61.52	0.04	7.85
PP	**2.29**	**2.9**	**75.27**	**0.46**	**19.90**
PSR	75.25	77.06	82.23	1.48	1.97
FL	44.90	46.12	98.02	1.19	2.66
DAFFF	6.0	5.5	97.10	-0.49	-8.09
DAFFH	40.09	38.90	98.02	-1.19	-2.98
Total				8.92	76.49
Selected	Costela de Vaca and BRS Marataoã				

It appears that direct selection of PP provides, for most of the studied variables, considerable genetic gains, PD, DAFFF and DAFFH.

The variable PP is the main GY determinant, given high direct phenotypic and genotypic effects. Direct selection on this easy-to-measure secondary component allows a response correlated with a high magnitude (>20%) genetic gain in the main variable GY.

Direct selection in POS also provides considerable gains in NGP, NPP, PL and PDC. For the variables TNP and PUP, whose heritability coefficients were low, it is possible to obtain genetic gains.

Falconer (1987) states that obtaining greater gains with indirect selection is possible when the auxiliary variables have higher heritability than the main variable, as for NGP and PL. Corroborating this, Gonçalves *et al.* (2007), stated that to obtain superior cultivars by simultaneously combining a series of favourable attributes and higher productivity, evaluating different selection index methodologies is important (28). Selection gains obtained by the methodology of Smith (1936) and Hazel (1943) are presented in table 3 (page 145).

Table 3. Estimates of original means ($\overline{X}_0$), selected cultivars ($\overline{X}_s$), heritability (h^2), covariances (Cov) and indirect selection gains (GS) based on the Smith (1936) and Hazel (1943) index for 7 traits, evaluated in 8 cowpea cultivars.

Tabla 3. Estimaciones de medias originales ($\overline{X}_0$), cultivares seleccionados ($\overline{X}_s$), heredabilidad (h^2), covarianzas (Cov) y ganancias de selección (GS) indirecta basadas en los índices de Smith (1936) y Hazel (1943) para 7 caracteres, evaluados en 8 cultivares de caupí.

Variables	$\overline{X}_0$	$\overline{X}_s$	**h^2%**	**Cov (Xj,I)**	**GS**	**GS%**
PP	**2.29**	**2.37**	**75.27**	**3.67**	**0.55**	**24.12**
PDC	0.59	0.55	61.52	0.46	0.07	11.75
GY	**1.78**	**2.02**	**77.10**	**3.30**	**0.50**	**27.83**
NPP	3.17	3.35	58.52	1.74	0.26	8.22
NGP	14.18	16.56	92.69	16.90	2.55	17.94
PUP	3.31	3.50	46.49	-0.12	-0.01	-0.55
TNP	227.31	225.37	21.00	254.90	38.38	16.89
Total					41.8	105.66
Index Variance	71.23	---	---	---	---	---
Selection Intensity	1.27	---	---	---	---	---
Selection Differential	10.36	---	---	---	---	---
Selected	Costela de vaca and Paulistinha					

This methodology allows obtaining significant and simultaneous genetic gains in important primary yield components, with the exception of PUP. However, this simultaneous selection only caused few changes in this variable (-0.01). Therefore, one can consider null changes in PUP and proceed with a safe selection.

In popcorn, Granate *et al.* (2002) used several selection index methodologies and obtained significant genetic gains. Gains obtained with the Smith (1936) and Hazel (1943) indices were superior to those predicted with other indices, as also obtained by Rodrigues *et al.* (2017), when selecting cowpea populations under water stress. According to Cruz *et al.* (2012), the Smith (1936) and Hazel (1943) indices are superior to direct selection because they consist of linear combinations of several economic variables, whose weighting coefficients maximize the index/genotypic aggregate correlation.

Table 4 shows genetic gains obtained according to Mulamba and Mock (1978), considering variable exclusion after multicollinearity.

Table 4. Original means ($\overline{X}_0$), of selected cultivars ($\overline{X}_s$), heritability (h^2), covariances (Cov) and indirect selection gains based on the sum of ranks for 7 traits, evaluated in 8 cowpea cultivars.

Tabla 4. Estimaciones de medias originales ($\overline{X}_0$), cultivares seleccionados ($\overline{X}_s$), heredabilidad (h^2) y ganancias de selección indirecta (GS) basadas en la suma de rangos para 7 caracteres, evaluados en 8 cultivares de caupí.

Variables	$\overline{X}_0$	$\overline{X}_s$	**h^2%**	**GS**	**GS%**
PP	**2.29**	**2.90**	**75.27**	**0.46**	**19.90**
PDC	0.59	0.66	61.52	0.05	7.85
GY	**1.78**	**2.25**	**77.10**	**0.36**	**20.12**
NPP	3.17	3.63	58.51	0.26	8.31
NGP	14.18	16.0	92.69	1.68	11.84
PUP	3.31	3.56	46.49	0.12	3.51
TNP	227.31	241.87	21.00	3.05	1.34
Total				5.98	72.87
Selected	Costela de Vaca and BRS Marataoã				

Once again, significant and simultaneous genetic gains were obtained in primary components of production. No undesired changes in PUP were obtained through the rank sum methodology. In fact, given the simplicity of result interpretation, the rank sum methodology is among the most used in genetic improvement for estimating selection gains. The significant genetic gains here obtained using the sum of ranks, although slightly lower than those obtained by Smith (1936) and Hazel (1943) methodologies, are given by an economic weight equivalent to CVg that considers all the evaluated variables as the main ones (6).

Table 5, shows genetic gain estimates based on the desired gain methodology proposed by Pesek and Baker (1969).

Table 5. Original averages ($\overline{X}_0$), of selected cultivars ($\overline{X}_s$), heritability (h^2), covariances (Cov) and indirect selection gains based on selection by the Pesek and Baker (1969) index for 7 traits evaluated in 8 cowpea cultivars.

Tabla 5. Estimaciones de medias originales ($\overline{X}_0$), cultivares seleccionados ($\overline{X}_s$), heredabilidad (h^2) y ganancias de selección indirecta (GS) basadas en la selección por médio del índice de Pesek y Baker (1969) para 7 caracteres, evaluados en 8 cultivares de caupí.

Variables	$\overline{X}_0$	$\overline{X}_s$	h^2%	GS	GS%
PP	**2.29**	**2.37**	**75.27**	**0.06**	**2.67**
PDC	0.59	0.55	61.52	-0.02	-3.93
GY	**1.78**	**2.02**	**77.10**	**0.19**	**10.40**
NPP	3.17	3.35	58.51	0.10	3.18
NGP	14.18	16.56	92.69	2.20	15.52
PUP	3.31	3.50	46.49	0.08	2.63
TNP	227.31	225.75	21.00	-0.40	-0.18
Total				2.21	30.29
Selected	Costela de vaca and Paulistinha				

The methodology based on desired gains provided simultaneous gains in the POS, GY, NPP, NGP and PUP variables. However, it caused undesired changes in PDC. Despite having provided significant gains in NGP (above 15%), it did not provide greater gains in POS and GY, as also evidenced in other studies (36). It should be noted that this methodology was developed after the difficulty of establishing relative economic weights to the variables, replacing them with the desired gains. These desired gains, according to Crossbie *et al.* (1980) and Vieira (1988) could be replaced by the genetic standard deviation for each variable. However, despite the use of genetic standard deviation, the results do not outweigh gains obtained with other indices. Rodrigues *et al.* (2017) also used the Pesek and Baker (1969) methodology along with the sum of ranks and the classic Smith (1936) and Hazel (1943) indices, obtaining similar results in magnitude and direction, but undesired changes in grain index when using the desired gains index. These divergent results can be explained by the limitations of the genetic structure of the breeding population (23). Thus, it is up to the breeder choosing the best methodology to find the greatest genetic gains, and practice selection with greater safety.

Conclusions

Direct selection in the secondary component PP provides significant genetic gains in the main variable GY;

The classic selection index presents a greater distribution of genetic gains for the main variable and for the primary components of production;

Cultivars Costela de vaca, BRS Marataoã and Paulistinha are recommended for cultivation and commercial exploitation in the semiarid region of Paraíba.

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