

Determination of trait associations using path coefficient analysis in Bambara groundnut (*Vigna subterranea* [L.] Verdc) landraces

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ABSTRACT

Bambara groundnut is considered a promising underutilized crop with potential to contribute to future food security. Understanding the associations among agronomic traits provides insight into their potential exploitation for yield improvement through agronomic and breeding interventions. The objective of this research was to assess the association between grain yield and its contributing traits using path coefficient analysis. The experiment was conducted in a randomised complete block design (RCBD) with three replications. Pearson correlation analysis showed a highly significant association between days to 50 % flowering and plant height ($r = 0.85^{**}$). Path coefficient analysis revealed that plant height (0.113), number of pods/plant (0.400158), number of seeds/pod (0.041182), and 100-seed weight/plot (0.016093) had a positive direct effect on seed yield. Leaf area (-0.10851) and days to 50 % flowering (-0.21159) had a negative direct effect on seed yield. Among these traits, the number of pods/plant had the highest positive effect, while days to 50 % flowering had the highest negative effect. The present study showed that characters including plant height and number of pods per plant need to be considered for indirect selection for improving seed yield for Bambara groundnut improvement.

Keywords: characteristics, correlation, improvement, pod yield, yield components

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RESUMEN

El maní Bambara es un cultivo promisorio y subutilizado, con potencial para contribuir a la seguridad alimentaria. Comprender las asociaciones

entre caracteres agronómicos permite su aprovechamiento para mejorar su rendimiento. El objetivo de este estudio fue evaluar la asociación entre el rendimiento de grano y los caracteres que lo determinan mediante el análisis de coeficientes de sendero. El experimento se realizó en un diseño de bloques completos al azar con tres repeticiones. El análisis de correlación de Pearson mostró una asociación altamente significativa entre los días hasta el 50 % de floración y la altura de planta ($r = 0,85^{**}$). El análisis de sendero reveló que la altura de planta (0,113), el número de vainas por planta (0,400158), el número de semillas por vaina (0,041182) y el peso de cien semillas por parcela (0,016093) tuvieron un efecto directo positivo sobre el rendimiento. El área foliar (-0,10851) y los días hasta el 50 % de floración (-0,21159) tuvieron un efecto directo negativo. El número de vainas por planta mostró el mayor efecto positivo, y los días hasta el 50 % de floración, el efecto negativo más alto. Estos caracteres deben considerarse para la selección indirecta en el mejoramiento del maní Bambara.

Palabras clave: características, correlación, rendimiento de vaina, componentes del rendimiento

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INTRODUCTION

Bambara groundnut (*Vigna subterranea* [L.] Verdc) belongs to the family Fabaceae and subfamily Papilionoideae and is the third most important grain legume after groundnut (*Arachis hypogea* L.) and cowpea (*Vigna unguiculata* [L.] Walp) in sub-Saharan Africa (Jonah et al., 2010). The crop has an estimated world production of 330,000 tonnes and is consumed by both humans and animals. It has the potential to reduce malnutrition and increase food accessibility (Belel, 2018).

In a study that was conducted by Akpalu et al. (2012), it was observed that yields of Bambara groundnut varied considerably among sites, seasons and genotypes with yields averaging 650 to 850 kg/ha, while seed yields of up to 4.1 t/ha were obtained in field trials in Swaziland with pod and seed yields of 4.6 and 3.4 t/ha, respectively. This suggests that Bambara groundnut has the potential of high yielding, but this may also depend on how the grower manages it at vegetative

stages. The crop is commonly cultivated in the dry savannah belt of West Africa, but now it is widely grown in Southern and Central Africa and is gradually becoming popular in Southeast Asian countries including Malaysia (Hillocks et al., 2012). The crop has a high economic value with significant contribution to the income and livelihood of resource-limited-farmers (Akohoue et al., 2019). According to Maunde et al. (2015) yield characters of crops such as number of seeds per pod, 100 seed weight, number of pods per plant, among others, have been proven to be associated with the final yield of the crop, and that relationship is likely to give an understanding into the importance of exploiting those characters in order to improve yield potential of crops through the use of certain agronomic practices and breeding programmes.

Correlation analysis is a biometrical technique utilised to determine the nature and degree of association between various traits indicating yield, while path analysis splits the correlation coefficient into direct and indirect effects so as to measure the relative contribution of each variable towards

yield (Aparna et al., 2017). Developing cultivars requires an understanding of the responses and relationships between yield-determining traits under the conditions in which the cultivars are to be deployed. Such relationships have been studied using correlation coefficients. But with correlation coefficients alone, breeders may still not depend on it for selection as they represent simple linear relationships between traits (Makanda et al., 2009). Hence, the objectives of the study were: (i) to use path coefficient analysis to evaluate the relationship between grain yield and yield related traits in Bambara groundnut and employ this evaluation as a basis for selecting lines as parents in a breeding programme; (ii) to determine the amount of correlation between yield and its related traits among twenty Bambara groundnut; (iii) to determine interrelationship between grain yield and its contributing characters.

MATERIALS AND METHODS

Description of experimental sites

The field experiment was conducted in two sites. One of the sites located in Limpopo Province

at Loskop Research Station (25° 10' 50" S, 29° 23' 16.1" E) with temperatures between 16 °C and 31 °C during 2019 cropping season and with an average rainfall of 497 mm at Loskop. The other site was located in the North-West Province at Molelwane Research farm at Mafikeng (25° 48' 00" S, 25° 38' 21" E), with temperatures ranging from 22 °C and 34 °C in 2020 cropping season and average annual rainfall of 541. The soil type at both Loskop and Molelwane Research Stations was classified as a Hutton series according to the South African soil classification system (Kasirivu et al., 2011) and is reddish with a sandy loam texture.

Twenty Bambara groundnut landraces were obtained from the Agricultural Research Council (ARC) gene bank. A randomised complete block design (RCBD) with three replications was used. Each plot was 2.7 m x 60 cm with inter- and intra-row spacing of 60 cm x 30 cm, respectively. Each plot had two rows, with each row consisting of ten plants. Sowing was done on a flat bed, with one seed sown at each station. Weeds were controlled by hand hoeing to keep the land free of weeds. No fertiliser was applied at either site.

Data collection

Table 1. Data taken from three randomly selected plants and averaged per plot

Evaluated traits	Methods
Plant height (mm)	Measured from the base of the plant to the top most leaf bud on the main stem using a meter ruler
Leaf area	Maximum length and width of central leaflet were measured at ten weeks from sowing. Estimated based on the central leaflet length and width using the method of Cornelissen et al. (2002) in the following equation: $A = \sigma * L * W * \pi / 4$ (2) where: L = Length of the leaflet (cm), W = Width of the leaflet (cm), $\pi = 3.1416$, $\sigma = 0.95$ correction factor (to account for the difference between the actual shape and an ellipse)
Days to 50 % flowering	Determined visually by counting the number of days when 50 % of the plants in a sub-plot had opened flowers
Number of seeds per pod	Determined by randomly selecting ten pods from a subplot. The pods were then shelled and the number of seeds counted
Number of pods per plant	Counted manually at harvest
Seed weight per plant	Counted manually at 12 % moisture and weighed using an electronic scale
Mass of 100 seeds	Weighed using an electronic scale at 12 % moisture content
Seed yield per hectare	Was derived from plot size which was given by the following formula Seed yield (kg/ha) $= \frac{\text{mass of seeds/plot} \times 10\,000 \text{ m}^2}{\text{area of plot (m}^2\text{)} \times 1 \text{ g}}$

Data analysis

Data gathered during the study were analysed using the Statistical Analysis System (SAS) version 9.4. Data were subjected to analysis of variance (ANOVA) and means were separated by Fisher's protected LSD (least significant difference) at 5 % significance level of probability. Phenotypic correlations coefficients (PCV) were computed among all the measured traits and path coefficients (P) calculated using the simultaneous solutions of the equations below based on the work of Kang (2015).

$$r_{16} = p_{16} + r_{12}p_{26} + r_{13}p_{36} + r_{14}p_{46} + r_{15}p_{56}$$

$$r_{26} = r_{12}p_{16} + p_{26} + r_{23}p_{36} + r_{24}p_{46} + r_{25}p_{56}$$

$$r_{36} = r_{13}p_{16} + r_{23}p_{26} + p_{36} + r_{34}p_{46} + r_{35}p_{56}$$

$$r_{46} = r_{14}p_{16} + r_{24}p_{26} + r_{34}p_{36} + p_{46} + r_{45}p_{56}$$

$$r_{56} = r_{15}p_{16} + r_{25}p_{26} + r_{35}p_{36} + r_{45}p_{46} + p_{56}$$

$$1 = p^2x_6 + p_{16}^2 + p_{26}^2 + p_{36}^2 + p_{46}^2 + p_{56}^2 +$$

$$2p_{16}r_{12}p_{26} + 2p_{16}r_{13}p_{36} + 2p_{16}r_{14}p_{46} + 2p_{16}r_{15}p_{56} +$$

$$2p_{26}r_{23}p_{36} + 2p_{26}r_{24}p_{46} + 2p_{26}r_{25}p_{56} + 2p_{36}r_{34}p_{46} + 2p_{36}r_{35}p_{56} + 2p_{46}r_{45}p_{56}$$

Where r = represents the correlation between variables, P = denotes path coefficients or direct effects. Each P represent the effect of one variable on another in the path analysis and the superscripts = (26, 26, 12) following r and P are indices that refer to specific variables in the model.

RESULTS

Assessment of genetic differences in the bambara groundnut is a prerequisite for selection of potential genotypes for breeding. There was large variation in the tested accessions based on yield traits (Table 4), suggesting that there was a high degree of variability of bambara groundnut yield traits among tested accessions across locations and seasons.

Correlation coefficient analysis

Highly significant correlation (Table 2) was observed between days to 50 % flowering and plant height ($r = 0.85^{**}$). Highly significant negative correlations were observed between days to 50 % flowering and leaf area ($r = -0.73^{**}$). Furthermore, highly significant negative correlation was observed between days to 50 % flowering and leaf area ($r = -0.82^{**}$). Significant positive association was observed between number of pods per plant and seed yield per plant ($r = 0.41$). Weak but positive trait association was observed between number of seeds per pod ($r = 0.04$), and days to 50 % flowering ($r = 0.10$) (Table 2).

Path coefficient analysis

Path coefficient analysis of characters evaluated (Table 3) showed various relationships that exist for direct and indirect plant selection for breeding Bambara. Seed yield/plant was more reliant on direct effects even though there are a few indirect effects present. Path coefficient analysis revealed that plant height (0.113), number of pods/plant (0.400), number of seeds/pod (0.041) and 100-seed weight/plot (0.016) had a positive direct effect on seed yield, while leaf area (-0.109) and days to 50 % flowering (-0.212) had a negative direct effect on seed yield. Among these, number of pods/plant had the highest positive effect and days to 50 % flowering had the highest negative effect. A high correlation was observed between number of pods/plant and seed yield/plant, mainly due to a high positive direct effect of number of pods/plant on seed yield/plant. Positive but indirect effect was via plant height, number of seeds/plant, 100-seed weight/plot and negative indirect effect was via leaf area and days to 50 % flowering. A few positive but not significant correlations were observed between leaf area and seed yield/plant. This was due to the

Table 2. Statistical Pearson relationship between yield and yield related traits in Bambara groundnut

	PH	Larea	D50 %F	NPP	NSPod	100SW	SYPlant
PH	1						
Larea	-0.73**	1					
D50 %F	0.85**	-0.82**	1				
NPP	-0.06	0.13*	-0.14	1			
NSPod	0.04*	-0.14	0.10*	0.07	1		
100SW	0.02	0.03	-0.02	-0.03	0.06	1	
SYPlant	-0.01	0.03	-0.08	0.41*	0.07*	0.01	1

Significant at ** $p \leq 0.01$; * $p \leq 0.05$

PH: plant height, Larea: leaf area, D50 %F: days to 50 % flowering, NPP: number of pods per plant, NSPod: number of seeds per pod, 100SW: one hundred seeds weight, SYPlant: yield per plant.

positive direct effect of number of pods/plants, plant height, number of seeds/pod and 100-seed weight/plot. The indirect negative effect was via days to 50 % flowering, number of seeds/pod and seed yield /plant due to a high indirect positive effect of number of pods/plant on seed yield/plant, plant height and 100-seed weight/plot. Indirect negative effect was observed between leaf area and days to 50% flowering and another positive correlation was observed between 100-seed weight/plot and seed yield/plant and this was due to high positive indirect effect of number of pods/plant on seed yield/plant, number of seeds/pod and plant height.

While some traits associations were observed in this correlation analysis, it is important to note that most correlations among measured variables were weak, suggesting that many factors influenced seed yield contributing traits. This indicates further investigation may be necessary to explore and understand the effect of trait relationships in Bambara groundnut breeding.

DISCUSSION

It was observed that most characters recorded positive but not significant phenotypic correlation

Table 3. Direct and indirect contribution of characters on seed yield/plant in Bambara groundnut

	PH	Larea	D50 %F	NPP	NSPod	100SW	SYPlant
PH	0.113371	0.079211	-0.18048	-0.02321	0.001771	0.000338	-0.009
Larea	-0.08276	-0.10851	0.172653	0.052021	-0.00581	0.000402	0.028
D50 %F	0.096706	0.088543	-0.21159	-0.05522	0.003912	-0.00035	-0.078
NPP	-0.00658	-0.01411	0.029199	0.400158	0.002759	-0.00043	0.411
NSPod	0.004875	0.0153	-0.0201	0.026811	0.041182	0.000933	0.069
100SW	0.002381	-0.00271	0.004655	-0.0108	0.002389	0.016093	0.012
Residual							0.820055

Significant at ** $p \leq 0.01$; * $p \leq 0.05$

PH: plant height, Larea: leaf area, D50 %F: days to 50 % flowering, NPP: number of pods per plant, NSPod: number of seeds per pod, 100SW: one hundred seeds weight, SYPlant: yield per plant.

Table 4. Results of statistical analysis (ANOVA) for Bambara groundnut genotypes showing yield per hectare planted in 2019 cropping season

Loskop		Mafikeng		Combined across sites	
genotypes	means	genotypes	means	genotypes	means
Bamb1	3258.7 b	Bamb1	1230 b	Bamb1	2244.2 bc
Bamb2	1455.9 cde	Bamb2	3581 a	Bamb2	2518.7 bc
Bamb3	744.4 e	Bamb3	1789 ab	Bamb3	1266.7 bc
Bamb4	1270.4 de	Bamb4	1544 ab	Bamb4	1407.4 bc
Bamb5	1190.7 e	Bamb5	2359 ab	Bamb5	1775.0 bc
Bamb6	2131.9 bcd	Bamb6	2374 ab	Bamb6	2403.0 bc
Bamb7	2314.8 bcde	Bamb7	2272 ab	Bamb7	2293.5 bc
Bamb8	5559.8 a	Bamb8	2400 ab	Bamb8	3979.9 a
Bamb9	1907.4 bcde	Bamb9	3159 ab	Bamb9	2530.3 a
Bamb10	2055.6 bcde	Bamb10	2574 ab	Bamb10	2314.4 bc
Bamb11	2022.8 bcde	Bamb11	2880 ab	Bamb11	2451.2 bc
Bamb12	2944.4 bc	Bamb12	1276 b	Bamb12	2110.2 bc
Bamb13	2123.0 bcde	Bamb13	2939 ab	Bamb13	2530.9 bc
Bamb14	3450.4 b	Bamb14	1991 ab	Bamb14	2720.6 ab
Bamb15	1385.4 cde	Bamb15	2181 ab	Bamb15	1783.3 bc
Bamb16	2191.1 bcde	Bamb16	1563 ab	Bamb16	1877.0 bc
Bamb17	1240.0 de	Bamb17	2815 ab	Bamb17	2027.4 bc
Bamb18	1578.3 cde	Bamb18	2498 ab	Bamb18	2038.2 bc
Bamb19	1468.9 cde	Bamb19	1970 ab	Bamb19	1719.6 bc
Bamb20	2184.4 bcde	Bamb20	1357 b	Bamb20	1770.9 bc
Fisher's - lsd	0.0004	lsd	0.6740	lsd	0.2280
cv	45.51	cv	55.96	cv	56.96

with seed yield in the current study. This is not something new as Jonah et al. (2010) also recorded results which are similar to the current study and that go beyond to prove that selecting based on correlation alone is not enough. For path coefficient analysis, it was observed that number of pods per plant had the highest direct effect on seed yield. Makanda et al. (2009) and Nandini et al. (2017) also recorded highest correlation and positive direct effect for the amount of pods/plant. This suggests that number of pods per plant is the most important component to consider in selecting for seed yield in Bambara groundnut. It also recorded a positive correlation with seed yield (Table 1) and again showed a direct effect in seed yield (Table 2), which simply means that genotypes with high number of pods increase the yield. Based on combined analysis of variance across locations the following genotypes were identified for hybridization: Bamb8 (3979.9), Bamb14 (2720.6) and Bamb9 (2530.3) performance performed better than the rest of the tested accessions. These genotypes were identified as high yielding and promising genotypes that can be used as parents for hybridization programme. The results for the current study prove to have performed better than previous studies by Belel (2018) who recorded yield values between 925.50-1349 kg/ha and 1419.60-2342.50 kg/ha on landraces that were grown under humid climate in Malaysia. Khan et al. (2020) recorded mean values between 1306.72 and 1635.29 kg/ha on accessions that were evaluated for perfection of yield, and Khan et al. (2021) recorded yield from 588.98-2191.77 kg/ha.

CONCLUSIONS

Most characters recorded positive but not significant trait correlation coefficients with seed yield per plant. Only the number of pods/plant had the highest direct effect on seed yield per plant, this was due to the high positive indirect contributions of all other traits except for leaf area and days to 50 % flowering. Based on combined analysis of variance across locations the following genotypes were identified for hybridization: Bamb8 (3979.9), Bamb14 (2720.6) and Bamb9 (2530.3), which performed better than the rest of the tested accessions. These genotypes were identified as high yielding and promising genotypes that can be used as parents for hybridization programmes.

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COMPETING INTERESTS

The authors declare no conflict of interest.

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