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# CHARACTER ASSOCIATIONS AND PATH ANALYSIS IN BAMBARA GROUNDNUT GROWN IN MID-ALTITUDE HIGHLAND OF JOS-PLATEAU, NIGERIA

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## ABSTRACT

Bambara groundnut is an indigenous African legume, which is the third most important after peanut and cowpea in terms of consumption and socio-economic impact in semi-arid Africa. There is, therefore, the need for adequate research attention, especially with regard to yield improvement. In this study, nine genotypes of the Bambara groundnut (Cream with white eye, Black with white eye, Cream with brown eye, Cream with black eye, Cream with black eye and brown stripes, Cream with brown stripes, Deep-brown with white eye, Cream with black stripes and Brown white eye) were evaluated at Kuru, Nigeria (Lat. $09^0$ 44'N, Long. $08^0$ 47'E, altitude 1, 217 m above sea level) in 2018 in order to determine character associations and to analyse the pathways to grain yield. Results showed that emergence rate, plant height, number of leaves per plant, leaf area index, relative growth rate, harvest index, number of pods per plant and shelling percentage were positively correlated with total grain yield. The Results of the path coefficient analysis showed that the number of days to onset of flowering exerted the highest direct influence on total grain yield. Then followed by harvest index, emergence rate, 100-seed weight, net assimilation rate, shelling%, days to 50% flowering, relative growth rate, number of seeds per pod, and number of pods per plant. The highest total effect (0.988) was observed in 100-seed weight, followed by days to first flowering (0.837), days to 50% flowering (0.701), shelling % (0.658), emergence rate (0.574), number of pods per plant (0.557), relative growth rate (-0.375), net assimilation rate (0.226), harvest index (0.183) and number of seeds per pod (- 0.126) in that order. The study demonstrated that combining correlation and path coefficient analyses is important in determining reliable trait associations that can be used for developing superior genotypes. Therefore, days to first flower, days to 50% flowering, harvest index, emergence rate and 100-seed weight should be considered as major selection indices for the improvement of the Bambara groundnut in the Jos-Plateau environment in Nigeria.

**Key words:** Correlation, direct effect, indirect effect, grain yield, *Vigna subterranea* (L.) Verdc.



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## INTRODUCTION

Bambara groundnut [*Vigna subterranea* (L.) Verdc] is an indigenous African legume, which is the third most important after peanut and cowpea in terms of consumption and socio-economic impact in semi-arid Africa [1]. The annual world production is 330, 000 tonnes with West Africa accounting for 45-50%; Nigeria alone accounts for 33, 000-49, 000 tonnes annually [2]. It is an herbaceous, intermediate annual plant with creeping stems at the ground level. It has a well developed taproot system with geotropic lateral roots. New roots often appear where nodes contact the soil. The fibrous lateral roots form nodules for nitrogen fixation [3, 4]. The flowers spread out close to the ground level on hairy peduncles. Flowers may be light-yellow or deep-yellow. After fertilisation, the pods are borne under the ground.

The subterranean pods are rich in carbohydrates (63-65%), protein (18-19%) and fat (6.5%), and are, therefore, used to address nutritional problems in humans and livestock [5, 6]. Bambara groundnut seeds are richer than peanuts in essential amino acids such as isoleucine, lysine, methionine, phenylalanine, threonine and valine. Consequently, Bambara groundnut has high potential for use to complement foods lacking in these amino acids [7, 4]. In African countries such as Nigeria and Ghana, the seeds are pounded and made into flour, which is usually added to maize to enrich the traditional preparations [8]. It is also used to make a variety of cakes or mixed with cereals to prepare several types of porridge [4]. The seeds can also be used to make different kinds of traditional foods such as “Kosai”, “Moimoi” and “Okpa” [9], while the haulms are used to feed livestock [10]. Bambara groundnut fixes atmospheric nitrogen through symbiosis with Rhizobium bacteria and is, therefore, useful in crop rotation and intercropping [11, 12]. Tilapia fish feed, consisting of Bambara groundnut and leaf protein from *Leucaena leucocephala* or *Gliricidia sepium,* has been reported to make fish grow well [13]. White seeds are mixed with guinea fowl meat to treat diarrhoea while black seeds are mixed with water and ground into powder to cure skin rashes or to alleviate swollen jaw disease in children [8].

Despite the nutritional and medicinal values of the crop, the research and extension activities in Nigeria majorly focus on cowpea [*Vigna unguiculata* (L.) Walp] with little attention given to the Bambara groundnut, which is now regarded as an orphan crop. Attempts at improving the Bambara groundnut have not been successful due to lack of accessions with stable and predictable yields [14].


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Yield is a complex and quantitatively inherited trait. In addition to simple correlation coefficient [15], path coefficient analysis provides the relative importance of direct and indirect effects of the yield components on yield [16]. Knowledge of the associations that exist between yield and yield-related traits is essential to identify selection procedure which is important for the improvement of grain yield [10]. Most cultivated varieties of Bambara groundnut in sub-Saharan Africa are landraces which are products of introduction and selection [10]; these need further improvement for productivity and nutritional quality. This study investigated character associations and path analysis in the Bambara groundnut grown in the mid-altitude highland environment of the Jos-Plateau in Nigeria, with the aim to identifying characters that have maximum effect and which could be used as indices for grain yield improvement.

## MATERIALS AND METHODS

The experiment was carried out during the rainy season between July and October 2018 at potato sub-station of the National Root Crops Research Institute, Kuru in Plateau State, Nigeria (Fig.1). The sources and agronomic characteristics of the nine genotypes of Bambara groundnut used in the study are as shown in Table 1. Table 2 shows the weather conditions during which the experiment was carried out. Plates 1-9 show the seed coat characteristics of the genotypes used in the study.

The genotypes were laid out in the field using the randomised complete block design in five replicates. Each net plot, measuring 4 m x 3.2 m, consisted of four rows each measuring 4 m x 0. 8 m. The seeds were sown on July 22, 2018 at inter-row and intra-row spacing of 0.8 m and 0.2 m, respectively, to give a total of 125, 000 plants per hectare. Weeding was done manually at the fourth and seventh week after sowing. The plots were earthed up at nine weeks after sowing to protect the young pods.

Data were collected on emergence rate, days to first flower, days to 50 % flowering, relative growth rate, net assimilation rate and harvest index. The plots were harvested at 127 days after sowing, after which the number of pods per plant, shelling percentage, number of seeds per pod and total grain yield were assessed. A multiple correlation analysis was carried out amongst growth and yield-related attributes. Statistical analysis with respect to correlation was done using the SPSS version 22.0 software while path coefficient analysis was done using Microsoft excel 2010 [17]. The correlation coefficient was partitioned into direct and indirect effects by solving the simultaneous equation [18, 19, 20, 21, 22].

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Path coefficients were computed using the following simultaneous equations which express basic relationships between correlation and path coefficients:

$P_1 + r_{12}P_2 + r_{13}P_3 + r_{14}P_4 + r_{15}P_5 + r_{16}P_6 + r_{17}P_7 + r_{18}P_8 + r_{19}P_9 + r_{110}P_{10} = r_1y$
$r_{12}P_1 + P_2 + r_{23}P_3 + r_{24}P_4 + r_{25}P_5 + r_{26}P_6 + r_{27}P_7 + r_{28}P_8 + r_{29}P_9 + r_{210}P_{10} = r_2y$
$r_{13}P_1 + r_{23}P_2 + P_3 + r_{34}P_4 + r_{35}P_5 + r_{36}P_6 + r_{37}P_7 + r_{38}P_8 + r_{39}P_9 + r_{310}P_{10} = r_3y$
$r_{14}P_1 + r_{24}P_4 + r_{34}P_4 + P_4 + r_{45}P_5 + r_{46}P_6 + r_{47}P_7 + r_{48}P_8 + r_{49}P_9 + r_{410}P_{10} = r_4y$
$r_{15}P_1 + r_{25}P_2 + r_{35}P_5 + r_{45}P_5 + P_5 + r_{56}P_6 + r_{57}P_7 + r_{58}P_8 + r_{59}P_9 + r_{510}P_{10} = r_5y$
$r_{16}P_1 + r_{26}P_2 + r_{36}P_3 + r_{46}P_4 + r_{56}P_5 + P_6 + r_{67}P_7 + r_{68}P_8 + r_{69}P_9 + r_{610}P_{10} = r_6y$
$r_{17}P_1 + r_{27}P_2 + r_{37}P_3 + r_{47}P_4 + r_{57}P_5 + r_{67}P_6 + P_7 + r_{78}P_8 = r_{79}P_9 + r_{710}P_{10} = r_7y$
$r_{18}P_1 + r_{28}P_2 + r_{38}P_3 + r_{48}P_4 + r_{58}P_5 + r_{68}P_6 + r_{78}P_7 + P_8 + r_{89}P_9 + r_{810}P_{10} = r_8y$
$r_{19}P_1 + r_{29}P_2 + r_{39}P_3 + r_{49}P_4 + r_{59}P_5 + r_{69}P_6 + r_{79}P_7 + r_{89}P_8 + P_9 + r_{910}P_{10} = r_9y$
$r_{110}P_1 + r_{210}P_2 + r_{310}P_3 + r_{410}P_4 + r_{510}P_5 + r_{610}P_6 + r_{710}P_7 + r_{810}P_8 + r_{910}P_9 + P_{10} = r_{10}y$
$R_x$ (Residual) = $1- \surd (r_1y + r_2y + r_3y + r_4y + r_5y + r_6y + r_7y + r_8y + r_9y + r_{10}y)$

Where,
1= Emergence rate
2= Number of days to onset of flowering
3= Number of days to 50% flowering
4= Relative growth rate
5= Harvest index
6= Net assimilation rate
7= Number of pods per plant
8= Shelling %
9= Number of seeds per pod
10= 100-seed weight
r = correlation
y = grain yield
P = direct contribution
R = Residual effect

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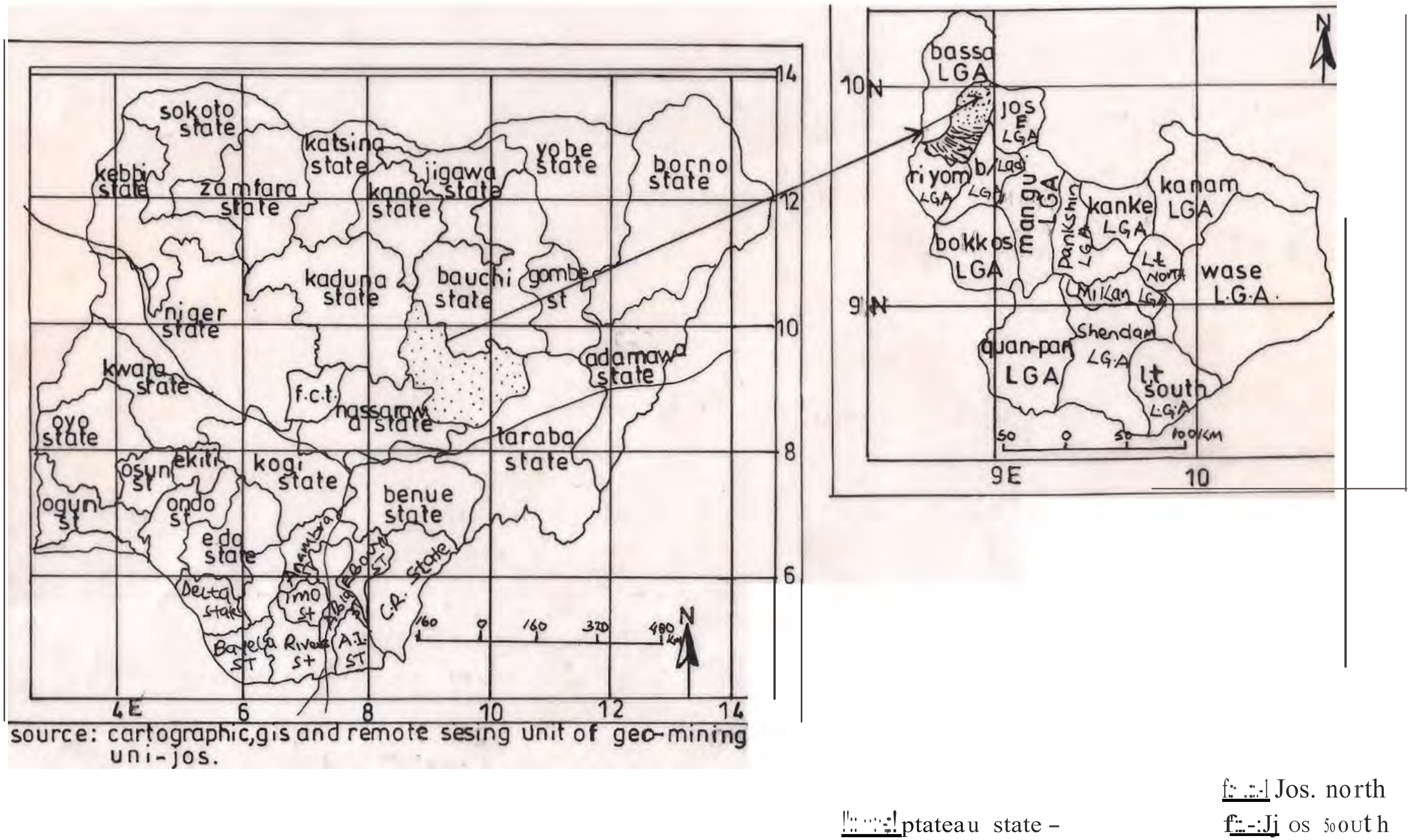


Figure 1: Plateau State, Nigeria showing the study areas

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Plate 1: Genotype Cream with white eye

Plate 2: Genotype Black with white eye



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Plate 3: Genotype Cream with brown eye


Plate 4: Genotype Cream with black eye

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Plate 5: Genotype Cream with black eye and brown stripes

Plate 6: Genotype Cream with brown stripes

Plate 7: Genotype Deep brown with white eye

Plate 8: Genotype Cream with black stripes

**Plate 9: Genotype Brown with white eye**

## RESULTS AND DISCUSSION

Total grain yield was positively correlated with emergence rate, plant height, number of leaves per plant, leaf area index, relative growth rate, harvest index and number of pods per plant. The net assimilation rate, number of days to onset of flowering, 50% flowering, number of seeds per pod and 100-seed weight were negatively correlated with seed yield (Table 3).

The net assimilation rate was negatively and significantly correlated with plant height at 56 DAS (-0.806**), but it was positively correlated with 100-seed weight (*0.836). The 100-seed weight and total stand count were positively correlated (0.787*). The number of pods per plant and the number of seeds per pod were negatively correlated (-0.703*). The number of days to first flower and number of days to 50 % flowering were positively correlated (0. 880**).

As observed in this study, a positive correlation has been reported between seed yield and emergence rate, plant height and pod yield per plant [10], which corroborated similar findings in the Bambara groundnut [9] and okra [23]. A positive correlation of shelling % and 100-seed weight with grain yield [24] as well as the number of pods per plant with grain yield [25] have been reported. The results suggest that seed yield in Bambara groundnut could be improved through


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selection for these characters. The positive correlation between plant height and seed yield may be ascribed to a greater photosynthetic capacity of the plant to develop a considerable height which will carry more leaves and flowers for higher pod yield, especially in the tropics where Bambara groundnut is cultivated [10]. Similar findings have been reported for sugarcane [26] and okra [27]. A negative correlation between seed yield and number of pods per plant as well as the number of seeds per pod has been reported in Bambara groundnut [28]. In this study, however, a positive relationship between seed yield and number of pods per plant was observed. Strong, positive correlations amongst characters show that they make positive indirect contribution to final grain yield [28]. The negative relationships amongst yield components could result from competition for ambient resources such as nutrients, moisture and light or from genetic causes such as linkage and pleiotropy [29].

The path coefficient analysis involving direct (bold-faced diagonally) and indirect contributions of growth and yield attributes to total grain yield in Bambara groundnut is shown in Table 4. There was a positive, direct association between grain yield and all the attributes studied. The correlation coefficient of grain yield with the attributes studied was positive except for the number of seeds per pod. The number of days to first flower exerted the highest direct influence on total grain yield (0.977), which was followed by emergence rate (0.560), 100-seed weight (0.403), harvest index (0.191), shelling percentage (0.156), days to 50 % flowering (0.154), net assimilation rate (0.092), relative growth rate (0.050), number of pods per plant (0.026) and number of seeds per pod (0.014).

The indirect, positive contribution to total grain yield was highest in the number of days to first flower through the net assimilation rate (0.901), followed by the number of days to 50% flowering through the net assimilation rate (0.843), number of days to first flower through 100-seed weight (0.427) and 100-seed weight through the number of days to 50% flowering (0.330) (Table 4). The indirect, negative contribution to total grain yield was highest in the number of days to first flower through the number of pods per plant (-0.900), followed by the number of days to first flower through shelling % (-0.877) and the number of days to 50% flowering through the number of pods per plant (-0.301) (Table 4).

The highest total effect (0. 988) was observed for 100-seed weight, followed by days to first flower (0.837), days to 50% flowering (0.701), shelling % (0.658), emergence rate (0.574), number of pods per plant (0.557), relative growth rate (0.375), net assimilation rate (0.226), harvest index (0.183) and number of seeds per pod (-0.126) in that order. In terms of percent contribution to total grain yield, the highest direct contribution was observed in the number of days to first flower, followed by harvest index, emergence rate, 100-seed weight, net assimilation rate, shelling%, days to 50% flowering, relative growth rate, number of seeds per pod and number of pods per plant in that order (Table 5). The residual effect was 0.221, representing 4.44 % of the total effect.

The high positive correlation and direct positive contribution of emergence rate, plant height, days to first flower, emergence rate, 100-seed weight and harvest index has demonstrated the significance of these characters in the improvement of the Bambara groundnut. It has been suggested that kernel yield per plant, 100-seed weight and shelling% could be selected for further improvement of the peanut [30]. Path coefficient analysis provides a means of separating the direct and indirect causes of associations, thereby permitting for an in-depth examination of the factors responsible for a given correlation and measuring the relative importance of each factor [28]. Correlation, along with path coefficient analysis, has been described as a powerful tool for determining reliable associations of traits useful in the development of superior genotypes [31].

The variability observed amongst the Bambara groundnut genotypes used in this study underscores the potential for the genetic improvement of the crop to meet the increasing demand for food and nutritional security for both humans and animals in the Sub-Saharan Africa [32]. Bambara groundnut is an indigenous African crop which produces almost completely balanced food, is easy to cultivate, and makes little demand on the soil; yet, it has been relegated to its own countries. Indigenous crops have a comparative advantage of resilience in their local environment, compared to exotic species that have assumed more popularity over time [32]. With little attention given to their improvement, production and value-chain addition through scientific research, these indigenous crops have yet to be exploited and have remained primordial in their development and integration.

As Africa attempts to achieve food security, emphasis needs to be placed on hitherto underutilised indigenous African crop species that have both food and nutrient security potentials for the sub-region. Several international fora and engagements on meeting the food sufficiency and nutrition needs of a fast-growing population have prompted the Food and Agriculture Organisation to re-discover the lost food crops of the world and re-invigorate research around their production and utilisation as a means of curbing hunger. This re-invigoration should include giving a new prominence to such crops like the Bambara groundnut beyond the local use [32].


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## CONCLUSION, AND RECOMMENDATIONS FOR DEVELOPMENT

The results of the correlation analysis in this study have shown that emergence rate, plant height, number of leaves per plant, leaf area index, relative growth rate, harvest index, stand count at harvest, number of pods per plant and shelling percentage were positively correlated with total grain yield. Net assimilation rate, number of days to first flower and 50% flowering, number of seeds per pod and 100-seed weight were negatively correlated with total grain yield. Results of the path coefficient analysis revealed that the number of days to first flower exerted the highest direct influence on total grain yield, followed by emergence rate, 100-seed weight, harvest index, shelling%, days to 50% flowering, net assimilation rate, relative growth rate, number of pods per plant and number of seeds per pod. Considering the results of correlation and path analyses together, emergence rate, days to first flower, days to 50% flowering, harvest index and 100-seed weight could be considered as major indices for the improvement of Bambara groundnut in the Jos-Plateau environment in Nigeria. Developing new varieties of the Bambara groundnut could contribute to addressing the food security challenge in sub-Saharan Africa. Result of the final grain yield showed that the accessions differed from 410.02 kg $ha^{-1}$ in the accession Deep brown with white eye to 180 kg $ha^{-1}$ in the accession Brown with white eye, but the differences were not statistically significant. Therefore, the nine accessions of the Bambara groundnut used in this study can be grown in the Jos-Plateau environment.


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**Table 1: Agronomic characteristics of the Bambara groundnut genotypes used in the study**

| Genotype | Seed coat colour | Source | No. of plants $ha^{-1}$ | NDM (WAS) | Average yield (kg $ha^{-1}$) | NDFF (WAS) | NDF 50% (WAS) |
|---|---|---|---|---|---|---|---|
| $V_1$ | Cream with white eye | Nasarawa ADP | 125,000 | 18 | 0.254 | 8 | 10 |
| $V_2$ | Black with white eye | Bauchi ADP | 125,000 | 18 | 0.301 | 9 | 10 |
| $V_3$ | Cream with brown eye | Ebonyi ADP | 125,000 | 18 | 0.398 | 9 | 10 |
| $V_4$ | Cream with black eye | Ebonyi ADP | 125,000 | 18 | 0.401 | 8 | 9 |
| $V_5$ | Cream with black eye and brown stripes | Nasarawa ADP | 125,000 | 18 | 0.254 | 8 | 10 |
| $V_6$ | Cream with brown stripes | Bauchi ADP | 125,000 | 18 | 0.191 | 9 | 10 |
| $V_7$ | Deep brow-n with white eye | Bauchi ADP | 125,000 | 18 | 0.413 | 8 | 9 |
| $V_8$ | Cream with black stripes | Gombe ADP | 125,000 | 18 | 0.313 | 9 | 10 |
| $V_9$ | Brown with white eye | Ebonyi ADP | 125,000 | 18 | 0.183 | 9 | 10 |

ADP = Agricultural Development Programme

WAS = Weeks after sowing

NDM= Number of days to maturity

NDFF= Number of days to onset of flowering

NDF50%=Number of days to 50% flowering

**Table 2: Mean values of meteorological data collected during the experimental period (June-October, 2018)**

| Months | Temperature ($^0$C) | | Relative humidity | Rainfall | Sunshine hour |
|---|---|---|---|---|---|
| | Min. | Max. | (%) | (mm) | (Hours) |
| June | 17 | 22 | 73 | 156.4 | 170.2 |
| July | 18 | 24 | 80 | 283.2 | 186.4 |
| August | 18 | 24 | 81 | 384.8 | 152.3 |
| September | 17 | 26 | 80 | 208.6 | 200.4 |
| October | 15 | 27 | 68 | 79.4 | 167.2 |

Source: National Root Crops Research Institute (NRCRI), Kuru, Plateau State (Lat. 09$^0$ 44' N, Long. 08$^0$ 47' E, Altitude 1,293 m)

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**Table 3: Correlation matrix of some growth and yield attributes of Bambara groundnut grown in Kuru, Nigeria in 2018**

| Traits | ER | PH56 | NL56 | LAI90 | RGR90 | NAR90 | HI120 | NFF | NDF50 | TSC | NPP | SP | NSPP | HSW | TGY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ER | 1 | | | | | | | | | | | | | | |
| PH56 | 0.182 | 1 | | | | | | | | | | | | | |
| NL56 | 0.660 | -0.069 | 1 | | | | | | | | | | | | |
| LI90 | 0.409 | 0.437 | -0.057 | 1 | | | | | | | | | | | |
| RGR0 | 0.203 | -0.451 | 0.135 | 0.428 | 1 | | | | | | | | | | |
| NAR0 | 0.110 | -0.806** | 0.259 | -0.043 | 0.762* | 1 | | | | | | | | | |
| HI120 | 0.299 | 0.629 | 0.254 | 0.388 | 0.190 | -0.340 | 1 | | | | | | | | |
| NFF | -0.224 | -0.191 | -0.120 | 0.319 | 0.065 | 0.173 | -0.491 | 1 | | | | | | | |
| NDF0 | -0.184 | -0.320 | -0.219 | 0.322 | 0.173 | 0.329 | -0.667* | 0.880** | 1 | | | | | | |
| TSC | 0.308 | -0.361 | 0.390 | -0.014 | 0.264 | 0.664 | -0.372 | 0.294 | 0.418 | 1 | | | | | |
| NPP | 0.024 | 0.011 | -0.069 | 0.346 | 0.430 | 0.230 | 0.235 | 0.370 | 0.321 | 0.398 | 1 | | | | |
| SP | 0.263 | 0.245 | -0.381 | 0.498 | 0.305 | 0.003 | 0.265 | -0.136 | 0.050 | 0.120 | 0.452 | 1 | | | |
| NSPP | 0.040 | 0.113 | -0.289 | -0.220 | -0.315 | -0.252 | -0.145 | -0.558 | -0.260 | -0.302 | -0.703* | -0.015 | 1 | | |
| HSW | 0.193 | -0.467 | 0.281 | 0.078 | 0.543 | 0.836** | -0.246 | 0.229 | 0.294 | 0.787* | 0.167 | 0.024 | -0.316 | 1 | |
| TGY | 0.645 | 0.307 | 0.335 | 0.233 | 0.104 | -0.091 | 0.451 | -0.291 | -0.233 | 0.273 | 0.557 | 0.578 | -0.126 | -0.151 | 1 |

ER = Emergence rate, PH 56 = plant height at 56 days after sowing, NL 56 = number of leaves per plant at 56 days after sowing, LAI 90 = leaf area index at 90 days after sowing, RGR 90 = relative growth rate at 90 days after sowing, NAR 90 = net assimilation rate at 90 days after sowing, HI 120 = harvest index at 120 days after sowing, NFF = number of days to onset of flowering, NDF 50 = number of days to 50% flowering, TSC = total stand count at harvest, NPP = number of pods per plant, SP = shelling percentage, NSPP = number of seeds per pod, HSW = 100–seed weight, TGY = total grain yield

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**Table 4: Path coefficient analysis showing direct (bold-faced diagonally) and indirect contributions of growth and yield attributes to total grain yield in Bambara groundnut**

| Character | ER | NDFF | NDF 50 | RGR 90 | HI 120 | NAR 120 | NPP | SP | NSPP | HSW | TGY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ER | 0.560 | -0.034 | -0.029 | -0.039 | 0.016 | 0.005 | -0.007 | 0.091 | 0.015 | -0.004 | 0.574 |
| NDFF | -0.034 | 0.997 | 0.141 | 0.013 | 0.128 | 0.901 | -0.900 | -0.877 | 0.041 | 0.427 | 0.837 |
| NDF 50 | -0.028 | 0.141 | 0.154 | 0.121 | -0.001 | 0.843 | -0.301 | -0.189 | -0.105 | 0.066 | 0.701 |
| RGR 90 | 0.031 | 0.001 | -0.034 | 0.050 | 0.002 | 0.066 | -0.032 | 0.085 | 0.118 | 0.088 | 0.375 |
| HI 90 | 0.034 | -0.043 | 0.026 | 0.030 | 0.191 | 0.091 | -0.113 | 0.110 | -0.215 | 0.072 | 0.183 |
| NAR 90 | 0.040 | -0.107 | 0.118 | 0.029 | 0.157 | 0.092 | -0.020 | -0.132 | -0.095 | 0.144 | 0.226 |
| NPP | 0.004 | -0.014 | 0.040 | 0.216 | -0.086 | -0.093 | 0.026 | 0.156 | 0.257 | 0.051 | 0.557 |
| SP | -0.040 | -0.031 | 0.220 | 0.178 | 0.032 | -0.015 | 0.156 | 0.156 | -0.005 | 0.007 | 0.658 |
| NSPP | -0.006 | -0.014 | -0.167 | 0.179 | 0.137 | 0.076 | -0.243 | -0.005 | 0.014 | -0.097 | -0.126 |
| HSW | 0.021 | -0.022 | 0.330 | 0.031 | -0.052 | 0.144 | 0.058 | 0.008 | 0.067 | 0.403 | 0.988 |

Residual effect = 0.221. Bold values are for the direct effects of attributes on yield (path coefficient); other values show indirect effects via different paths except the total correlation with grain yield
ER = Emergence rate, NDFF = number of days to onset of flower, NDF 50 = number of days to 50% flowering, RGR 90 = relative growth rate at 90 days after sowing, HI 120 = harvest index at 90 days after sowing, NAR 120 = net assimilation rate at 120 days after sowing, NPP= number of pods per plant, SP= shelling percentage, NSPP= number of seeds per pod, HSW = 100-seed weight, TGY = total grain yield

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**Table 5: Path analysis showing percent contributions of ten attributes to total grain yield of Bambara groundnut grown in mid altitude highland of Jos-Plateau, Nigeria**

| No. | Pathways of association | Direct effect Path coefficient(p) | % contribution | Indirect effect path coefficient (pxr) | % contribution | Correlation coefficient (r) |
|---|---|---|---|---|---|---|
| 1. | Emergence rate | | | | | |
| a) | Direct effect ($P_1Y$) | 0.560 | 97.56 | | | |
| b) | Indirect effect via: | | | | | |
| | No of days to first flower($P_2Yr_{12}$) | | | -0.034 | 5.92 | |
| | No of days to 50% flowering ($P_3Yr_{13}$) | | | -0.029 | 5.05 | |
| | Relative growth rate ($P_4Yr_{14}$) | | | -0.39 | 6.79 | |
| | Harvest index ($P_5Yr_{15}$) | | | 0.016 | 2.79 | |
| | Net assimilation rate ($P_6Yr16$) | | | 0.005 | 0.87 | |
| | No of pods per plant ($P_7Yr_{17}$) | | | -0.007 | 1.22 | |
| | Shelling % ($P_8Yr_{18}$) | | | 0.091 | 15.85 | |
| | No of seeds per pod ($P_9Yr_{19}$) | | | 0.015 | 2.61 | |
| | 100-seed weight ($P_{10}Yr_{10}$) | | | -0.004 | 0.70 | |
| c) | Total effect | | | | | 0.574 |

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| No. | Pathways of association | Direct effect Path coefficient(p) | % contribution | Indirect effect path coefficient (pxr) | % contribution | Correlation coefficient (r) |
|---|---|---|---|---|---|---|
| 2. | No of days to first flower | | | | | |
| a) | Direct effect ($P_2Y$) | 0.997 | 119.12 | | | |
| b) | Indirect effect via: | | | | | |
| | Emergence rate ($P_1Yr_{21}$) | | | -0.034 | 4.06 | |
| | No of days to 50% flowering ($P_3Yr_{23}$) | | | 0.141 | 16.85 | |
| | Relative growth rate ($P_4Yr_{24}$) | | | 0.013 | 1.56 | |
| | Harvest index ($P_5Yr_{25}$) | | | 0.128 | 15.29 | |
| | Net assimilation rate ($P_6Yr_{26}$) | | | 0.901 | 107.65 | |
| | No of pods per plant ($P_7Yr_{27}$) | | | -0.900 | 107.53 | |
| | Shelling % ($P_8Yr_{28}$) | | | -0.877 | 104.78 | |
| | No of seeds per pod ($P_9Yr_{29}$) | | | 0.041 | 4.90 | |
| | 100-seed weight ($P_{10}Yr_{10}$) | | | 0.427 | 51.02 | |
| c) | Total effect | | | | | 0.837 |

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| No. | Pathways of association | Direct effect Path coefficient(p) | % contribution | Indirect effect path coefficient (pxr) | % contribution | Correlation coefficient (r) |
|---|---|---|---|---|---|---|
| 3. | No of days to 50% flowering | | | | | |
| a) | Direct effect ($P_3Y$) | 0.154 | 21.97 | | | |
| b) | Indirect effect via: | | | | | |
| | Emergence rate ($P_1Yr_{31}$) | | | -0.028 | 3.99 | |
| | No of days to first flower ($P_2Yr_{32}$) | | | 0,141 | 20.11 | |
| | Relative growth rate ($P_4Yr_{34}$) | | | 0.121 | 17.26 | |
| | Harvest index ($P_5Yr_{35}$) | | | -0.001 | 0.14 | |
| | Net assimilation rate ($P_6Yr_{36}$) | | | 0.843 | 120.26 | |
| | No of pods per plant ($P_7Yr_{37}$) | | | -0.301 | 42.94 | |
| | Shelling % ($P_8Yr_{38}$) | | | -0.189 | 26.96 | |
| | No of seeds per pod ($P_9Yr_{39}$) | | | -0.105 | 14.98 | |
| | 100-seed weight ($P_{10}Yr_{310}$) | | | 0.066 | 9.42 | |
| c) | Total effect | | | | | 0.701 |


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| No. | Pathways of association | Direct effect Path coefficient(p) | % contribution | Indirect effect path Coefficient (pxr) | % contribution | Correlation coefficient (r) |
|---|---|---|---|---|---|---|
| 4. | Relative growth rate | | | | | |
| a) | Direct effect ($P_4Y$) | 0.050 | 13.33 | | | |
| b) | Indirect effect via: | | | | | |
| | Emergence rate ($P_1Yr_{41}$) | | | 0.031 | 8.27 | |
| | No of days to first flower ($P_2Y_{42}$) | | | 0.001 | 0.27 | |
| | No of days to 50% flowering ($P_3Yr_{43}$) | | | -0.034 | 9.07 | |
| | Harvest index ($P_5Yr_{45}$) | | | 0.002 | 0.53 | |
| | Net assimilation rate ($P_6Yr_{46}$) | | | 0.066 | 17.60 | |
| | No of pods per plant ($P_7Yr_{47}$) | | | -0.032 | 8.53 | |
| | Shelling % ($P_8Yr_{48}$) | | | 0.085 | 22.67 | |
| | No of seeds per plant ($P_9Yr_{49}$) | | | 0.118 | 31.47 | |
| | 100-seed weight ($P_{10}Yr_{410}$) | | | 0.088 | 23.47 | |
| c) | Total effect | | | | | 0.375 |

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| No. | Pathways of association | Direct effect Path coefficient(p) | % contribution | Indirect effect path coefficient (pxr) | % contribution | Correlation coefficient (r) |
|---|---|---|---|---|---|---|
| 5. | Harvest index | | | | | |
| a) | Direct effect ($P_5Y$) | 0.191 | 104.37 | | | |
| b) | Indirect effect via: | | | | | |
| | Emergence rate ($P_1Yr_{51}$) | | | 0.034 | 18.58 | |
| | No of days to first flower ($P_2Y_{52}$) | | | -0.043 | 23.50 | |
| | No of days to 50% flowering ($P_3Yr_{53}$) | | | 0.026 | 14.21 | |
| | Relative growth rate ($P_4Yr_{54}$) | | | 0.030 | 16.39 | |
| | Net assimilation rate ($P_6Yr_{56}$) | | | 0.091 | 49.73 | |
| | No of pods per plant ($P_7Y_{57}$) | | | -0.113 | 61.75 | |
| | Shelling % ($P_8Yr_{58}$) | | | 0.110 | 60.11 | |
| | No of seeds per pod ($P_9Yr_{59}$) | | | -0.215 | 117.49 | |
| | 100-seed weight ($P_{10}Yr_{510}$) | | | 0.072 | 39.34 | |
| c) | Total effect | | | | | 0.183 |

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| No. | Pathways of association | Direct effect Path coefficient(p) | % contribution | Indirect effect path coefficient (pxr) | % contribution | Correlation coefficient (r) |
|---|---|---|---|---|---|---|
| 6. | Net assimilation | | | | | |
| a) | Direct effect ($P_6Y$) | 0.092 | 40.71 | | | |
| b) | Indirect effect via: | | | | | |
| | Emergence rate ($P_1Yr_{61}$) | | | 0.040 | 17.70 | |
| | No of days to first flower ($P_2Y_{62}$) | | | -0.107 | 47.35 | |
| | No of days to 50% flowering ($P_3Yr_{63}$) | | | 0.118 | 52.21 | |
| | Relative growth rate ($P_4Yr_{64}$) | | | 0.029 | 12.83 | |
| | Harvest index ($P_5Yr_{65}$) | | | 0.157 | 69.47 | |
| | No of pods per plant ($P_7Yr_{67}$) | | | -0.020 | 8.85 | |
| | Shelling % ($P_8Yr_{68}$) | | | -0.132 | 58.41 | |
| | No of seeds per pod ($P_9Yr_{69}$) | | | -0.095 | 42.03 | |
| | 100-seed weight ($P_{10}Yr_{610}$) | | | 0.144 | 63.72 | |
| c) | Total effect | | | | | 0.226 |

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| No. | Pathways of association | Direct effect Path coefficient(p) | % contribution | Indirect effect path coefficient (pxr) | % contribution | Correlation coefficient (r) |
|---|---|---|---|---|---|---|
| 7. | No of pods per plant | | | | | |
| a) | Direct effect ($P_7Y$) | 0.026 | 4.67 | | | |
| b) | Indirect effect via: | | | | | |
| | Emergence rate ($P_1Yr_{71}$) | | | 0.004 | 0.72 | |
| | No of days to first flower ($P_2Y_{72}$) | | | -0.014 | 2.51 | |
| | No of days to 50% flowering ($P_3Yr_{73}$) | | | 0.040 | 7.18 | |
| | Relative growth rate ($P_4Yr_{74}$) | | | 0.216 | 38.78 | |
| | Harvest index ($P_5Yr_{75}$) | | | -0.086 | 15.44 | |
| | Net assimilation rate ($P_6Yr_{76}$) | | | -0.093 | 16.70 | |
| | Shelling % ($P_8Yr_{78}$) | | | 0.156 | 28.01 | |
| | No of seeds per pod ($P_9Yr_{79}$) | | | 0.257 | 46.14 | |
| | 100-seed weight($P_{10}Yr_{710}$) | | | 0.051 | 9.16 | |
| c) | Total effect | | | | | 0.557 |

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|---|---|---|---|---|---|---|
| 8. | Shelling % | | | | | |
| a) | Direct effect ($P_8Y$) | 0.156 | 23.71 | | | |
| b) | Indirect effect via: | | | | | |
| | Emergence rate ($P_1Yr_{81}$) | | | -0.040 | 6.07 | |
| | No of days to first flower ($P_2Y_{82}$) | | | -0.031 | 4.71 | |
| | No of days to 50% flowering ($P_3Yr_{83}$) | | | 0.220 | 33.43 | |
| | Relative growth rate ($P_4Yr_{84}$) | | | 0.178 | 27.05 | |
| | Harvest index ($P_5Yr_{85}$) | | | 0.032 | 4.86 | |
| | Net assimilation rate ($P_6Yr_{86}$) | | | -0.015 | 2.28 | |
| | No of pods per plant ($P_7Yr_{87}$) | | | 0.156 | 23.71 | |
| | No of seeds per pod ($P_9Yr_{89}$) | | | -0.005 | 0.76 | |
| | 100-seed weight ($P_{10}Yr_{810}$) | | | 0.007 | 1.06 | |
| c) | Total effect | | | | | 0.658 |

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|---|---|---|---|---|---|---|
| 9. | No of seeds per pod | | | | | |
| a) | Direct effect ($P_9Y$) | 0.014 | 11.11 | | | |
| b) | Indirect effect via: | | | | | |
| | Emergence rate ($P_1Yr_{91}$) | | | -0.006 | 4.76 | |
| | No of days to first flower ($P_2Y_{92}$) | | | -0.014 | 11.11 | |
| | No of days to 50% flowering ($P_3Yr_{93}$) | | | -0.167 | 132.54 | |
| | Relative growth rate ($P_4Yr_{94}$) | | | 0.179 | 142.06 | |
| | Harvest index ($P_5Yr_{95}$) | | | 0.137 | 108.73 | |
| | Net assimilation rate ($P_6Yr_{96}$) | | | 0.076 | 60.32 | |
| | No of pods per plant ($P_7Yr_{97}$) | | | -0.243 | 192.86 | |
| | Shelling % ($P_8Yr_{98}$) | | | -0.005 | 3.97 | |
| | 100-seed weight ($P_{10}Yr_{910}$) | | | -0.097 | 76.98 | |
| c) | Total effect | | | | | -0.126 |

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|---|---|---|---|---|---|---|
| 10. | 100-seed weight | | | | | |
| a) | Direct effect ($P_{10}Y$) | 0.403 | 40.79 | | | |
| b) | Indirect effect via: | | | | | |
| | Emergence rate ($P_1Yr_{101}$) | | | 0.021 | 2.13 | |
| | No of days to first flower ($P_2Y_{102}$) | | | -0.022 | 2.23 | |
| | No of days to 50% flowering ($P_3Yr_{103}$) | | | 0.330 | 33.40 | |
| | Relative growth rate ($P_4Yr_{104}$) | | | 0.031 | 3.14 | |
| | Harvest index ($P_5Yr_{105}$) | | | -0.052 | 5.26 | |
| | Net assimilation rate ($P_6Yr_{106}$) | | | 0.144 | 14.57 | |
| | No of pods per plant ($P_7Yr_{107}$) | | | 0.058 | 5.87 | |
| | Shelling % ($P_8Yr_{108}$) | | | 0.008 | 0.81 | |
| | No of seeds per pod ($P_9Yr_{109}$) | | | 0.067 | 6.78 | |
| c) | Total effect | | | | | 0.988 |

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