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Genetic Variations and Contributions of Some Floral Traits to Pod Yield in Bambara Groundnut (*Vigna subterranea* L. Verdc) under Two Cropping Seasons in the Derived Savanna of the South-East Nigeria

Benedict C. Oyiga* • Michael I. Uguru

Department of Crop Science, University of Nigeria, Nsukka, Enugu State, Nigeria

***Corresponding author*: * ceejaybeecee@gmail.com**

ABSTRACT

This study was conducted to determine the genetic variation, character association and path coefficient analysis between floral traits and pod yield of 13 bambara groundnut (*Vigna subterranea* L. Verdc) genotypes. The genotypes were evaluated in replicated field experiments at the Deptartment of Crop Science Research Field, University of Nigeria, Nsukka in the early and late planting seasons. The result showed significant differences among the genotypes in most of the traits studied. The genotypic and heritabilty estimates were high in pistil length, stamen length and stigma-anther separation at both planting dates indicating that these traits have high transmitting ability to next generation and therefore, selection of these traits would be more efficient. The number of pods per plant had significant positive correlation with anther diameter in the early planting . However, number of pods per plant recorded negative correlation values with stigma-anther separation in the early and late planting indicating that decrease in stigma-anther separation will favour pod set in bambara groundnut. The path coefficient analysis showed that anther diameter had the highest positive direct effect (0.57) on number of pods per plant, followed by pistil length (0.25) in the early planting. In the late planting, stamen length had the largest positive direct effect (1.19) on number of pods but was masked by the negative indirect effect via pistil length (-1.27) and stigma-anther separation (-0.44) resulting in the significant negative correlation of the number of pods per plant with stamen length. Therefore, genotypes with large anthers could be reliably looked for, while selecting high yielding genotypes in the early planting. However, selection of genotypes with reduced stigma–anther separation and shorter pistil should be adopted in the improvement of the crop during late planting.

Keywords: anther diamater, correlation, genetic variability, heritability, path analysis, pistil length, stigma-anther separation

INTRODUCTION

Bambara groundnut (*Vigna subterranea* L. Verdc.) belongs to the family *Papilionaceae.* It originated from Africa and is primarily grown for its seeds. In Nigeria, bambara groundnut is regarded as the cheapest source of protein and are widely consumed by both urban and rural dwellers. The yield have been reported to be low, between 50 and 4000 kg/ha (Johnson 1968; Massawe *et al*. 2003) and the average pod yield was 650 and 850 kg/ha (Stanton *et al*. 1966). Makanda *et al*. (2009) had earlier reported that there is little information on the bambara groundnut research and cultivar development and, this had made the pod yield improvement of bambara groundnut relatively difficult. Moreover, this crop has not been improved through coordinated breeding programmes (Massawe *et al.* 2002). Thus, the available genotypes are selections from the aboriginal landraces. Therefore, there is a dire need to develop high yielding genotypes to meet the day to day requirements.

Yield is the most important and complex trait in crops. It reflects the interaction of the environment with all growth and development processes that occur throughout the life cycle (Quarrie *et al.* 2006). Grain yield is directly determined by yield-component traits (such as seed weight and number of pods), and is highly influenced by both genetic and environmental factors (Hassan *et al*. 2005; Wattoo *et al*. 2009). This makes direct selection for number of pods per plant in the breeding programme of bambara groundnut rather difficult. Therefore, a successful selection would depend upon the information on the genetic variability and association of the pod yield with its'component traits. Hence, it is essential to partition overall variability into its heritable and non-heritable components with the help of genetic parameters like genetic coefficient of variation and heritability. These genetic parameters would indicate the magnitude of variance in the genetic materials. However, information on the genetic variability of floral traits in bambara groundnut is lacking and this had made the improvement of the crop seemingly difficult. Therefore, there is need to determine the genetic variability of some floral traits in the crop to enable the breeders identify and select the genotypes possessing floral traits with pronounced contributions to pod yield during the improvement programme. Presently, there is paucity of information on the association and the contributions of floral traits to the pod yield in bambara groundnut. This information is very important in understanding the podding ability of the bambara groundnut and would also be very useful in the designing of best selection method(s) for pod yield improvement of the crop. Poehlman (1991) and Singh and Singh (1995) reported that selection based on yield components is advantageous if information on the different yield component traits are available. Oyiga *et al*. (2010) had earlier reported that floral traits such as stigma diameter, anther diameter and stigma-anther separation are major pod yield determining characters in bambara groundnut. Similarly, Syafaruddin *et al*. (2006) reported that flower structure, especially the anther–stigma separation affects pollination efficiency, and thus to potentially increase or decrease seed production in crops.

There is also need to understand the association and

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contributions of these floral traits to pod yield in bambara groundnut outside the traditional growing season in the derived savanna of Nigeria. This would provide information desirable for developing selection methodologies for pod yield at different planting dates in the derived savanna. The phenology of bambara groundnut as reported by Linnemann and Azam-Ali (1993) and Mkandawire and Sibuga (2002) is dependent on environmental conditions. Linnemann (1994) and Karikari *et al.* (1997) have shown that different growing conditions stimulated different trait responses among genotypes of bambara groundnut. This may mean different trait emphasis during selection in different planting dates, as trait response may vary due to changes in the growing conditions. This research was therefore initiated with the following objectives: (1) to study the variation of important floral traits and identify the traits of utmost importance for selection in bambara groundnut breeding programme during the early and late planting seasons, (2) to evaluate the heritability for number of pods per plant and some of its related floral traits in order to select the more desirable traits that would support prolific podding in bambara groundnut in the two planting seasons and, (3) to determine the character association among the floral traits and their direct and indirect contribution to pod set in bambara groundnut during the early and late planting season.

MATERIALS AND METHODS

Thirteen bambara groundnut accessions (**Table 1**) were evaluated at early (April - July) and late (August - November) planting dates in 2007 in the the research field of the Department of Crop Science, University of Nigeria, Nsukka (Lat. 06° 52′ N; Long. 07° 24′ E; Alt. 447.2 m a.s.l.). The research field contains the "B" soil type in University of Nigeria, Nsukka soil survey map. It is well drained ferrallitic sandy loam soil of Nkpologu series. The monthly temperature, rainfall distribution, number of rainy days and the relative humidity are presented in **Table 2**. The accessions used were classified based on their seed coat colour according to the descriptors list for *V. subterranea* edited by the International Plant Genetic Resources Institute (IPGRI *et al.* 2000). Seeds of each genotype were grown in a randomized complete block design (RCBD) with three replications in a plot size of 20 m × 13 m. The seeds were sown at a depth of about 2.5 cm at a spacing of 30 cm × 75 cm. Data were collected on the stigma diameter, anther diameter, anther length, pistil length and stamen length using an ocular micrometer. The stigma–anther separation was computed by subtracting the stamen length from the pistil length (Mal and Lovett-Doust 1997; Faivre and McDade 2001). At harvest, the number of pods per plant was obtained by counting.

Data analysis

The data collected were subjected to analysis of variance (ANOVA) to understand the level of viability existing among the accessions using Genstat Discovery Edition 3 (Genstat 2007) software. The phenotypic variation for each trait was partitioned into genetic and non-genetic factors and estimated according to Comstock (1952), Johanson *et al.* (1955) and Uguru (2005):

$V_p = MS_g/r$; $V_g = (MS_g-MS_e)/r$; $V_e = MS_e$

where V_p, V_g and V_e are phenotypic variance, genotypic variance and environmental variance, respectively, and MS_g, MS_e and r are the mean squares of genotypes, mean squares of error and number of replications, respectively.

The phenotypic variance is the total variance among phenotypes, the genotypic variance is the part of the phenotypic variance that can be attributed to genotypic effects and the error or environmental variance is the variance due to environmental effects. To compare the variations among traits, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV) and environmental coefficient of variation (ECV) were computed according to the method suggested by Allard (1960) and Burton (1952):

Table 1 Accessional numbers and place of collection of the accessions

Accession number	Place of collection	Ecological Zone
Bg-01	Quaanpan, LGA	Southern Guinea savanna
Bg-02	Mikang, LGA	Southern Guinea savanna
Bg-03	Langtan South, LGA	Southern Guinea savanna
Bg-04	Langtan North, LGA	Southern Guinea savanna
Bg-05	Pankshin, LGA	Southern Guinea savanna
Bg-06	Shendam, LGA	Southern Guinea savanna
Bg-07	Langtan South, LGA	Southern Guinea savanna
Bg-08	Mikang, LGA	Southern Guinea savanna
Bg-09	Shendam, LGA	Southern Guinea savanna
Bg-10	Quaanpan, LGA	Southern Guinea savanna
Bg-11	Pankshin, LGA	Southern Guinea savanna
Bg-12	Langtan North, LGA	Southern Guinea savanna
Bg-13	Langtan South, LGA	Southern Guinea savanna

$$PCV = \frac{\sqrt{V_p}}{X} \times 100$$

$$GCV = \frac{\sqrt{V_g}}{X} \times 100$$

$$ECV = \frac{\sqrt{V_e}}{X} \times 100$$

where X is the grand mean for each of the studied traits.

Broad sense heritability (h^2B) was calculated according to Burton and DeVane (1953) and Allard (1960) as the ratio of the genotypic variance (V_g) to the phenotypic variance (V_p). Correlations were calculated to examine inter-character relationships among the traits using SPSS for Windows Version 16.0 (SPSS, Inc., Chicago, IL). Path coefficient analyses were computed to determine the contribution of each floral trait to number of pods per plant using the analysis for moment structures (AMOS) software program.

RESULTS AND DISCUSSION

Genetic variability

The mean squares and genetic parameter estimates of 13 bambara groundnut accessions in the early and the late planting dates are presented in **Table 3**. The analysis of variance showed that the mean squares for the accessions were highly significant for pistil length, stamen length and stigma-anther separation. A highly significant difference among accessions is a descernable evidence of inherent genetic variability among the accessions. The observed variability among the accessions were mostly contributed by the three floral traits, pistil length, stamen length and stigma-anther separation. Nausherwan *et al*. (2008) reported that an effective breeding programme largely depends upon genetic variability.

The phenotypic variance was partitioned into heritable (genotypic variance) and non-heritable (environmental variance) components (**Table 3**). The table showed that the magnitude of genotypic variance for pistil length, stamen length and stigma-anther separation was higher than the environmental variance, their phenotypic and genotypic variances were close to each other. It indicates that the genotypic component was the major contributor to the total variance for these traits during the early planting. The environmental variance was, however, low in some of the floral traits such as pistil length, stamen length and stigma-anther separation. Low environmental variance means that environmental influences were low compared to genetic factors in the variability observed. This would suggest that pistil length, stamen length and stigma-anther separation have broad genetic base hence improvement can be achieved through selection. The phenotypic coefficient of variation (PCV) was the highest (51.58%) for stigma diameter followed by stigma-anther separation (48.49%), number of pods per plant (28.64%) and anther diameter (9.22%) whereas, minimum value of PCV was recorded for stamen length (5.02%) (**Table 3**).

Table 2 Mean rainfall (mm), temperature (°C), and the relative humidity during the experimental period.

Month	Temp (°C) (± SEM)**		Rainfall (mm)	Rainy days	Relative humidity (%) (± SEM)**	
	Min.	Max.	(± SEM)**		At 10 am	At 4 pm
			Early planting			
April	22.97 ± 0.24 a	32.67 ± 0.36 a	121.66 ± 0.33 e	8	74.53 ± 0.52 c	64.53 ± 1.33 d
May	21.90 ± 0.28 b	31.13 ± 0.34 b	193.55 ± 0.27 c	11	76.32 ± 0.46 b	70.81 ± 0.76 b
June	21.83 ± 0.26 b	29.37 ± 0.25 c	327.66 ± 0.35 a	16	77.43 ± 0.34 a	72.93 ± 0.67 a
July	21.20 ± 0.17 c	28.52 ± 0.27 d	62.99 ± 0.43 f	14	78.42 ± 0.38 a	73.35 ± 0.64 a
			Late planting			
August	21.16 ± 0.11 c	27.58 ± 0.29 e	323.60 ± 0.27 a	17	79.06 ± 0.43 a	74.29 ± 0.63 a
September	21.13 ± 0.16 c	28.27 ± 0.32 f	169.67 ± 0.45 d	19	78.07 ± 0.46 a	74.23 ± 0.73 a
October	20.71 ± 0.20 c	29.52 ± 0.22 c	267.20 ± 0.22 b	18	76.61 ± 0.47 b	71.77 ± 0.61 b
November	20.30 ± 0.26 b	30.40 ± 0.32 b	55.12 ± 0.21f	4	76.33 ± 0.58 b	68.53 ± 1.08 b

** Different letters within a column indicate significant differences according to analysis of variance ($P < 0.01$).

Table 3 Mean squares and genetic parameters for some floral traits in the 13 bambara groundnut accessions during early planting dates.

Traits	Mean squares	Mean	σ^2_P	σ^2_g	σ^2_e	PCV	GCV	ECV	H^2 b(%)
PTL	2.8692**	5.5364	0.0797	0.07674	0.00167	5.10	5.00	0.74	96.29
SML	2.8606**	5.6169	0.0795	0.07882	0.00192	5.02	5.00	0.78	99.19
SAS	0.0549**	0.0805	0.0015	0.00148	0.00013	48.49	47.80	14.06	97.18
AND	0.0522	0.4130	0.0015	0.00014	0.00477	9.22	2.87	16.72	9.71
ANL	0.0542	0.5183	0.0015	0.00025	0.00375	7.48	3.08	11.82	16.92
STD	1.1395	0.3450	0.0317	0.00410	0.10730	51.58	18.56	94.95	12.95
NPP	469.9	43.700	156.63	13.0667	430.700	28.64	8.27	47.49	8.34

PTL: pistil length, SML: stamen length, SAS: stigmma-anther separation, AND: anther diameter, ANL: anther length, STD: stigma diameter, NPP: number of pods per plant, H^2 b: heritability in a broadsense

Table 4 Mean squares and genetic parameters for some floral traits in the 13 bambara groundnut accessions during late planting season.

Traits	Mean squares	Mean	σ^2_P	σ^2_g	σ^2_e	PCV	GCV	ECV	H^2 b (%)
PTL	1.9802**	5.244	0.0550	0.04487	0.03039	4.47	4.04	3.32	81.58
SML	2.3594**	5.355	0.0655	0.05526	0.03085	4.78	4.39	3.28	84.31
SAS	0.0076**	0.1113	0.0025	0.00248	0.00015	45.15	44.7	10.96	98.03
AND	0.0021*	0.5031	0.0007	0.00039	0.00093	5.27	3.94	6.06	55.89
ANL	0.0013	0.5496	0.0004	0.00019	0.00075	3.81	2.50	4.98	43.11
STD	0.0012	0.2701	0.0004	0.00029	0.00035	7.45	6.28	6.94	71.08
NPP	30.5210**	3.5600	10.1766	9.70300	1.41200	89.61	87.50	33.38	97.65

PTL: pistil length, SML: stamen length, SAS: stigmma-anther separation, AND: anther diameter, ANL: anther length, STD: stigma diameter, NPP: number of pods per plant, H^2 b: heritability in a broadsense

The highest estimates of genotypic coefficient of variability (GCV) were observed for stigma-anther separation (47.80%) while stamen length (5.00%), pistil length (5.00%), anther length (3.08%), number of pods per plant (8.27%) and anther diameter (2.87%) recorded low GCV (**Table 3**). High GCV indicates the presence of exploitable genetic variability for these traits. The environmental coefficient of variation (ECV) ranged from 0.74% (pistil length) to 94.95% (stigma diameter). Nausherwan *et al.* (2008) reported that the polygenic variation may be phenotypic, genotypic or environmental and the relative values of these three types of coefficients give an idea about magnitude of the variability.

A narrow range of difference between PCV and GCV was recorded for pistil length (5.1 and 5.0), stamen length (5.02 and 5.00) and stigma-anther separation (48.49 and 47.80), (**Table 3**) indicating that the above traits are mostly governed by genetic factors with minimal environmental influence on the phenotypic expression of the traits. Hence, selection of these traits on the basis of the phenotypic value may be effective. On the contrary, a wide difference between PCV and GCV was observed in the stigma diameter (51.58 and 18.56) and number of pods per plant (28.64 and 8.27) indicating higher influence of environment on the traits thereby reducing possible response to selection on phenotypic basis. GCV values only are not enough to determine the level of genetic variability among accessions. Genetic variation could further be investigated with the help of heritability estimates. This measures the heritable portion of the total variation. High broad sense heritability estimates were observed for pistil length (96.29%), stamen length (99.19%) and stigma-anther separation (97.18%). This would appear to suggest reduced environmental influence thereby validating the results obtained with the GCV values. The low GCV (8.27) and heritability (8.34) obtained for number of pods per plant in the early planting dates is not surprising since pod yield is a product of many complex traits. Therefore, direct selection for pod yield improvement may not produce the desired result but indirect selection of other traits that influence pod yield may be feasible and more reliable. Low GCV and heritability values have also been reported by Ogunbodede and Fatula (1985) and Vange and Egbe (2009) in cowpea (*Vigna unguculata* (L.) Walp) and pigeon pea (*Cajanus cajan* L.), respectively.

The mean squares, genotypic and phenotypic variance, genotypic coefficient of variability (GCV), phenotypic coefficient of variability (PCV) and broad sense heritability for six floral traits in the late planting date are presented in **Table 4**. The mean squares values showed significant genotype effects on pistil length, stamen length, stigma-anther separation, anther diameter and number of pods per plant. This suggest the existence of considerable variations that could be exploited. Following the same trend with the results obtained in the early planting, the magnitude of genotypic variance of pistil length, stamen length and stigma-anther separation was higher than the environmental variance (**Table 4**). The phenotypic and genotypic variances did not differ much in the late planting. The genotypic component is therefore considered to be the major contributor to the total variance for pistil length, stamen length and stigma-anther separation, thereby suggesting that the traits will respond to selection.

The level of variability during the late planting season (**Table 4**) revealed that the estimates of phenotypic and genotypic coefficient of variations were high for number of pods per plant (89.61 and 87.50%, respectively) and stigma-anther separation (45.15 and 44.70%, respectively). The remaining traits recorded low PCV and GCV estimates. The differences between PCV and GCV were very small for all the traits studied except for number of pods per plant suggesting minimal effect of the environment on the floral traits. However, the wide range between PCV and GCV value observed for number of pods per plant suggest large influence of environment on the expression of the trait. Thus, selection based on number of pods per plant may not be an effective means of improving yield. This result is in line with the result obtained in the early planting. High heritability values were recorded for all the traits studied except for the anther diameter (55.89%) and anther length (43.11%) which showed moderate heritability. The high values of heritabilty obtained for pistil length (81.58%), stamen length (84.31%), stigma-anther separation (98.03%), stigma diameter (71.08%) and number of pods per plant (97.65%) indicate that selection could be effective for improving the traits. Ntawuruhunga (2010) reported that it takes more time to improve the traits with moderate heritability because of their low genetic variance. Moderate to low heritabilty estimates makes selection considerably difficult or virtually impractical due to the masking effect of the environment on genotypic effects (Singh 1993). Stigma-anther sepration showed less variation between PCV and GCV and was accompanied by a high heritability in the late planting. This trait should be considered for selection in the late planting, because it is most likely that the trait is controlled by additive gene effects.

Correlation

The study of inter-relationship among various characters in the form of correlation is one of the very important aspects in selection programme for the breeder to make an effective selection based on the correlated and uncorrelated responses. The knowledge of the nature and magnitude of associations among different characters are important. Indirect selection is important when desirable characters have low heritability measure.

The correlation coefficients among the six floral traits studied during the early and late planting season are presented in **Table 5**. The table revealed that number of pods per plant had positive and significant correlation with anther diameter (r = 0.653*) during the early planting. This suggests that increase in the anther diameter would lead to an increase in the number of pods that will be produced. It is very probable that bambara groundnut genotypes with large anthers would produce higher number of pollen grains for enhanced pollination and seed set. Therefore, selection of genotypes with large anthers could be a reliable strategy for pod yield improvement in bambara groundnut especially if early planting is envisaged. Stigma-anther separation had negative correlation values with number of pods per plant in both the early (r = -0.504) and late (r = -0.679) planting dates. The negative correlation observed between the two traits at both planting dates suggest that number of pods per plant increases with decrease in the separation between the stigma and anther. Spencer *et al.* (1987) had earlier reported a large negative correlation (r = -0.87) between stigma-anther separation and seed set in *Turnera ulmifolia* complex. The results revealed that plants with reduced stigma-anther separation (herkogamy) appear to produce higher number of pods than those with wider separation. It is very probable that reduced stigma-anther separation increases the chances of pollen deposition on the stigma thereby enhancing pollination with the plant's own pollen. Herkogamy has been deemed a mechanism for reducing self-fecundity (Barrett 2002) and, a strong negative link has also been reported between the degree of herkogamy and out-crossing rates (Holtsford and Ellstrand 1992; Belaoussoff and Shore 1995; Karron *et al.* 1997).

Negative and significant correlations were recorded between the number of pods per plant and pistil length ($r = -0.586^{*}$) and stamen length ($r = -0.580^{*}$) at late planting indicating an inverse relationships between the number of pods per plant and the two traits. To increase the number of pods per plant, breeders should accord higher emphases on the genotypes with shorter pistil and stamen lengths. The correlations of stamen length with pistil length were found to be positive and highly significant at both early and late plantings ($r = 0.910^{**}$ and 0.966^{**}, respectively) indicating that both traits increase or decrease simultaneously.

Path coefficient analysis

Path coefficient analysis measures the direct influence and contribution of one trait upon the other and would permits separation of correlation coefficients into components of direct and indirect effects. Partitioning of the total correlation into direct and indirect effects would provide actual information on the contribution of traits and thus form the basis for selection to improve the yield.

Path diagrams showing cause and effect relationships of pod yield and its components are presented in **Figs. 1** (early planting) and **2** (late planting). The direct and indirect effects for number of pods per plant using the six floral traits during the early and late plantings are presented in **Table 6**. In the early planting, the path coefficient analysis revealed that the anther diameter showed highest positive direct effect towards number of pods per plant (0.57), followed by pistil length (0.25). The result showed that the positive and significant correlation obtained between the number of pods per plant and anther diameter was due to the high direct contribution of the anther diameter. Considering the direct effects of anther diameter on the number of pods per plant and its association with yield, it appears to be the most reliable selection criteria for pod yield improvement in the early planting. The stamen (-0.47) and ather length (-0.44) were observed to have high negative direct effects on number of pods per plant. However, the correlation between the stamen and number of pods per plant were non significant

Table 5 Correlation coefficients among floral traits and number of pod per plant of 13 accessions of bambara groundnut under two planting planting dates (PD).

	PD	1	2	3	4	5	6	7
1. Stigma diameter	Early	1.000						
	Late	1.000						
2. Anther diameter	Early	-0.265	1.000					
	Late	0.346	1.000					
3. Anther length	Early	0.190	0.217	1.000				
	Late	-0.339	0.114	1.000				
4. Pistil length	Early	-0.364	-0.048	-0.532	1.000			
	Late	0.225	0.019	0.234	1.000			
5. Stamen length	Early	-0.276	-0.243	$-.624^{*}$	$.910^{**}$	1.000		
	Late	0.200	-0.093	0.108	$.966^{**}$	1.000		
6. Stigma-anther separation	Early	0.372	$-.806^{**}$	-0.201	-0.101	0.030	1.000	
	Late	0.121	-0.296	-0.345	0.334	0.481	1.000	
7. Number of pods/plant	Early	-0.222	$.652^{*}$	-0.139	0.038	-0.110	-0.504	1.000
	Late	-0.411	-0.155	-0.032	$-.586^{*}$	$-.580^{*}$	$-.679^{*}$	1.000

Table 6 Path analysis showing direct [diagonal (in **bold**)] and indirect influence of floral traits on number of pod pods per plant on bambara groundnut under two planting dates.

	Indirect effect to NPP via						Total correlation to NPP
	SAS	SML	PTL	ANL	AND	STD	
Early panting dates							
SAS	**-0.1000**	-0.1410	-0.0250	0.0880	-0.4617	0.0037	**-0.636**
SML	0.0030	**-0.4700**	0.2275	0.2728	-0.1368	0.0028	**-0.1007**
PTL	0.0100	-0.4277	**0.2500**	0.2332	-0.0285	-0.0036	**0.0334**
ANL	0.0200	0.2914	-0.1325	**-0.4400**	0.1254	0.0019	**-0.1338**
AND	0.0810	0.1128	-0.0125	-0.0968	**0.5700**	-0.0027	**0.6518***
STD	-0.0370	0.1316	-0.0900	-0.0836	-0.1539	**0.0100**	**-0.2229**
Late planting dates							
SAS	**-0.9200**	0.5712	-0.4323	0.0840	0.0510	-0.0312	-0.6773*
SML	-0.4416	**1.1900**	-1.2707	-0.0264	0.0153	-0.0520	-0.5854*
PTL	-0.3036	1.1543	**-1.3100**	-0.0552	-0.0034	-0.0598	-0.5777*
ANL	0.3220	0.1309	-0.3013	**-0.2400**	-0.0187	0.0884	**-0.0187**
AND	0.2760	-0.1071	-0.0262	-0.0264	**-0.1700**	-0.0910	**-0.1447**
STD	-0.1104	0.2380	-0.3013	0.0816	-0.0595	**-0.2600**	-0.4116

SAS: stigma-anther separation, SML: stamen length, PTL: pistil length, ANL: anther length, AND: anther diameter and STD: stigma diameter

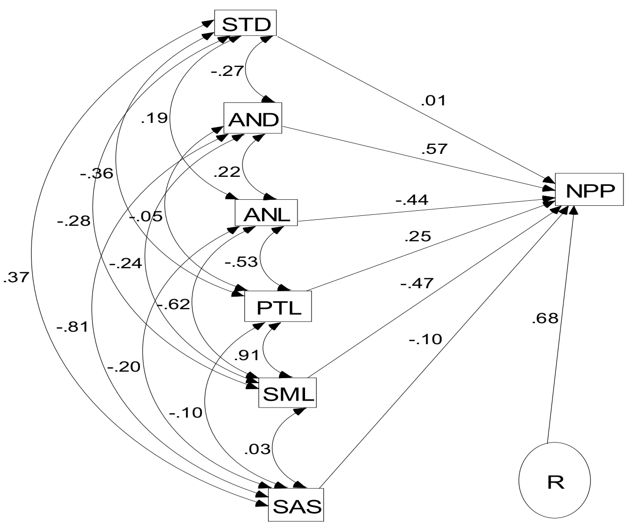

Fig. 1 Path diagram representing cause and effect relationships among floral traits and pod yield in bambara groundnut during the early planting date.

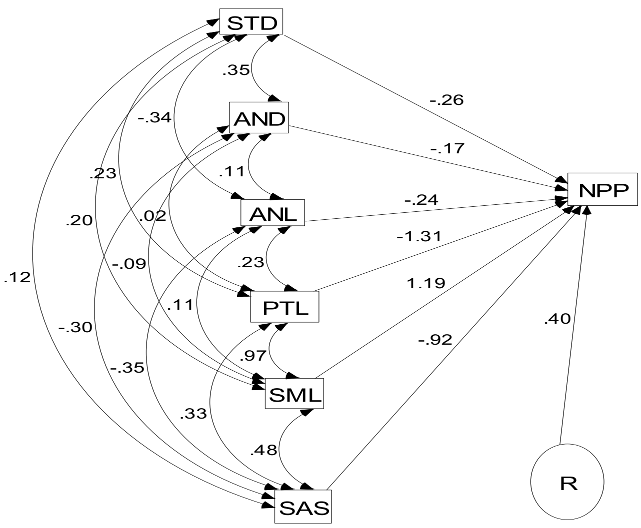

Fig. 2 Path diagram representing cause and effect relationships among floral traits and pod yield in bambara groundnut during the late planting date.

due to the masking effect via pistil (0.228) and anther length (0.273). Similarly, the negative direct effect of anther length on number of pod per plant was masked via anther diameter (0.125) and stamen length (0.291) leading to non significant correlation between anther length and number of pods per plant.

Although, the correlations of number of pods per plant with the anther length were not significant, highest positive indirect effect was recorded in anther length (0.291) via stamen length. This was followed by stamen length (0.273) via anther length, pistil length (0.233) via anther length and, stamen length (0.228) via pistil length in that order. This suggest that increase in the number of pods per plant per plant were to some extent, influenced by the above traits. Therefore, the indirect selection of genotypes with longer stamens and anthers could be effective in increasing the number of pods in the early planting season. Stigma-anther separation had high negative indirect effect (-0.46) via anther diameter implying that genotypes with large anthers would have reduced herkogamy and increased number of pods per plant. Selection of genotypes with large anthers would result in prolific podding. Oyiga *et al.* (2010) has reported that reduction in the stigma-anther separation enhances pollination efficiency and would lead to higher pod yield in bambara groundnut.

In the late planting, the results in **Table 6** revealed that the direct effect of stamen length on number of pods per plant was highest and positive (1.19). However, this influence was nulified by the negative indirect effects through pistil length (-1.27), stigma-anther separation (-0.44) and anther length (-0.03) which resulted in the significant negative correlation observed between the number of pods per plant and stamen length. The results indicate that the indirect selection via pistil length and stigma-anther separation are more efficient than the direct selection of stamen length during the late planting dates.

The stigma-anther separation and pistil length recorded large negative direct effect on number of pod per plant with r values of -1.31 and -0.92, respectively. The corresponding correlation coefficients of these two floral traits on number of pods per plant were also significant with negative direction suggesting the important of the two floral traits in the crops' seed set and pod yield. Notwithstanding the high negative direct effect of pistil length on pod yield, the negative indirect effect via stigma-anther separation contributed appreciably to the significant negative correlation (r = -0.58*) obtained by cushioning the high positive indirect effect produced via stamen length. The direct contribution of stigma-anther separation to the significantly negative correlation between stigma-anther separation and number of pods per plant was maximum. Therefore, for pod yield improvement, crops with reduced separations between stigma and anther could be selected as are reliable indicator for increase pod yield in bambara groundnut. The negative direct effect of stigma-anther separation on number of pods per plant established in this study supports that the breeding for reduced stigma-anther separation remains the most effective method of breeding for high pod yield (Spencer *et al.* 1987). Hence, stigma-anther separation should be given prior attention in bambara groundnut improvement programme because of its major influence on pod yield in late planting. Oyiga *et al.* (2010) had earlier reported a strong negative link between the stigma-separation and number of pods per plant. Similarly in late planting, pistil length could be a selection indicator for pod yield, its negative correlation coefficient number of pods per plant implies that shorter pistil length will produce higher number of pods per plant.

In conclusion, the level of genetic variability observed in the present study can guarantee substantial improvement through selection of relevant floral traits. The high heritability estimates obtained for pistil length, stamen length and stigma-anther separation at both planting dates suggests that these characters are highly heritable. To select for farmers that plant bambara groundnut in the early season, anther diameter should be accorded substantial weightage. For the late growers, selection emphases should be on anther diameter, stigma-anther separation and pistil length. In both cases, large anther is a recurrent floral trait and therefore should be strongly emphasized for any breeding work aimed at improving bambara groundnut. Therefore, for improvement of bambara groundnut, genotypes with large anthers should be selected in the early planting while selection of genotypes with reduced stigma-anther separation and shorter pistil should be adopted during late planting.

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