Australian Journal of Crop Science AJCS
AJCS 4(2):91-97(2010) ISSN:1835-2707

# Studies on the floral traits and their implications on pod and seed yields in bambara groundnut [*Vigna subterrenea* (L.) Verdc]

**Oyiga B.C Uguru M.I and Aruah C.B.**

**Department of Crop Science, University of Nigeria, Nsukka, Nigeria**

***Email: ceejaybeecee@yahoo.com**

**Abstract**

Two field experiments were conducted in April and August, 2007 at the Department of Crop Science Research Farm, University of Nigeria, Nsukka to evaluate the floral structure of thirteen cultivars of bambara groundnut. The result showed that the differences between the two planting dates were significant for all the traits measured except for stigma diameter. Interaction of cultivars and planting dates had significant effect on pistil length, stamen length and stigma-anther separation. It is evident from the results obtained that exploitable variations existed among the cultivars. The principal component analysis revealed that the first three principal components contributed 83.90% and 84.28% of the total variability for the early and late plantings, respectively. It also showed that cultivars were differentiated on the basis of anther diameter and seed weight per plant during the early planting and, stamen length and number of pods per plant in the late planting in the PC1. Cultivars were differentiated by pistil length for the early planting and anther length for the late planting along the second principal component axis. The cluster plots grouped the 13 bambara groundnut cultivars into two clusters in both early and late planting dates. In the early planting, clusters I and II comprised five cultivars each. The cultivars in cluster I are associated with long pistil and stamen with lower stigma and anther diameters values while cluster II cultivars are characterized with high number of pods per plant, high seed weight per plant, very marginal stigma-anther separation and high anthers and stigma diameters. During the late planting, the cluster I consists of seven cultivars with large stigma diameter, longer pistil and stamen with larger stigma-anther separation. The cluster II consists of five cultivars characterized with large anthers, marginal stigma-anther separation and higher number of pods and seed weight per plant. Seed weight and number of pods per plant were significantly correlated with anther diameter. However, seed weight per plant was negatively correlated with stigma-anther separation (r = -0.59**) implying that seed weight per plant increased with decrease in stigma-anther separation.

***Keywords:*** Bambara groundnut, floral biology, inserted stigma, stigma-anther separation, *Vigna subterrenea* (L.) Verdc.

## Introduction

Different plant species are charcterized by a wide range of floral traits that influence the pattern of mating between plants. Mating systems are basically distinguished by the occurrence of female and male reproductive organs on the same or on different plant individuals (dioecy or cosexuality), or on the same or different flowers (hermaphroditism or monoecy) (Richards 1997). In plants with hermaphroditic flowers, the reproductive organs can be separated in space (*i.e.*, stigma-anther separation or herkogamy) or they can function at different times (dichogamy). All of these traits have the capacity to determine the breeding systems in crop plants. For instance, the plant species with large stigma-anther separation had higher outcrossing rates than those with little separation.

Bambara groundnut [*Vigna subterranean* (L.) Verdc] produces perfect flowers and it is basically an inbreeder (Massawe et al., 2003). The anthers dehisce and the stigma becomes receptive even before the flowers open.

The fertilization of the ovule takes place on the day of anthesis (Linnemann, 1994). Bambara groundnut has not been improved through coordinated breeding programmes. Improvement through the conventional breeding methods has been largely constrained by the failure of the crop to set seeds after artificial hybridization. Thus, the available cultivars are selections from the aboriginal landraces. In any bambara groundnut improvement programme aimed at developing improved cultivars with novel traits, artificial hybridization is essential. Hybridization of selected parental lines allows creation of new forms through genetic recombinations. The resulting hybrids serve as sources of genetic variations on which selection can be imposed. The production of genotypes with novel traits would require a clear understanding of the floral biology and the yield attributes of the crop. This is particularly important for a crop like bambara groundnut that is an inbreeder with no records of successful outcrossing. A detailed study of the floral morphology

**Table 1.** Mean rainfall (mm), temperature ($^0$C), and the relative humidity during the experimental period.

| Month | Temperature ($^0$C) | | Rainfall (mm) | Relative humidity (%) | |
|---|---|---|---|---|---|
| | Min. | Max. | | At 10 am | At 4 pm |
| April | 22.67 | 32.67 | 121.66 | 74.53 | 64.53 |
| May | 21.9 | 31.73 | 193.55 | 76.32 | 70.81 |
| June | 21.83 | 30.97 | 327.66 | 77.53 | 72.93 |
| July | 21.2 | 30.50 | 62.99 | 78.74 | 73.61 |
| **Average** | **21.9** | **31.47** | **176.47** | **76.78** | **70.47** |
| August | 21.87 | 27.65 | 323.6 | 79.06 | 74.29 |
| September | 21.37 | 28.27 | 169.67 | 78.07 | 73.54 |
| October | 20.71 | 29.71 | 267.2 | 76.61 | 71.77 |
| November | 20.71 | 30.4 | 55.12 | 76.33 | 68.11 |
| **Average** | **21.17** | **29.01** | **203.9** | **77.52** | **71.93** |

will be important in providing explanation for the outcrossing failures. Anchirina et al. (2001) and Lacroix et al. (2003) implicated paucity of information on the reproductive biology and the yield characteristics of bambara groundnut as the major constraints militating against the improvement of the crop. There is also lack of research result on the relationships among the floral and the yield components in bambara groundnut. This has created an information gap on the yield related traits that will be relevant in the improvement of the crop. This study was therefore initiated to address these issues and possibly provide some explanations for the artificial hybridization failures in bambara groundnut.

## Materials and methods

Two experiments were conducted in April and August 2007. Both experiments were carried out in the experimental field of the Department of Crop Science, University of Nigeria, Nsukka (Lat 06$^0$ 52'N; Long 07 24' E, 447.2m a.s.l.). The monthly rainfall distribution, temperature and the relative humidity are presented in Table 1. The 13 bambara groundnut cultivars that were used in the present study were sourced from bambara groundnut producing areas of Nigeria. The cultivars were classified based on the seed coat colour (Massawe *et al.,* 2000) and were given accession numbers *viz:* Bg-01, Bg-02, Bg-03, Bg-04, Bg-05, Bg-06, Bg-07, Bg-08, Bg-09, Bg-10, Bg-11, Bg-12, and Bg-13. The cultivars were grown in a randomized complete block design (RCBD) with three replications. The plot size was 180 m$^2$ and the seeds were planted at a spacing of 30 x 75 cm. Four kilograms of well cured pig dung (equivalent to 222 kg/ha) was applied to each plot before planting. The plots were weeded manually to keep weed pressure low.

### *Data Collection*

Data were collected on the stigma diameter, anther diameter, anther length, pistil length and stamen length using an ocular micrometer. The stigma–anther separation (herkogamy) was computed by subtracting the stamen length from the pistil length (Mal and Lovett-Doust, 1997; Faivre and McDade, 2001). Positive values of stigmatic exertion (stigma longer than the longest anther) would indicate exerted stigma position, while negative values of stigmatic exertion (stigma shorter than the longest anther) represent inserted stigma position (PereraO and Poulos,1993). Positive and negative herkogamy values point to the existence of approach herkogamy and reverse herkogamy, respectively ( Asier *et al.,* 2009). Data on the number of pods per plant and seed weight per plant were collected at harvest.

### *Data Analysis*

Analysis of variance was conducted using Genstat software version 7.22 to determine the effect of planting dates, cultivars, and the interactions between planting dates and cultivars on all the traits collected. The Fisher's Least Significant Difference (F-LSD) was used to detect significant differences between treatment means. The principal component and cluster analyses were done to identify the variability among the cultivars and their groupings (Johnson, 1998; Manly, 1994). The Pearson correlation coefficient was employed to estimate the relationships between the yield attributes and the floral traits.

## Results

The analyses of variance on the floral and yield traits are presented in Table 2. Planting date had significant effect ($P<0.05$) on all the floral and yield traits measured with the exception of stigma diameter. There were also significant differences among the cultivars on pistil length, stamen length and stigma-anther separation. Cultivar x Planting date interaction had significant influence on pistil length, stamen length and stigma-anther separation (Table 2). The mean values of all the floral and yield traits are shown in Table 3.

**Table 2**. Mean square analysis of variance for floral and yield traits of bambara groundnut cultivars averaged over two planting dates.

| SV | df | Mean squares | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SD | AD | AL | PL | SL | SAS | NPP | SWP |
| PD | 1 | $109360^{ns}$ | 159007** | 19188* | 1.672** | 1.339** | 0.0185** | 31400.3** | 6341.1** |
| C | 12 | $42988^{ns}$ | $1703^{ns}$ | $3270^{ns}$ | 0.354** | 0.380** | 0.0061** | $252.4^{ns}$ | $223.8^{ns}$ |
| PDXC | 12 | $53186^{ns}$ | $4753^{ns}$ | $2564^{ns}$ | 0.050* | 0.055* | 0.0061** | $248.1^{ns}$ | $204.8^{ns}$ |
| Error | 50 | 53634 | 3160 | 2712 | 0.017 | 0.017 | 0.00014 | 225.7 | 147.6 |

PD = Planting dates, C = Cultivars, SD= stigma diameter (mm), AD= anther diameter(mm), AL= anther length (mm), PL= pistil lenghth (mm), SL= stamen length, SAS= anther-stigma separation (mm), NPP= number of pods per plant and SWP= seed weight per plant (g)

**Table 3**. Effect of cultivar, planting date and cultivar x planting date interactions on the floral and yield traits of 13 bambara groundnut cultivars

| Cultivar | SD | | | AD | | | AL | | | PL | | | SL | | | SAS | | | NPP | | | SWP | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Early | Late | Mean | Early | Late | Mean | Early | Late | Mean | Early | Late | Mean | Early | Late | Mean | Early | Late | Mean | Early | Late | Mean | Early | Late | Mean |
| **Bg-01** | 0.94 | 0.24 | **0.59** | 0.37 | 0.50 | **0.44** | 0.54 | 0.56 | **0.55** | 5.20 | 5.14 | **5.17** | 5.33 | 5.20 | **5.27** | 0.13 | 0.06 | **0.09** | 36.0 | 5.0 | **20.5** | 10.50 | 1.92 | **6.21** |
| **Bg-02** | 0.28 | 0.27 | **0.27** | 0.44 | 0.49 | **0.47** | 0.50 | 0.54 | **0.52** | 5.73 | 5.51 | **5.62** | 5.85 | 5.85 | **5.75** | 0.12 | 0.13 | **0.13** | 52.0 | 4.0 | **28.0** | 12.10 | 0.09 | **6.10** |
| **Bg-03** | 0.30 | 0.27 | **0.29** | 0.38 | 0.53 | **0.46** | 0.55 | 0.53 | **0.54** | 5.16 | 4.75 | **4.96** | 5.27 | 4.79 | **5.03** | 0.11 | 0.05 | **0.08** | 53.0 | 7.0 | **30.0** | 14.80 | 1.92 | **8.36** |
| **Bg-04** | 0.28 | 0.24 | **0.26** | 0.39 | 0.51 | **0.45** | 0.50 | 0.54 | **0.52** | 5.57 | 5.30 | **5.43** | 5.63 | 5.43 | **5.53** | 0.06 | 0.13 | **0.10** | 45.0 | 5.0 | **25.0** | 16.30 | 1.56 | **8.93** |
| **Bg-05** | 0.31 | 0.28 | **0.30** | 0.43 | 0.51 | **0.47** | 0.48 | 0.57 | **0.53** | 5.84 | 5.36 | **5.60** | 6.49 | 5.49 | **5.72** | 0.10 | 0.13 | **0.12** | 25.0 | 2.0 | **13.5** | 9.60 | 0.49 | **5.05** |
| **Bg-06** | 0.29 | 0.29 | **0.29** | 0.42 | 0.47 | **0.44** | 0.45 | 0.52 | **0.48** | 5.71 | 5.26 | **5.48** | 5.94 | 5.42 | **5.58** | 0.03 | 0.16 | **0.10** | 72.0 | 0.0 | **36.0** | 47.40 | 0.36 | **23.88** |
| **Bg-07** | 0.31 | 0.24 | **0.27** | 0.33 | 0.54 | **0.44** | 0.50 | 0.60 | **0.55** | 5.38 | 5.23 | **5.30** | 5.52 | 5.34 | **5.43** | 0.14 | 0.11 | **0.13** | 22.0 | 2.0 | **12.0** | 9.30 | 0.54 | **4.92** |
| **Bg-08** | 0.31 | 0.27 | **0.29** | 0.43 | 0.55 | **0.49** | 0.59 | 0.54 | **0.57** | 5.55 | 4.95 | **5.25** | 5.60 | 5.03 | **5.31** | 0.05 | 0.08 | **0.06** | 42.0 | 4.0 | **23.0** | 20.90 | 2.06 | **11.48** |
| **Bg-09** | 0.29 | 0.27 | **0.28** | 0.47 | 0.46 | **0.47** | 0.52 | 0.54 | **0.53** | 5.28 | 5.14 | **5.21** | 5.33 | 5.33 | **5.33** | 0.06 | 0.19 | **0.13** | 44.0 | 0.0 | **22.0** | 20.40 | 0.00 | **10.20** |
| **Bg-10** | 0.31 | 0.29 | **0.30** | 0.41 | 0.50 | **0.45** | 0.53 | 0.53 | **0.53** | 5.24 | 5.22 | **5.23** | 5.32 | 5.38 | **5.35** | 0.08 | 0.17 | **0.12** | 45.0 | 2.0 | **23.5** | 18.40 | 0.22 | **9.31** |
| **Bg-11** | 0.29 | 0.28 | **0.28** | 0.41 | 0.47 | **0.44** | 0.48 | 0.55 | **0.52** | 6.00 | 5.50 | **5.75** | 6.10 | 5.62 | **5.86** | 0.11 | 0.12 | **0.11** | 45.0 | 0.0 | **22.5** | 10.30 | 0.00 | **5.15** |
| **Bg-12** | 0.29 | 0.29 | **0.29** | 0.45 | 0.51 | **0.48** | 0.57 | 0.57 | **0.57** | 5.42 | 5.20 | **5.31** | 5.43 | 5.21 | **5.32** | 0.01 | 0.02 | **0.02** | 48.0 | 5.0 | **26.5** | 40.70 | 2.15 | **21.43** |
| **Bg-13** | 0.31 | 0.29 | **0.30** | 0.45 | 0.49 | **0.47** | 0.52 | 0.56 | **0.54** | 5.91 | 5.63 | **5.77** | 5.97 | 5.73 | **5.85** | 0.06 | 0.10 | **0.08** | 40.0 | 0.0 | **20.0** | 16.70 | 0.00 | **8.35** |
| **Mean** | **0.35** | **0.27** | | **0.41** | **0.5** | | **0.52** | **0.55** | | **5.54** | **5.24** | | **5.62** | **5.36** | | **0.08** | **0.11** | | **44.0** | **4.0** | | **19.00** | **1.00** | |
| **F-LSD$_{0.05}$ for:** | | | | | | | | | | | | | | | | | | | | | | | | |
| **Cultivars (C)** | | | **NS** | | | **NS** | | | **NS** | | | **0.05** | | | **0.15** | | | **0.01** | | | **NS** | | | **NS** |
| **Planting dates (PD)** | | | **NS** | | | **0.26** | | | **0.24** | | | **0.02** | | | **0.06** | | | **0.01** | | | **6.83** | | | **5.53** |
| **C X PD** | | | **NS** | | | **NS** | | | **NS** | | | **0.07** | | | **0.21** | | | **0.02** | | | **NS** | | | **NS** |

SD= stigma diameter (mm), AD= anther diameter(mm), AL= anther length (mm), PL= pistil lenghth (mm), SL= stigma length, SAS= anther-stigma separation (mm), NPP= number of pods per plant and SWP= seed weight per plant (g)

The results show that planting date had significant effect on anther length, stamen length, pistil length, anther diameter, stigma-anther separation, number of pods per plant and seed yield per plant. All the traits evaluated recorded higher mean values during the early planting than in the late planting except for anther length, anther diameter and stigma-anther separation. Variations among cultivars were significant ($p<0.05$) in pistil length, stamen length and stigma-anther separation. The pistil length was significantly higher in Bg-13 (5.77 mm) but did not difer statistically from Bg-11 (5.75 mm). These cultivars were followed by Bg-02 (5.62 mm), Bg-05 (5.60 mm), Bg-06 (5.48 mm) and Bg-04 (5.43 mm) in that order. The cultivar, Bg-11 produced the longest stamen (5.85 mm) which did not differ significantly from the stamen lengths of Bg-13 (5.85 mm), Bg-02 (5.75 mm) and Bg-05 (5.72 mm). The cultivars varied in thier stigma-anther separation ranging from 0.02 mm in Bg-12 to 0.13 mm in Bg-02, Bg-07and Bg-09. Planting date and cultivar interaction showed significant effect on pistil length, stamen length and stigma-anther separation (Table 3). Mean length of the pistil varied from 4.75 mm in Bg-03 to 6.00 mm in Bg-11. The cultivars produced longer pistil during the early planting when compared with the values obtained during the late planting. Stamen length varied from 4.79 mm in Bg-03 to 6.49 mm in Bg-05, the shortest was recorded during the late planting. The stigma-anther separation was very marginal and varied from 0.01 mm in Bg-12 to 0.19 mm in Bg-09.

***Principal component Analysis (PCA)***

Table 4 shows the result of the principal component analysis on the floral and yield traits of 13 bambara groundnut cultivars during the early and late planting dates. The principal components in the early planting differed from those of the late planting. The traits affecting the PC1 were anther diameter and seed weight per plant while pistil length affected the PC2. The PC3 had high loading for stigma diameter. The first three components contributed 83.90% of the variability among the 13 cultivars evaluated for eight quantitative traits. The PC1 contributed 41.29% to the total variation while PC2 and PC3 contributed 32.04% and 10.57% to the total variation, respectively. The two-dimensional scatter plot (Fig. 1) apparently distributed the cultivars into two clusters. The cluster mean values are presented in Table 5. The cluster I

**Table 4.** Eigenvector values for principal components using floral and yield traits in early and late planting date

| Parameters | Early planting | | | Late planting | | |
|---|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | PC1 | PC2 | PC3 |
| Anther diameter | 0.5073 | -0.0519 | 0.0348 | 0.0352 | 0.1790 | 0.7302 |
| Anther length | 0.0811 | -0.4725 | 0.5446 | 0.0216 | 0.7469 | -0.0573 |
| Number of pods/plant | 0.4250 | 0.0670 | -0.4958 | 0.4434 | 0.0258 | -0.1628 |
| Pistil length | -0.0141 | 0.5769 | 0.1269 | -0.4220 | 0.3604 | 0.0191 |
| Stamen length | -0.1044 | 0.5800 | 0.0539 | -0.4469 | 0.2458 | -0.0768 |
| Stigma position | -0.4953 | -0.0502 | -0.2604 | -0.3825 | -0.3644 | -0.2575 |
| Stigma diameter | -0.2089 | -0.3114 | -0.5790 | -0.2029 | -0.2870 | 0.5968 |
| Seed weight/plant | 0.5055 | 0.0296 | -0.1852 | 0.4863 | 0.0627 | 0.0907 |
| Percentage variation | 41.29 | 32.04 | 10.57 | 47.75 | 18.46 | 18.07 |

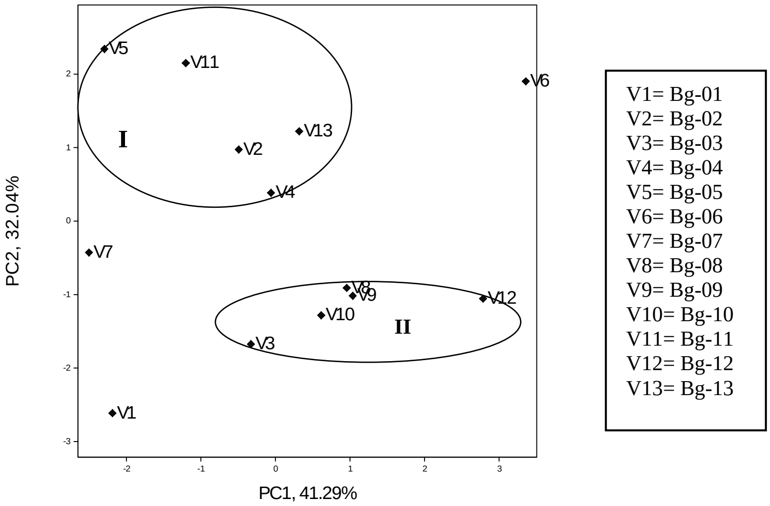


**Fig 1.** Scatter diagram of bambara groundnut cultivar based on their principal component scores superimposed with clustering during the early planting

consist of cultivars with longer pistil and stamen with smaller stigma and anther diameter. The cluster II cultivars are characterized with high number of pods per plant, high seed weight per plant, very marginal stigma-anther separation and large anther and stigma diameter. In the late planting date, traits affecting the first principal component axis were stamen length and number of pods per plant. The trait representing populations along the second principal axis was anther length while anther diameter affected the third principal axis. The scatter plot of the first two principal components revealed that the cultivars were grouped basically into two clusters (Fig. 2). The cluster mean values are presented in Table 5. The cluster I comprised cultivars with larger stigma diameter, longer pistil and stamen with larger stigma-anther separation. However, cluster II has cultivars with larger anther diameter, little stigma-anther separation and higher number of pods and seed weight per plant. The correlation coefficients (r) among the various floral and yield traits are presented in Table 6. Seed weight per plant expressed highly significant positive correlation with anther diameter (r = 0.51**) and number of pods per plant (r = 0.87**). Stamen diameter, stamen length and pistil length had non-significant but positive correlations (r= 0.08, r= 0.28 and r= 0.37, respectively) with seed weight per plant. Anther length had negative and non-significant correlation with seed weight per plant (r = - 0.348). However, seed weight per plant had significant negative correlation with stigma-anther separation (r = - 0.605**). The number of pods per plant also had a significant positive correlation (r = 0.41*) with anther diameter and a significant negative correlation with stigma-anther separation (r = - 0.47*). There was also highly significant but negative correlation of stigma-anther separation with anther diameter (r= -0.53**). Stigma-anther separation correlated positively with stigma diameter (r = 0.103). Anther length and pistil length had weak negative correlation values (r = - 0.04 and r = - 0.167, respectively) with stigma-anther separation. The results showed a strong but negative relationship between the pistil length and anther length (r = - 046*) and a highly significant positive relationship between pistil length and stamen length (r = 0.99**).

## Discussion

It is evident that bambara groundnut exhibits a considerable variation with respect to the anther diameter, style and stamen lengths. Although part of this variation can be attributed to ontogenic changes in the flower traits, some of the variations are associated with the environmental changes at both planting dates. These floral traits are quantitative traits which are under the continuous influence of the environment. The signifficant environmental effect on floral traits have also been reported on crops such as *Brassica rapa*

**Table 5.** Cluster means for 8 traits in 13 bambara groundnt cultivars

| *Traits* | *Clusters* | | | |
|---|---|---|---|---|
| | *Early Planting* | | *Late Planting* | |
| | *I* | *II* | *I* | *II* |
| Stigma diameter | 0.29 | 0.30 | 0.28 | 0.26 |
| Anther diameter | 0.40 | 0.48 | 0.40 | 0.43 |
| Anther length | 0.50 | 0.55 | 0.54 | 0.55 |
| Pistil length | 5.81 | 5.33 | 5.37 | 5.07 |
| Stamen length | 6.01 | 5.39 | 5.55 | 5.13 |
| Stigma anther separation | 0.09 | 0.06 | 0.14 | 0.07 |
| Number of pods/plant | 41.40 | 46.40 | 1.14 | 5.20 |
| Seed weigth/plant | 13.00 | 23.04 | 0.17 | 1.92 |

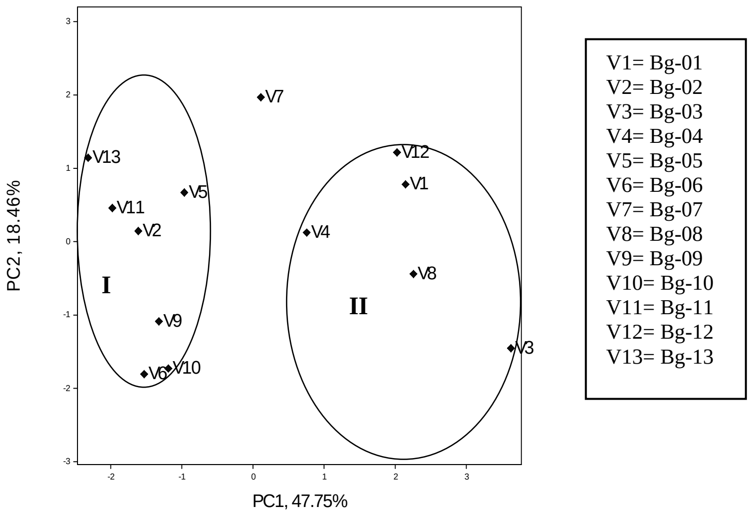


**Fig 2.** Scatter diagram of bambara groundnut cultivar based on their principal component scores superimposed with clustering during the late planting

(Williams and Corner, 2001; Yoshioka *et al.*, 2004). Similar result has also been reported in the invasive weed, *Lythrum salicaria* (Mal and Lovett-doust, 2005). The marginal stigma-anther separation observed among the cultivars was not only to ensure autodeposition efficiency and inbreeding success but also to reduce the chances of outcrossing. Some floral traits were significantly affected by the interactions of the cultivars and planting dates, indicating differential response of gentypes when grown at different planting dates. Similar result has been reported in pepper (PereraO and Poulos , 1993).

The position of the stigma in relation to the anthers suggested the existence of reverse herkogamy or inserted stigma (stigma shorter than the longest anther) in bambara groundnut. This indicates the occurrence of homostyly, which provides an elegant explanation for the self-compatibility system in bambara groundnut (Doku 1968; Free 1993 and Roubik, 1995). The proximity and the position of the stigma below the anther would enforce self pollination and fertilization in the crop. This type of floral arrangement makes autodeposition possible *(i.e.* increasing the possibility for natural self- pollination) through the contact between the stigma and the anthers. This could explain why bambara groundnut is an inbreeder. The reduced stigma–anther separation in the cultivars may provide an opportunity for reproductive assurance when ‘‘legitimate’’ mating partners (or pollinators) are not available. The distance between anther and stigma often affects the selfing efficiency (Jacquemart and Thompson, 1996; Karron *et al.*, 1997; Affre and Thompson, 1998; Pailler *et al.,* 1998). The inherent inbreeding behaviour of bambara groundnut (Massawe *et al.*, 2003) is therefore largely attributed to the reduced stigma-anther separation, which facilitates the natural transfer of pollen to the stigma within the flower. Moreover, the ease of transfer of the pollen grains to the stigmatic surface favours fruit set. Thus, reduced stigma-anther separation as obtained in the present study is advantageous for increased pod and seed yield. The principal components for the early planting differed from those of the late planting indicating some degree of interaction of the cultivars with the environmental factors. Information obtained through PCA may assist plant breeders to identify a limited number of highly differentiated populations for use in hybridization and selection programs. The result of the PCA revealed that anther diameter, seed weight per plant and pistil length were the most important traits for distinction and separation of bambara groundnut cultivars during the early planting while

**Table 6.** Correlation coefficients among the floral traits in bambara groundnut genotypes

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| **1. ST.D** | 1.000 | | | | | | | |
| **2. AN.L** | -0.017 | 1.000 | | | | | | |
| **3. AN.D** | -0.088 | 0.054 | 1.000 | | | | | |
| **4. SM.L.** | -0.035 | -0.524** | -0.068 | 1.000 | | | | |
| **5. PT.L** | -0.052 | -0.456* | 0.087 | 0.985** | 1.000 | | | |
| **6. NPP** | 0.191 | -0.477* | 0.407 | 0.346 | 0.467* | 1.000 | | |
| **7. SAS** | 0.103 | -0.04 | -0.529** | 0.062 | -0.167 | -0.454* | 1.000 | |
| **8. SWP** | 0.075 | -0.348 | 0.509** | 0.283 | 0.372 | 0.868** | -0.605** | 1.000 |

SD= stigma diameter (mm), AD= anther diameter(mm), AL= anther length (mm), PL= pistil lenghth (mm), SL= stigma length, SAS= anther-stigma separation (mm), NPP= number of pods per plant and SWP= seed weight per plant (g)

stamen length, number of pods per plant and anther length were used for the classification and separation of the cultivars in the late planting. These traits have been the principal source of taxonomic characterization in crop plants (Chweya, 1997 and Asier *et al.,* 2009). The principal component analysis for the early and late planting revealed that the principal components I and II for anther diameter, anther length, pistil length, stamen length, number of pods per plant and seed weight were positive indicating that the six traits had significant contribution towards diversity. The members of cluster II at both planting dates are promising in number of pods and seed weight per plant and are therefore recommended candidates for selection for further hybridization program. The stigma-anther separation had significant but negative correlation with number of pods per plant (r = -0.47*) and seed yield (r = -0.59**). Negative correlation indicated inverse relationship of the stigma-anther separation with the traits. Spencer *et al.* (1987) reported a large negative correlation between stigma-anther separation and seed set (r = -0.87) in *Turnera ulmifolia* complex. Plants with reduced separation between stigma and anther appear to produce higher number of pods and seed weight than those with wider separations. One possible explanation could be that a lesser degree of herkogamy increases rates of pollination with the plant's own pollen and produces substantially higher seed yield. Herkogamy has been deemed a mechanism for reducing self-fecundity (Barrett, 2002). A strong positive link has been reported between the degree of herkogamy and out-crossing rates (Holtsford and Ellstrand, 1992; Belaoussoff and Shore, 1995; Karron *et al.,* 1997). A positive correlation shows that the changes of two variables are in the same direction, *i.e.,* high values of one variable are associated with high values of the other. The positive and significant relationship observed for anther diameter with number of pods per plant (r = 0.41*) and seed weight per plant (r = 0.51**) means that increase in anther diameter increases the number of pods and seed yield per plant. This indicates that selection of crops with large anthers is a reliable strategy for seed and pod yield improvement in bambara groundnut. It is therefore very probable that bambara groundnut lines with larger anthers produce higher number of pollen grains for enhanced pollination and seed set. The positive, though non-significant relationship observed between stigma diameter and number of pod per plant indicates that the larger the stigma diameter the higher the number of pods produced. Large stigma diameter provides a larger receptive surface area for pollen deposition. Webb and Lloyd (1986) reported that large receptive area of the stigma is an advantage as it is able to capture higher number of pollen grains. Similarly, Vasudeva *et al.* (2004) had also reported strong positive correlation between stigma diameter and average number of pollen captured which had resulted in higher seed yield in teak (*Tectona grandis* Linn. F). The pistil length had highly significant positive correlation (r = 0.99**) with stamen length indicating that both traits could be increased simultaneously. The significant and positive correlation between the number of pods per plant and seed yield per plant is in line with expectation. Previous workers on mungbean, *Vigna radiata* (L.) Wilczek (Shah, 1993) and Lentil, *Lens culinaris* Medik (Salehi *et al.,* 2008) reported significant and positive correlation between the number of pods per plant and seed yield per plant. From the results obtained in this study, it is reasonable to conclude that floral traits are important in determining the level of pollination success and subsequent pod yield in bambara groundnut.

**Reference**


Affre L, Thompson JD (1998) Floral trait variation in four *Cyclamen* (Primulaceae) species. Plant Syst Evol 212:279-293

Anchirina VM, Yiridoe EK, Bennett-Lartey SO (2001) Enhancing sustainable production and genetic resource conservation of bambara groundnut. A survey of indegenous agricultural knowledge systems. Outlook in Agriculture 30 (4):281-288

Asier RL, Pablo G, Jose LG, and Javier G, (2009) Floral morphology and reproductive success in herkogamous *Narcissus cyclamineus* (Amaryllidaceae). Plant Syst Evol 278:149–157

Barrett SCH (2002) Sexual interference of the floral kind. Heredity 88:154–159

Belaoussoff S, Shore JS (1995) Floral correlates and fitness consequences of mating-system variation in *Turnera ulmifolia*. Evolution 49:545–556

Chweya JA (1997) Genetic Enhancement of Indigenous Vegetable in Kenya. Guarine L (ed) Proceedings of IPGRI Workshops, Traditional African Vegetables in Africa. Rome, Italy

Doku EV (1968) Flowering, pollination and pod formation in bambara groundnut (*Voandzeia subterranea*) in Ghana. Exp Agr 4:41-48

Faivre AF, Mcdade LA (2001) Population-level variation in the expression of heterostyly in three species of Rubiaceae: does reciprocal placement of anthers and stigmas characterize heterostyly? Am J Bot 88:841–853

Free J B (1993) Insect Pollination of Crops. Academic Press London, UK

Holtsford TP, Ellstrand NC (1992) Genetic and environmental variation in floral traits affecting outcrossing rate in *Clarkia tembloriensis* (Onagraceae). Evolution 46:216–225

Jacquemart AL, Thompson JD (1996) Floral and pollination biology of three sympatric *Vaccinium* (Ericaceae) species in the Upper Ardennes Belgium. Canadian Journal of Botany 74:210-221

Johnson DE (1998) Applied multivariate methods for data analysis. New York, Duxbury Press

Karron JD, Jackson RT, Thumser NN, Schlicht SL (1997) Outcrossing rates of individual *Mimulus ringens* genets are correlated with anther– stigma separation. Heredity 79:365–370

Lacroix B, Assoumou NY, Sangwan RS (2003) Efficient *in vitro* direct shoot regeneration systems in bambara groundnut (*Vigna subterrenea* (L.) Verdc). Plant Cell Rep 21:1153-1158

Liannemann AR (1994) Phenological development in bambara groundnut (*Vigna subterranea*) at alternate exposure to 13 and 14 h photoperiods. Journal of Agricultural Science 123:333-340

Mal TK, Lovett-Doust J (1997) Morph frequency and floral variation in a heterostylous colonizing weed *Lythrum salicaria*. Canadian Journal of Botany 75:1034-1045

Mal TK, Lovett-Doust J (2005) Phenotypic Plasticity in Vegetative and Reproductive Traits in an Invasive Weed *Lythrum Salicaria* (Lythraceae) in Response to Soil Moisture. American Journal of Botany 92(5):819–825

Manly BFJ (1994) Multivariate Statistical Methods. Champman and Hall, New York, USA

Massawe FJ, Schenkel W, Basu S, Temba EM (2003) Artificial hybridisation in bambara groundnut (*Vigna subterranea* (L) VERDC.). In: Proceedings of the International Bambara Groundnut Symposium, Botswana College of Agriculture. Botswana, 193-209

Massawe FJ, Dickson M, Robert JA, Azam Ali SN (2000) Genetic diversity in bambara groundnut (*Vigna subterranea* L. verdc) landraces revealed by AFLP markers. Genome 45:1175-1180

Pailler T, Humeau L, Thompson JD (1998) Distyle and heteromorphic incompatibility in oceanic island species of *Erythroxylum* (Erythroxylaceae). Plant Syst Evol 213:187-198

PereraO KDA, Poulos JM (1993) Studies on Stigma Position of Seventeen Pepper Accessions. Capsicum and Eggplant Newsletter 12:44-46

Richards AJ (1997) Plant breeding systems. 2nd ed, Chapman and Hall, UK

Roubik DW (1995) Pollination of cultivated plants in the tropics. Food and Agriculture Organization of the United Nations, Rome. Bull 118, Italy

Salehi M, Haghnazari A, shekari F, Faramarzi A (2008) The study of seed yield and seed yield components of Lentil (*Lens culinaris* Medik) under normal and drought stress condition. Pakistan Journal of Biological Sciences 11(5):758-762

Shah MA, Rahim J, Hassan S, Rashid A, Jan H (1993) Screening of mungbean genotypes for genetic parameters and protein content. Sarhad J Agric 9(4):317-321

Spencer C, Barrett H, Shore JS (1987) Variation and Evolution of Breeding Systems in The*turnera Ulmifolia* L Complex (Turneraceae). Evolution 41(2):340-354

Vasudeva R, Hanumantha M, Rajesh PG (2004) Genetic variation for floral traits among teak (*Tectona grandis* Linn. F.) clones. Implications to seed orchard fertility. Current Science 87:3

Webb CJ, Lloyd DG (1986) The avoidance of interference between the presentation of pollen and stigmas in Angiosperms. II Herkogamy. New Zealand Journal of Botany 24:163-178

Williams JL, Corner JK (2001) Sources of phenotypic variation in floral traits in wild raddish *Raphanus rapaanistrum* (Brassicaceae). Am J Bot 88:1577-1581

Yoshioka Y, Iwuta RO, Ninomiya S (2004) Analysis of petal shape variation of *Primula sieboldii* E morren by elliptic fourier descriptors and PCA. Ann Bot 94:657-66