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*Research Article*

# A Preliminary Evaluation of Variability, Genetic Estimates, and Association among Phenotypic Traits of African Yam Bean Landraces from Ghana

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A field experiment was conducted at the Research and Teaching Farm, School of Agriculture and Technology (SOAT), University of Energy and Natural Resources (UENR), Dormaa Ahenkro Campus, Ghana, to determine the genetic variability, heritability, genetic advance, and correlation among growth and yield traits of the African yam bean in Ghana. There were significant differences ($p < 0.05$) for the traits studied, except for days to 50% emergence, petiole length, days to maturity, stem diameter, days to 50% flowering, pod weight, pod beak length, pod weight per plant, seed length, and seed width. The phenotypic coefficient of variation and genotypic coefficient of variation for the yield and yield components ranged from 9.43% to 18.92% and 3.25% to 15.93%, respectively, and from 9.35% to 20.08% and 2.15% to 23.28%, respectively, for the growth parameters. Heritability ranged from 34.54% to 91.81, and the GAM ranged from 2.77% to 45.96% for the growth parameters. The heritability and GAM for the yield parameters ranged from 11.85% to 73.56% and 1.94% to 27.64%, respectively. The correlation analysis revealed a positive and highly significant ($p < 0.001$) relationship between petiole length and leaf length ($r = 0.573$), number of seeds per pod and number of leaves ($r = 0.520$), pod beak length and peduncle length ($r = 0.560$), pod weight per plant and pod weight per plot ($r = 0.971$), seed weight per plant and 100 seed weight ($r = 0.967$), grain yield and 100 seed weight ($r = 0.999$) and seed weight per plant ($r = 0.970$), 100 seed weight and pod per plant ($r = 0.576$). The study revealed diversity among the AYB landraces collected, which provides an opportunity for improvement of the African yam bean in Ghana. There is the need for the conservation of these landraces for further evaluations and the improvement of the promising landraces and traits through breeding programmes.

## 1. Introduction

Food security has been one of the most fundamental challenges for the welfare of humans and socio-economic growth in Africa [1]. Most people are unable to obtain and use all the food that is required for living a healthy life [2]. According to Antwi-Agyei et al. [3], food and nutrient security have become a major challenge for both the rich and poor, given the increasing population, changes in dietary consumption patterns, and effect of climate variability and change on natural resources. In recent times, the issue of food security and its sustainability have been of significant concern globally [4]. Due to the increasing focus on a few staple food crops, the issue of global food insecurity is becoming alarming [5]. Food insecurity could be alleviated through the conservation and improvement of underutilized and neglected plant species, which can help in preventing food crises [6].

African yam bean (*Sphenostylis stenocarpa* Hochst ex. A. Rich Harms) is one of the neglected and underutilized crops that can be used to address the issues of food security in tropical Africa. African yam bean (AYB) is a climbing legume which mostly adapts to lowland tropical conditions [7] and has edible grain and tubers. In Ghana, there is no accurate information on the characteristics of AYB to recognize the significant landraces for preservation and genetic improvement. Knowledge on the evaluation and existing variation in yield and other desirable characters is lacking, and such knowledge is necessary to initiate strategies for conservation and genetic improvement of the species. Improvement efforts on this crop to enhance the production of nutritious food for the world's poor mostly depend on the identification, maintenance, and use of its genetic resources [8].

Although the issue of the vast genetic and economic potentials of the crop is well known, the AYB has not received significant research attention in Ghana, especially in reducing malnutrition among Africans. Devos et al. [9] indicated that the threat of losing certain germplasm lies all over the cultivated food crop species in most parts of tropical Africa, most importantly those not receiving significant research attention.

Nonetheless, in Ghana, there is a lack or no significant research on the characterization and estimation of genetic diversity among the available germplasm of AYB, as compared to Nigeria, where a lot of work has been documented on the morphological characterization and nutritional composition of AYB [10]. Such vital information on AYB could enhance its germplasm conservation, breeding, and genetic improvement. There is an urgent need in Ghana for further collection of AYB genetic resources to broaden the species' genetic base and safeguard species against the genetic erosion. The knowledge of genetic variability and biodiversity would play a great role in the selection and screening of desirable traits for the improvement of the crop. Assessment of the genetic diversity of genotypes of African yam bean would facilitate the development and improvement of cultivars for adaptation to specific production constraints, such as longer periods of maturity and cooking, hardness of the seed, and the presence of antinutritional factors in the grains. Hence, this study would provide sufficient information on the knowledge of the genetic diversity of the crop and the need for further research for the improvement of the crop. Also, the evaluation of the accessions would help in the augmentation, rejuvenation, multiplication, characterization, evaluation, and utilization of the germplasm collected. Therefore, the present study was undertaken to assess the extent of genetic variability, heritability, genetic advance, and association among growth and yield traits using fifteen AYB landraces from Ghana.

## 2. Materials and Methods

*2.1. Experimental Site.* Fifteen (15) landraces of African yam beans were sourced from farmers in the active growing areas of the Upper West Region and the Volta Region of Ghana (Table 1). The study was conducted at the Research and Teaching Farm, School of Agriculture and Technology, University of Energy and Natural Resources, Dormaa Campus, Sunyani, Ghana. Dormaa Central Municipality is situated in the western part of the Bono Region and lies within longitudes 3° and 3° 30″ West and latitudes 7° and 7° 30″ North. The municipality has a semi-deciduous forest, a semi-equatorial forest, and a high grassland type of vegetation. The surface soil (0–20 cm) of the study area is sandy loam.

The field study was laid out in a Randomized Complete Block Design (RCBD) with three replications and planted at a distance of 1 m × 0.75 m with 2 seeds per hill. The seeds were tested for viability before planting. All recommended agronomic practices were followed. Growth and yield data were collected on three selected and tagged plants on each plot using the AYB descriptors [11].

### 2.2. Statistical Analysis

*2.2.1. Analysis of Variance.* Data collected were analyzed using the Statistical Tool for Agricultural Research (STAR) Version: 2.0.1 (c) Copyright International Rice Research Institute (IRRI) 2013–2020. Analysis of Variance (ANOVA) was used to estimate the mean squares for the different sources of variation; moreover, the treatment means were separated by the Least Significant Difference (LSD) method at 5% probability level.

*2.2.2. Estimation of Variance Components.* The phenotypic, genotypic, and environmental variances were calculated according to the formula suggested in Prasad et al. [12]; they are as follows:

$$\text{Genotypic variance}\left(\sigma^2 g\right) = \frac{\text{MSG} - \text{MSE}}{r},$$
$$\text{Phenotypic variance}\left(\sigma^2 \text{ph}\right) = \sigma^2 g + \sigma^2 e, \quad (1)$$
$$\text{Environmental variance}\left(\sigma^2 \text{e}\right) = \frac{MSE}{r},$$

where: $MSG$ = Genotypic mean squares, EMS = Error mean square, $r$ = number of replications.

*2.3. Estimation of the Genetic and Phenotypic Coefficient of Variation, Broad-Sense Heritability, and Genetic Advance.* Various variance components were used to estimate the genotypic coefficient of variability (GCV), phenotypic coefficient of variability (PCV), environmental coefficient of variability (ECV), heritability in the broad sense ($h^2$), and genetic advance (GA) using the formulae proposed by [13–16] as follows:

Table 1: Description of the African yam bean landraces and location of collection.

| S/N | Naming | Seed characteristics | Location | Region |
|---|---|---|---|---|
| 1 | AYBNR01 | Grey seed coat with black eyes | Tumu | Upper west region |
| 2 | AYBNR02 | Grey seed coat with black eyes | Kuppam | Upper west region |
| 3 | AYBNR03 | Grey seed coat with brown eyes | Chinchang | Upper west region |
| 4 | AYBVR04 | Grey seed coat with black eyes | Likpe Mate | Volta region |
| 5 | AYBNR05 | Variegated seed coat | Sorbelle | Upper west region |
| 6 | AYBVR06 | Reddish brown | Likpe Mate | Volta region |
| 7 | AYBNR07 | Grey seed coat with black eyes | Chinchang | Upper west region |
| 8 | AYBNR08 | Grey seed coat with brown eyes | Chinchang | Upper west region |
| 9 | AYBVR09 | Reddish brown | Likpe Mate | Volta region |
| 10 | AYBNR10 | Grey seed coat with black eyes | Kuppam | Upper west region |
| 11 | AYBVR11 | Grey seed color with brown eyes | Likpe Mate | Volta region |
| 12 | AYBRI1 | Variegated seed coat | Kuppam | Upper west region |
| 13 | AYBHS1 | Grey seed coat with black eyes | Ho station market | Volta region |
| 14 | AYBHS2 | Reddish brown seed coat | Ho station market | Volta region |
| 15 | AYBVR12 | Variegated seed coat | Likpe Mate | Volta region |

$$\text{Genotypic coefficient of variability (GCV \%)} = 100 \times \frac{\sqrt{\sigma^2 g}}{X},$$
$$\text{Phenotypic coefficient of variability (PCV \%)} = 100 \times \frac{\sqrt{\sigma^2 ph}}{X}, \tag{2}$$
$$\text{Environmental coefficient of variability (ECV \%)} = 100 \times \frac{\sqrt{\sigma^2 e}}{X},$$

where: $\sigma^2 g$ = genotypic variation, $\sigma^2 ph$ = phenotypic variations, $\sigma^2 e$ = environmental variance, $X$ = grand mean for the character under consideration.

The estimation of heritability in a broad sense was computed as follows:

$$\text{Heritability (broad} - \text{sense)} = h^2 = \frac{\sigma^2 g}{\sigma^2 g + \sigma^2 e}, \tag{3}$$

where: $\sigma^2 g$ = the estimate of genotypic variance, $\sigma^2 e$ = the estimate of environmental variance.

The genetic advance was calculated as follows:

$$\text{Genetic Advance} = \text{heritability} \times \text{K} \times \sqrt{\sigma ph}, \tag{4}$$

where $K$ (selection differential expressed in phenotypic standard deviations at 5% probability level) = 2.06.

## 3. Results and Discussion

*3.1. Analysis of Variance.* The mean square for growth and yield traits is presented in Table 2. There were significant differences ($p < 0.05$) among the landraces for internode length, number of leaves per plant, leaf width, leaf length, and peduncle length. However, for the yield traits, significant differences ($p < 0.05$) were observed among the landraces for the number of pods per peduncle, number of pods per plant, number of seeds per plot, 100-seed weight, pod length, seed weight, and grain yield. This shows that there was a wide degree of variability among the landraces of AYB studied for the growth and yield parameters. The significant differences ($p < 0.05$) among most of the traits indicate essential genetic differences among the genotypes, which can be exploited for improving AYB in Ghana. Variations among landraces of AYB for morphological traits have been reported by Akande [17], Adewale et al. [18], Akinyosoye et al. [19], and Agbowuro [20].

*3.2. Mean Performances of the Various Genetic Resources.* The mean performance of the various genetic resources is presented in Tables 3 and 4. The days to 50% seedling emergence ranged from a mean value of 5.67 to 6.67 among the landraces. Landraces AYBHS2, AYBNR02, AYBNR05, AYBNR06, AYBNR07, AYBNR08 and AYBVR11 took 5.67 days to emerge, while the days to 50% emergence for AYBVR09 was 6.67. The highest mean internode length of 15.72 cm was measured in AYBNR07, while the least mean internode length was recorded in AYBHS2. AYBHS1 recorded the longest leaves at 11.24 cm, whereas the shortest leaves at 8.87 cm were recorded for AYBNR05. The leaf width of the landraces ranged from 3.77 cm to 4.62 cm, with AYBVR12 recording the highest mean value of 4.62 cm, while the least mean value of 3.77 cm was observed in AYBHS2. AYBRI1 produced the highest number of leaves per plant, while the lowest number of leaves per plant was noticed in AYBNR06. The longest peduncle of 14.59 cm was

Table 2: The mean square of the growth and yield and yield traits of AYB.

| Traits | Replication ($df = 2$) | Landraces ($df = 14$) | Error ($df = 28$) |
|---|---|---|---|
| Internode length | 9.2840 | 21.8950** | 8.5530 |
| Petiole length | 1.9050 | 2.8950ns | 1.9370 |
| Number of leaves | 121.8000 | 1372.9000*** | 392.6000 |
| Stem diameter | 0.0522 | 0.0347ns | 0.0559 |
| Peduncle length | 4.8060 | 26.1950*** | 2.1440 |
| Leaf length (cm) | 0.2720 | 2.8090*** | 1.0060 |
| Leaf width | 0.1779 | 0.4767*** | 0.1722 |
| Days to 50% emergence | 0.1556 | 0.4032ns | 0.6794 |
| Days to maturity | 37.2700 | 94.1500ns | 57.2900 |
| Days to 50% flowering | 2.7560 | 12.1170ns | 6.7560 |
| Pods/peduncle | 0.0963 | 1.3407** | 0.5558 |
| Pods/plant | 0.4740 | 28.0460** | 8.1600 |
| Seeds/pod | 8.0670 | 17.0000** | 4.4950 |
| 100 seed weight | 2.0910 | 25.4470** | 7.8590 |
| Pod length (cm) | 0.6000 | 22.3430** | 7.7430 |
| Pod weight (g) | 0.1259 | 0.2777ns | 0.1380 |
| Pod beak length (cm) | 0.3539 | 0.4497ns | 0.2712 |
| Pod weight/plant | 19.4600 | 31.8400ns | 17.0100 |
| Seed length (cm) | 0.0006 | 0.0155 | 0.0014 |
| Seed width (mm) | 0.0007 | 0.0072 | 0.0047 |
| Seed weight/plant | 4.4300 | 55.1400*** | 17.4700 |
| Grain yield (kg/ha) | 6816.0000 | 60814.0000*** | 18173.0000 |

Where * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$ significant level of probability, $df$ = degree of freedom.

Table 3: The mean performances of the vegetative traits of the landraces.

| Landraces | DSE 50 | IL | LL | LW | NL | PDL | PL | DM | SD |
|---|---|---|---|---|---|---|---|---|---|
| AYBNR01 | 6.33 | 14.70 | 10.01 | 4.19 | 128.9 | 9.41 | 7.49 | 168.00 | 1.16 |
| AYBNR02 | 5.67 | 15.16 | 9.93 | 4.18 | 127.1 | 10.30 | 7.10 | 151.3 | 0.96 |
| AYBNR03 | 6.33 | 14.77 | 10.68 | 4.27 | 119.7 | 14.18 | 8.94 | 161.7 | 1.00 |
| AYBVR04 | 6.33 | 13.34 | 10.57 | 4.21 | 106.6 | 14.33 | 8.12 | 162.0 | 0.95 |
| AYBNR05 | 5.67 | 12.89 | 8.87 | 4.11 | 102.8 | 14.59 | 7.77 | 162.0 | 1.02 |
| AYBVR06 | 5.67 | 11.21 | 10.14 | 4.18 | 102.4 | 11.90 | 8.24 | 167.3 | 0.94 |
| AYBNR07 | 5.67 | 15.72 | 10.4 | 4.09 | 118.9 | 12.39 | 8.77 | 167.3 | 1.01 |
| AYBNR08 | 5.67 | 14.17 | 10.46 | 4.50 | 119.6 | 9.92 | 8.73 | 162.0 | 0.96 |
| AYBVR09 | 6.67 | 14.89 | 10.31 | 4.42 | 111.8 | 9.56 | 8.56 | 169.3 | 1.03 |
| AYBNR10 | 6.33 | 11.23 | 10.48 | 4.01 | 119.00 | 13.09 | 8.84 | 163 | 0.98 |
| AYBVR11 | 5.67 | 13.78 | 10.52 | 4.61 | 130.10 | 12.12 | 8.97 | 170.7 | 1.04 |
| AYBRI1 | 6.33 | 11.42 | 9.89 | 4.41 | 144.90 | 12.41 | 8.70 | 154.3 | 1.07 |
| AYBHS1 | 5.67 | 13.61 | 11.24 | 4.31 | 137.70 | 13.47 | 8.57 | 167.7 | 0.93 |
| AYBHS2 | 6.00 | 11.11 | 10.91 | 3.77 | 131.90 | 11.90 | 8.90 | 162.7 | 1.07 |
| AYBVR12 | 6.33 | 13.82 | 10.91 | 4.62 | 124.30 | 12.81 | 8.60 | 156.7 | 1.05 |
| CV (%) | 13.7 | 21.7 | 9.7 | 9.7 | 18.5 | 12 | 16.5 | 4.6 | 23.4 |
| LSD (5%) | 13.79 | 2.73 | 0.94 | 0.39 | 16.3 | 13.67 | 42.99 | 12.66 | 22.0909 |

LL = leaf length, LW = leaf width, LA = leaf area, IL = internode length, PL = petiole length, NL = number of leaves, PDL = peduncle length, and SD = stem diameter.

found in AYBNR05, while the shortest peduncle of 9.41 cm was noticed in AYBNR01.

The days to 50% flowering ranged from 91 days (AYBNR06) to 98 days (AYBHS2, AYBVR12). The highest number of pods per peduncle, 5 was observed in AYBHS1, AYBNR07, AYBNR03, AYBVR11, AYBHS1, and AYBHS2, while the lowest number of pods per peduncle of 3 was noticed in AYBNR10. The results of the number of pods per plant indicated that AYBNR05 and AYBVR12 produced the highest value, while AYBNR03 gave the least value. The number of pods per plant ranged from 13 to 19. The results showed that AYBNR01 and AYBNR03 recorded the highest number of seeds per pod (21), whereas AYBNR05 and AYBNR06 recorded the lowest number of seeds per pod (14). The highest value of 100-seed weight was observed in AYBVR11, and the lowest value was found in AYBHS2. The 100-seed weight ranged from 20.93 g to 29.73 g.

The seed weight per plant ranged from 32.20 g to 44.60 g for AYBI1 and AYBVR11, respectively. AYBVR11 gave the highest grain yield of 1487 kg/ha, while the lowest grain yield of 1072 kg/ha was produced by AYBHS2.

Table 4: The mean performances of the yield and yield traits of the landraces.

| Landrace | DF 50% | Pods/peduncle | Pods/plant | Seeds/pod | 100 seed wt | PdL | Pod wt | PBL | PWt/P | SL | SW | SWt | kg/ha |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AYBNR01 | 93 | 4 | 15 | 21 | 29.17 | 25.33 | 1.86 | 1.03 | 22.28 | 0.75 | 0.50 | 43.75 | 1458 |
| AYBNR02 | 95 | 4 | 15 | 20 | 27.23 | 26.67 | 1.61 | 1.40 | 19.32 | 0.83 | 0.47 | 40.85 | 1362 |
| AYBNR03 | 95 | 5 | 14 | 21 | 23.87 | 30.00 | 1.52 | 2.20 | 18.28 | 0.8 | 0.50 | 35.80 | 1193 |
| AYBVR04 | 96 | 4 | 18 | 17 | 25.57 | 24.33 | 1.47 | 1.53 | 16.17 | 0.72 | 0.53 | 35.79 | 1278 |
| AYBNR05 | 94 | 4 | 19 | 14 | 26.63 | 26.67 | 1.82 | 1.97 | 19.98 | 0.73 | 0.47 | 38.27 | 1332 |
| AYBVR06 | 91 | 4 | 16 | 14 | 28.40 | 25.00 | 1.54 | 2.37 | 16.94 | 0.73 | 0.37 | 42.60 | 1420 |
| AYBNR07 | 93 | 5 | 15 | 16 | 22.10 | 28.00 | 1.44 | 1.60 | 15.88 | 0.67 | 0.40 | 33.15 | 1105 |
| AYBNR08 | 94 | 4 | 16 | 16 | 25.30 | 23.67 | 1.64 | 1.20 | 19.99 | 0.87 | 0.50 | 36.37 | 1265 |
| AYBVR09 | 96 | 4 | 18 | 20 | 28.37 | 26.00 | 1.93 | 1.23 | 21.27 | 0.63 | 0.52 | 39.71 | 1418 |
| AYBNR10 | 93 | 3 | 17 | 16 | 28.33 | 25.67 | 1.89 | 1.77 | 20.83 | 0.8 | 0.47 | 42.50 | 1417 |
| AYBVR11 | 93 | 5 | 17 | 20 | 29.73 | 29.00 | 2.24 | 1.83 | 24.64 | 0.88 | 0.53 | 44.60 | 1487 |
| AYBRI1 | 95 | 4 | 13 | 15 | 21.47 | 19.00 | 1.81 | 1.18 | 19.91 | 0.7 | 0.53 | 32.20 | 1073 |
| AYBHS1 | 96 | 5 | 16 | 18 | 27.87 | 25.67 | 1.83 | 1.33 | 20.09 | 0.72 | 0.43 | 41.80 | 1393 |
| AYBHS2 | 98 | 5 | 15 | 20 | 20.93 | 22.67 | 2.54 | 1.50 | 27.98 | 0.81 | 0.47 | 32.43 | 1072 |
| AYBVR12 | 98 | 4 | 19 | 18 | 28.60 | 28.33 | 1.51 | 1.73 | 16.61 | 0.8 | 0.50 | 42.90 | 1430 |
| CV (%) | 2.7 | 17.3 | 17.7 | 12 | 10.7 | 10.8 | 20.9 | 32.7 | 20.6 | 15.3 | 14.2 | 10.8 | 10.3 |
| LSD (5%) | 4.35 | 6.96 | 26.67 | 35.46 | 46.89 | 46.54 | 62.14 | 8.71 | 68.97 | 19.57 | 11.41 | 6.99 | 22.55 |

DF = days to flowering, Wt = weight, SL = seed length, SW = seed width, SWt = seed weight, PdL = length, and PBL = pod beak length.

*3.3. Estimation of Variability.* Genotypic variances, phenotypic variances, environmental variance, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability, genetic advance (GA), and genetic advance as percent of the mean (GAM%) for growth and yield parameters are presented in Tables 5 and 6 respectively. The GV, PV, and EV ranged from 0.01 to 326.79, 0.02 to 457.64, and 0.01 to 130.85, respectively, for the growth parameters, whereas the GV, PV, and EV for the yield parameters ranged from 0.001 to 14213.67, 0.01 to 20271.33, and 0.001 to 6057.67, respectively. The PV values were higher than the GV values for all the traits studied. However, the higher phenotypic variance than the genotypic variance indicates the influence of the environment on the expression of the traits and the higher chance to improve the traits through the process of selection.

The GCV and PCV values ranged from 2.15% to 23.28% and 9.35% to 20.08%, respectively, for the growth parameters. The genotypic coefficient of variation (GCV) ranged from 1.4% for days to 50% flowering to 15.93% for the number of pods per plant, while the phenotypic coefficient of variation (PCV) also ranged from 2.12% for days to 50% flowering to 24.32% for pod beak length for the yield traits. According to Sivasubramanian and Menon [21], genotypic and phenotypic coefficients of variation of less than 10% are considered to be low, 10–20% are considered to be moderate, and greater than 20% is considered to be high. The PCV values were higher than those of the GCV for all the parameters, which shows a wide range. Nonetheless, a wide range of PCV and GCV values were reported in common bean (*Phaseolus vulgaris*) [22–25]. Peduncle length recorded the highest GCV and PCV of 23.28 and 24.30, respectively. The lowest GCV and PCV of <10% were recorded for leaf width, days to 50% emergence, and days to maturity. The environmental coefficient of variation (ECV) ranged from 2.68 for days to maturity to 12.55 for the internode length. Ejara et al. [26] also recorded low GCV estimates for the days to maturity and the days to flowering in common bean (*Phaseolus vulgaris*). The findings are also in agreement with the works of Pandey et al. [27] and Akter et al. [28]. Similar findings have been reported by Marame et al. [29] and Ogunbayo et al. [30] in hot pepper (*Capsicum annuum* L.) and rice (*Oryza sativa*), respectively.

Broad-sense heritability estimates help plant breeders select genotypes based on their phenotypic performance. According to Singh [31], a broad sense heritability estimate is considered high when the value is greater than 80%, moderate when it ranges from 60–79%, medium when it ranges from 40–59% and low when it is less than 40%. The heritability estimates in this study ranged from 34.54% for petiole length to 91.81% for peduncle length. However, the heritability estimates for the yield parameters ranged from 11.85% to 73.56% for the number of seeds per pod and seed length (cm), respectively. Low heritability values (<40%) were observed for pod beak length, seed length (cm), and seed width (cm). Pod weight, number of pods per peduncle, and pod weight per plant recorded medium heritability estimates (40–59%), while number of pods per plant, number of seeds per pod, 100-seed weight, pod length, seed weight per plant, and grain yield had moderately high heritability estimates (60–79%). The genetic advance expressed in percent mean was highest for number of leaves per plant and peduncle length, whereas petiole length, stem diameter, days to 50% emergence, and days to maturity showed low GAM values for the growth traits. Deshmukh et al. [32] classified genetic advance as a percent of the mean as low (<10%), moderate (10–20%), and high (>20%). The genetic advance by percent means ranged from 1.94% to 27.64% for days to 50% flowering and number of pods per plant, respectively. High GAM (>20%) was observed for the number of pods per plant and the number of seeds per pod. Number of pods per peduncle, 100-seed weight, pod length, pod weight, pod beak length, pod weight per plant, seed weight per plant and the grain yield recorded moderate

Table 5: Mean and genetic estimates of some vegetative traits of the African yam bean.

| Traits | Mean | GV | PV | EV | GCV (%) | PCV (%) | ECV (%) | $h^2$ (%) | GA (%) | GAM |
|---|---|---|---|---|---|---|---|---|---|---|
| IL | 13.45 | 4.45 | 7.30 | 2.85 | 15.68 | 20.08 | 12.55 | 60.94 | 3.39 | 25.21 |
| PL | 8.42 | 0.33 | 0.97 | 0.63 | 6.86 | 11.67 | 9.43 | 34.54 | 0.70 | 8.30 |
| NL | 121.70 | 326.79 | 457.64 | 130.85 | 14.85 | 17.58 | 9.40 | 71.41 | 31.47 | 25.86 |
| SD | 1.01 | 0.01 | 0.02 | 0.01 | 9.90 | 14.00 | 9.90 | 50.00 | 0.15 | 14.42 |
| PDL | 12.16 | 8.02 | 8.73 | 0.71 | 23.28 | 24.30 | 6.93 | 91.81 | 5.59 | 45.96 |
| LL | 10.35 | 0.60 | 0.94 | 0.34 | 7.49 | 9.35 | 5.63 | 64.18 | 1.28 | 12.36 |
| LW | 4.26 | 0.10 | 0.16 | 0.06 | 7.48 | 9.36 | 5.75 | 63.88 | 0.52 | 12.31 |
| DSE50 | 6.02 | 0.09 | 0.23 | 0.13 | 5.07 | 7.91 | 5.99 | 41.18 | 0.40 | 6.71 |
| DM | 163.07 | 12.29 | 31.38 | 19.10 | 2.15 | 3.44 | 2.68 | 39.15 | 4.52 | 2.77 |

LW = leaf width, IL = internode length, NL = number of leaves, PL = petiole length, LL = leaf length, PDL = peduncle length, SD = stem diameter, GV = genotypic variation, PV = phenotypic variation, PCV = phenotypic coefficient of variation, GCV = genotypic coefficient of variation, GA = genetic advance, GAM (%) = genetic advance as percent of mean, and $H^2$ = broad sense heritability.

Table 6: Mean and genetic estimates of some reproductive, grain yield, and yield components of the African yam bean.

| Traits | Mean | GV | PV | EV | GCV (%) | PCV (%) | ECV (%) | $h^2$ (%) | GA (%) | GAM |
|---|---|---|---|---|---|---|---|---|---|---|
| DF 50% | 94.64 | 1.79 | 4.04 | 2.25 | 1.41 | 2.12 | 1.59 | 44.24 | 1.83 | 1.94 |
| Pods/peduncle | 4.31 | 0.26 | 0.45 | 0.19 | 11.88 | 15.53 | 10.00 | 58.54 | 0.81 | 18.73 |
| Pods/plant | 16.16 | 6.63 | 9.35 | 2.72 | 15.93 | 18.92 | 10.21 | 70.91 | 4.47 | 27.64 |
| Seeds/pod | 17.67 | 4.17 | 5.67 | 1.50 | 11.55 | 13.47 | 6.93 | 73.56 | 3.61 | 20.41 |
| 100 seed weight | 26.24 | 5.86 | 8.48 | 2.62 | 9.27 | 11.10 | 6.17 | 69.12 | 4.15 | 15.80 |
| Pod length (cm) | 25.73 | 4.87 | 7.45 | 2.58 | 8.57 | 10.61 | 6.24 | 65.35 | 3.67 | 14.28 |
| Pod weight (g) | 1.78 | 0.05 | 0.09 | 0.05 | 12.14 | 17.12 | 12.07 | 50.31 | 0.32 | 17.74 |
| Pod beak length (cm) | 1.59 | 0.06 | 0.15 | 0.09 | 15.32 | 24.32 | 18.89 | 39.69 | 0.32 | 19.89 |
| Pod weight/plant | 20.01 | 4.94 | 10.61 | 5.67 | 11.11 | 16.28 | 11.90 | 46.58 | 3.13 | 15.62 |
| Seed length (cm) | 0.76 | 0.01 | 0.01 | 0.01 | 3.25 | 9.43 | 8.85 | 11.85 | 0.018 | 2.30 |
| Seed width (mm) | 0.48 | 0.01 | 0.01 | 0.01 | 6.08 | 10.23 | 8.22 | 35.39 | 0.04 | 7.45 |
| Seed weight/plant | 38.50 | 12.56 | 18.38 | 5.82 | 9.20 | 11.14 | 6.27 | 68.32 | 6.03 | 15.67 |
| Grain yield (kg/ha) | 1314 | 14213.67 | 20271.33 | 6057.67 | 9.07 | 10.84 | 5.92 | 70.12 | 205.65 | 15.65 |

GCV = genotypic coefficient of variation, GV = genotypic variation, PV = phenotypic variation; PCV = phenotypic coefficient of variation; GAM = genetic advance as percent of mean.

GAM (10–20%). Low GAM (<10%) was recorded in days to 50% flowering, seed length, and seed width (Tables 5 and 6). A high heritability coupled with a high GAM was recorded for peduncle length. Internode length and the mean number of leaves recorded moderately high heritability and a high GAM. This indicates that these traits were simply inherited in nature and possessed additive gene effects. These traits can be considered favorable for the African yam bean improvement programme through effective phenotypic selection of these traits and the high expected genetic gain from selection of the important traits. Low heritability and low GAM were estimated in the number of days to maturity and the petiole length, respectively. Seed length recorded low heritability and GAM, while the number of pods per plant and the number of seeds per pod recorded moderately high heritability and high GAM. The low heritability together with low GA indicates that expression of these traits is under the involvement of nonadditive gene action and there would not be an effective phenotypic selection of these traits. Traits that recorded high heritability estimate together with high GA and GCV can be good predictors for seed yield in crops [33].

*3.4. Association Among Traits.* Tables 7 and 8 present the associations among the vegetative and yield parameters. According to Ghimire and Mandal [34], correlation is a significant tool for selection of dependent traits in plant breeding to improve on targeted parameters. There was positive and significant ($p < 0.05$) correlation between petiole length and leaf length ($r = 0.573$), number of seeds per pod and number of leaves per plant ($r = 0.520$), pod beak length and peduncle length ($r = 0.560$), pod weight per plant and pod weight ($r = 0.971$), seed weight per plant and 100-seed weight ($r = 0.967$), grain yield and 100-seed weight ($r = 0.999$), pods per plant ($r = 0.578$) and seed weight per plant ($r = 0.970$), 100-seed weight and number of pods per plant ($r = 0.576$). The positive and significant association observed between the traits indicates they can be improved concurrently, whereas traits with negative associations can be improved separately. It is evident that an increase in one of the positively correlated traits would result in a corresponding increase in the associated traits, and a negative correlation indicates that an increase in the correlated trait would result in a decrease in the other trait.

Table 7: Association of morphological traits of African yam bean landraces.

| | DF | DM | DSE 50 | IL | LL | LW | NL | PDL | PL | PPPDL |
|---|---|---|---|---|---|---|---|---|---|---|
| DM | −0.235 | | | | | | | | | |
| DSE 50 | 0.238 | −0.079 | | | | | | | | |
| IL | −0.007 | 0.106 | −0.037 | | | | | | | |
| LL | 0.413 | 0.201 | 0.142 | 0.036 | | | | | | |
| LW | −0.089 | −0.001 | 0.091 | 0.344 | 0.127 | | | | | |
| NL | 0.433 | −0.234 | 0.033 | −0.036 | 0.364 | 0.161 | | | | |
| Peduncle length (cm) | 0.145 | −0.103 | −0.06 | −0.304 | 0.044 | −0.157 | −0.186 | | | |
| Petiole length (cm) | 0.145 | 0.305 | 0.142 | −0.247 | 0.573$^{**}$ | 0.169 | 0.205 | 0.26 | | |
| Pods/peduncle | 0.026 | 0.081 | −0.445 | 0.247 | −0.029 | 0.386 | 0.396 | 0.09 | 0.113 | |
| Pods/plant | 0.253 | 0.178 | 0.101 | −0.472 | −0.286 | −0.395 | −0.297 | 0.04 | 0.051 | −0.348 |
| Stem diameter | 0.040 | 0.071 | 0.413 | 0.018 | −0.19 | 0.037 | 0.383 | −0.289 | −0.03 | 0.257 |
| Seeds/pod | 0.372 | 0.139 | 0.256 | 0.402 | 0.276 | 0.05 | 0.520$^{*}$ | −0.345 | −0.086 | 0.145 |
| 100 seed weight | −0.257 | 0.128 | 0.145 | −0.388 | −0.427 | −0.202 | −0.054 | −0.411 | −0.191 | −0.232 |
| Pod length (cm) | −0.077 | 0.211 | −0.128 | 0.073 | −0.233 | −0.408 | −0.015 | 0.04 | 0.13 | 0.161 |
| Pod weight (g) | 0.178 | 0.344 | −0.076 | −0.009 | 0.197 | 0.416 | 0.431 | 0.013 | 0.122 | 0.185 |
| Pod beak length (cm) | −0.315 | 0.200 | −0.327 | −0.381 | −0.11 | −0.346 | −0.428 | 0.560$^{*}$ | 0.217 | 0.041 |
| Pod weight/plant | 0.148 | 0.300 | −0.091 | 0.11 | 0.179 | 0.449 | 0.469 | −0.108 | 0.031 | 0.224 |
| Seed length (cm) | 0.002 | −0.072 | −0.486 | −0.09 | 0.196 | 0.052 | 0.333 | −0.045 | 0.07 | 0.228 |
| Seed width (cm) | 0.470 | −0.004 | 0.425 | 0.264 | 0.299 | 0.357 | 0.118 | −0.044 | 0.085 | −0.045 |
| Seed weight/plant (cm) | −0.287 | 0.111 | 0.063 | −0.436 | −0.351 | −0.236 | 0.105 | −0.393 | −0.162 | −0.147 |
| Grain yield (kg/ha) | −0.245 | 0.142 | 0.134 | −0.396 | −0.417 | −0.204 | −0.039 | −0.41 | −0.192 | −0.229 |

Where $^{*} = p < 0.05$, $^{**} = p < 0.01$, $^{***} = p < 0.001$ significant level of probability, LL = leaf length, LW = leaf width, LW = leaf width, IL = internode length, PL = petiole length, NL = number of leaf, PDL = peduncle length, PPPDL = pods per peduncle, DF = days to 50% flowering, DM = days to maturity, and DSE 50 = days to 50% emergence.

Table 8: Association of morphological traits of African yam bean landraces.

| | Pods/plant | SD | SPP | 100 SW | Pod length | PW | PBL | PWPP | SL | SWd | SW/P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stem diameter (cm) | 0.068 | | | | | | | | | | |
| Seeds/pod | −0.151 | 0.279 | | | | | | | | | |
| 100 seed weight (g) | 0.576$^{*}$ | 0.362 | 0.195 | | | | | | | | |
| Pod length | 0.272 | 0.145 | 0.398 | 0.433 | | | | | | | |
| Pod weight (g) | −0.088 | 0.042 | 0.305 | −0.055 | −0.242 | | | | | | |
| Pod beak length (cm) | 0.122 | −0.368 | −0.24 | 0.11 | 0.504 | −0.197 | | | | | |
| Pod weight/Plant | −0.18 | 0.062 | 0.417 | −0.046 | −0.223 | 0.971$^{***}$ | −0.27 | | | | |
| Seed length (cm) | −0.056 | −0.199 | 0.288 | 0.169 | 0.218 | 0.243 | 0.164 | 0.357 | | | |
| Seed width (cm) | 0.179 | 0.278 | 0.375 | 0.025 | −0.128 | 0.219 | −0.411 | 0.267 | 0.218 | | |
| Seed weight/plant | 0.433 | 0.394 | 0.247 | 0.967$^{***}$ | 0.450 | 0.014 | 0.158 | 0.028 | 0.269 | −0.068 | |
| Grain yield (kg $ha^{-1}$) | 0.578$^{*}$ | 0.353 | 0.209 | 0.999$^{***}$ | 0.429 | −0.024 | 0.11 | −0.015 | 0.182 | 0.022 | 0.970$^{***}$ |

Where; SD = stem diameter, SPP = seeds per pod, 100 SW = 100 seed weight, PW = pod weight, PBL = Pod beak length, SL = seed length, SWd = seed width, and SW/P = seed weight per plant.

## 4. Conclusion

From the results obtained, there were significant differences ($p < 0.05$) among the landraces, except for the number of days to 50% emergence, petiole length, days to maturity, stem diameter, days to 50% flowering, pod weight, pod beak length, pod weight per plant, seed length, and seed width. The variations among the landraces suggest a higher chance of identifying genotypes which can be improved and incorporated in breeding programmes for AYB. The phenotypic variance values were greater than the genotypic variance values for all the traits studied.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Authors' Contributions

All authors agreed to the submission of the manuscript for publication.

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