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Research Article

Characterization of African Yam Bean (*Sphenostylis stenocarpa*) Mutant Lines using Phenotypic Markers

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Abstract: Phenotypic characterization has been recognized as very important for the identification and selection of promising lines in improvement programs. This study aimed at characterizing and selecting early-maturing and high-yielding African yam bean (AYB) mutant lines at M_2 generation. The experiment was carried out at the experimental field of the Institute of Agricultural Research and Training, Nigeria. The experimental design used was a randomized complete block design with three replications. Nineteen promising AYB M_2 mutant lines were selected with their four parents (making 23 lines) and further evaluated for agronomic characters in the field. The results obtained revealed that coefficients of variation ranged from 3.23% (maturity) to 141.81% (seed yield/plant). The M_2 mutant lines flowered and matured earlier than their parents and outyielded their parents by 62.64%. The principal component (PC) showed that the first four PCs accounted for 75.54% of the total variation. The first PC accounted for first flowering, 50% flowering, first podding, and 50% podding. The second PC was responsible for pod yield/plant and seed yield/plant, whereas peduncle length and pod length were associated with the third PC, while the fourth PC was responsible for maturity. The breeding lines were delineated into three heterotic groups with cluster I had three lines; members had the highest pod yield/plant (60.22 g), seed yield/plant (27.33 g), and early-maturing. Cluster II consisted of 17 lines with moderate pod yield/plant, seed yield/plant, and longest pod length. Cluster III contained three mutant lines; exhibited the lowest pod yield/plant, seed yield/plant, and longest peduncle. A highly significant association existed between seed yield/plant and pod yield/plant (r = 0.97**), but negatively correlated with first flowering (r=-0.23*) and 50% first flowering (r=-0.24*). Therefore, AYB lines identified could be utilized by plant breeders/geneticists to develop AYB varieties that are early-maturing and high-yielding in improvement programs.

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1. Introduction

African yam bean (*Sphenostylis stenocarpa*) is an underutilized legume cultivated in Nigeria, Zaire, the Central African Republic, Ethiopia, and Gabon. Except for Africa, no other continent has a record of the crop's origin (Adewale et al., 2008). Although not all African yam bean (AYB) produce tubers, it is considered a dual crop because it has both tubers and seeds (Akinyosoye et al., 2017).

The grain and tuber of the AYB contain around 29 and 19% crude protein, respectively (Oboh et al., 1998). The tubers are richer in protein than Irish potatoes and 10 times that of cassava tubers, and the seeds are palatable like ordinary beans and cowpea (*Vigna unguiculata*) (Onyeike and Omubo-Dede, 2002). Apart from its high nutrient content, the bean has been claimed to be a source of phytochemicals and bioactive substances that provide health advantages to consumers, including the prevention of lifestyle illnesses (Duodu and Apea-Bah, 2017; Soetan et al., 2018). Despite its agronomic and economic benefits, AYB's use, conservation, and management have not been fully exploited (Ojuederie et al., 2015). In Nigeria, there is currently no known released AYB; it is only domiciled with elderly farmers (Adewale et al., 2012).

One of the major constraints affecting the utilization and adoption of AYB is late maturity, low seed yield, and extra agronomic practices like staking (Popoola *et al.*, 2019). The majority of known accessions of AYB are late maturing, with physiological maturity occurring between 6 and 7 months following sowing, depending on genotypes (Akinyosoye et al., 2017). Mutation breeding is a fast, cost-effective, reliable, and proven strategy for creating and selecting novel agronomic characters (FAO/IAEA, 2017), which aids in the identification and release of novel genes that govern the traits of interest (FAO/IAEA, 2017). Mutation has resulted in the development of 3220 mutant cultivars in more than 220 crops, which have been distributed to farmers globally (Bado et al., 2015). Mutants are sources of variation that can be used to introduce new populations with unique and beneficial alleles.

The phenotypic characterization of breeding lines is critical for researchers, breeders, farmers, and local communities to optimize the use of genetic resources (Zannou et al., 2008). Phenotypic characterization also serves as a foundation for the selection of traits and the conservation of genetic resources. Thus, this method is cheap, reliable, and very easy to identify contributing or discriminating characters among breeding lines (Olomitutu *et al.*, 2022). To validate the extent of genetic variability in germplasm, some scientists have used many statistical techniques, among which are principal components (PCA) and cluster analyses. PCA and cluster analyses are statistical methods for the characterization of germplasm based on their origins, genetic constitutions, and contributions of traits to the total variations (Ogunbodede, 1997; Akinyosoye *et al.*, 2017; Okunlola *et al.,* 2020). PCA and cluster analyses have been used to determine the extent of phenotypic variability in germplasm collections, namely maize, mungbean, pea, soybean, alfalfa, and AYB, among others (Matus *et al.,* 1999; Akinyosoye *et al.*, 2017; Okunlola *et al.,* 2020). Also, understanding the relationships among important traits is very useful in indirect selection (Kumar *et al.*, 2015; Sesay *et al.*, 2017). Information on AYB mutation breeding and mutant cultivars in Nigeria is scarce. Phenotypic characterization to assess phenotypic variation is vital for early field-based evaluation and selection. As a result, it is becoming increasingly imperative to develop AYB varieties that are early maturing and high yielding that can adapt to Nigeria's different agro-environments. Therefore, this research work aimed at characterizing and selecting early maturing and high yielding AYB mutant lines in the M_2 generation of AYB cultivars.

2. Materials and Methods

2.1. Genetic materials

The four parents of the mutant lines were obtained from International Institute for Tropical Agriculture, Ibadan, Nigeria, and induced with different concentrations of chemical mutagen (sodium azide) in the previous study (Akinyosoye *et al.*, 2021). Nineteen promising AYB M_2 mutant lines were selected from the M_1 generation, which was previously evaluated in the field for agronomic characters.

2.2. Experimental site

The experiment was carried out during the cropping season between April and October 2021 at the experimental field in Ibadan of the Institute of Agricultural Research and Training, Nigeria. According to the Food and Agriculture Organization classification system, the dominant soil type in Ibadan is Ferric lixisols (Sonneveld 2006). Ibadan is located 200 m above sea level at latitude and longitude of 7°22'N and 3°55'E, respectively, in Nigeria's lowland forest-savanna transition ecology. Rainfall received for the year ranged from 91.44 to 152.40 mm, falling majorly between April and

October with a peak in September. Also, the experimental location received an average rainfall of 107.10 mm and a temperature of 26.23°C per annum (Table 1).

Table 1. Rainfall and temperature distribution in Ibadan in 2021

Month	Rainfall (mm)	Temperature (°C)
Januarry	7.62	26.32
February	20.32	27.44
March	45.72	28.00
April	91.44	27.44
May	137.16	26.88
June	193.04	25.76
July	187.96	24.64
August	180.34	24.64
September	231.14	25.20
October	152.40	25.76
November	30.48	26.32
December	7.62	26.32
Mean	**107.10**	**26.23**

2.3. Experimental design and crop management

The selected AYB mutant lines, along with their four parents (making 23 lines), were assessed for agronomic characters. The experiment was designed with a randomized complete block design and three replications. Two seeds were sown per hole at 1 m intra-row and 1 m inter-row in a 25 m^2 plot size, resulting in 50 plants per plot. Pest infestations were controlled, particularly during the reproductive stage, with cypermethrin (200 g/l pyrethroids) diluted with a tablespoon of fungicide powder benlate [50% methyl 1-(butylcarbamoyl-2-benzimidazole carbamate)]. Other cultural practices such as plowing and harrowing of land before planting, weed management, and staking were carried out.

2.4. Agronomic data collection

Each plot had ten representative plants sampled, and the average of the values was recorded in a plot. The following data were collected: days to first flowering (number of days from sowing to first flower opening in a plot), days to 50% flowering (number of days from sowing to 50% flower opening in a plot), first podding and 50% podding (number of days from sowing to first pod and 50% pod formation, respectively in a plot), days to 70% physiological maturity (number of days from sowing to when 70% of the plants have reached physiological maturity in a plot), number of seeds per pod (measured as mean of seeds of randomly selected 10 dry pods in a plot), pod length (measured in centimetres as mean of the length of randomly selected 10 dry pods in a plot), pods per peduncle (measured as mean of pods of randomly selected 10 peduncle before harvesting in a plot), peduncle length (measured as mean of peduncle of randomly selected 10 peduncle before harvesting in a plot), pod and seed yield per plant (measured in gramme by dividing total pods and seeds weight in a plot by number of plants at harvest, respectively in a plot).

2.2. Statistical analyses

The obtained data were analysed using analysis of variance (ANOVA). The Duncan Multiple Range Test (DMRT) was used to separate the treatments at 5% and 1% significance levels. Components with Eigenvalues greater than 1.0 were chosen using principal component analysis (PC). Characters with values greater than 0.6 were selected as important for PC (Matus et al.,1999). AYB lines were classified into various clusters based on hierarchical clustering and squared Euclidean distance using Palaeontological Statistics (PAST, version 2.17) software. The data were also subjected to K-means clustering analysis. The Pearson's correlation coefficient between agronomic characters was calculated using the Statistical Tool for Agricultural Research (Version: 2.0.1).

3. Results

3.1. Phenotypic variation and agronomic performance in agronomic characters of AYB lines

The coefficients of variation (CV) revealed significant variability among the AYB lines, where the CV ranged from 3.23% for days to 70% physiological maturity to 141.81% for seed yield per plant and pod length, as well as seed and pod yields per plant, were significant at 5% level of significance (Table 2).

Table 2. Range and coefficient of variation for some agronomic characters of African yam bean lines evaluated

Variable	Min.	Max.	Mean	F-test	SE(0.05)	CV%
First flowering	90.00	104.00	95.68	Ns	0.41	3.55
50% flowering	93.00	108.00	100.88	Ns	0.43	3.57
First podding	95.00	109.00	103.33	Ns	0.43	3.45
50% podding	100.00	116.00	108.32	Ns	0.43	3.29
70% physiological maturity	147.00	164.00	152.68	Ns	0.59	3.23
Pods/peduncle	2.00	4.30	2.47	Ns	0.06	21.13
Peduncle length (cm)	24.00	36.30	31.86	Ns	0.28	7.35
Pod length (cm)	15.00	30.50	22.40	*	0.39	14.39
Pod yield/plant (g)	1.50	155.00	22.46	*	2.88	90.96
Seed yield/plant (g)	0.25	96.00	8.78	*	1.57	141.81

*, ** Significant at ($p < 0.05$) and ($p < 0.01$), respectively level of significance; ns: non-significant; SE(0.05): Standard error; %CV: Coefficient of variation in percentage; Min.: Minimum; Max.: Maximum.

Table 3. Mean performance for agronomic characters of African yam bean lines

SN	LINES	Seed yield/plant (g)	First flowering (g)	50% flowering (g)	First podding	50% podding	70% physiological maturity	Pods/ peduncle	Peduncle length (cm)	Pod length (cm)	Pod yield/plant (g)
	Mutant lines										
1	IART-1	33.50a	92.33a	98.00a	99.00a	104.67a	149.33a	2.43a	29.60a	20.57a-d	59.17ab
2	IART-2	24.83ab	93.00a	101.33a	107.67a	112.33a	154.67a	2.20a	32.17a	23.30a-d	64.67a
3	IART-3	23.67ab	95.67a	99.67a	103.67a	109.00a	154.00a	2.23a	29.00a	22.97a-d	56.83ab
4	IART-4	11.78abc	94.67a	102.33a	101.67a	107.00a	153.33	2.43a	30.67a	25.80a	29.78a-d
5	IART-5	11.67abc	94.67a	98.67a	101.33a	107.00a	148.33a	3.20a	33.53a	23.60a-d	38.00a-d
6	IART-6	10.83abc	95.33a	100.33a	102.33a	107.33a	147.00a	2.27a	30.23a	20.87a-d	28.17a-d
7	IART-7	7.83abc	95.67a	102.00a	103.00a	107.67a	151.67a	2.33a	31.10a	21.03a-d	18.06cd
8	IART-8	7.67abc	94.33a	99.00a	104.00a	109.33a	154.00a	2.35a	31.45a	23.50a-d	19.67cd
9	IART-9	7.22abc	94.67a	99.33a	101.67a	106.67a	152.67a	2.35a	31.17a	23.43a-d	18.22cd
10	IART-10	6.67abc	97.33a	102.67a	104.67a	109.33a	156.00a	2.10a	30.33a	19.60cd	20.50bcd
11	IART-11	6.67abc	97.67a	101.67a	105.00a	112.00a	154.33a	2.27a	34.27a	22.87a-d	23.33bcd
12	IART-12	6.44abc	94.00a	99.33a	103.33a	107.67a	153.33a	2.53a	32.17a	24.03ab	14.66d
13	IART-13	5.56abc	95.00a	99.67a	101.33a	106.67a	151.67a	2.53a	33.03a	19.67cd	11.78d
14	IART-14	5.22abc	97.00a	101.33a	103.33a	107.00a	152.67a	2.17a	32.60a	20.10a-d	16.11d
15	IART-15	5.11abc	94.00a	102.33a	100.67a	106.33a	159.67a	2.87a	32.53a	20.50a-d	14.17d
16	IART-16	3.67bc	94.00a	98.67a	99.67a	105.00a	150.33a	2.20a	32.33a	23.33a-d	9.17d
17	IART-17	3.33bc	97.00a	101.67a	104.33a	109.33a	150.33a	3.13a	32.13a	18.47d	10.33d
18	IART-18	3.25bc	95.67a	100.00a	101.33a	106.33a	154.00a	2.77a	32.10a	22.90a-d	9.00d
19	IART-19	1.67c	96.67a	101.33a	105.67a	109.67a	151.67a	2.33a	30.67a	23.00a-d	7.00d
	Parents										
20	AYB 94	3.33bc	100.0a	104.00a	107.33a	110.67a	159.33a	2.10a	33.83a	25.53a	7.50d
21	AYB 61	6.67abc	99.00a	104.00a	108.00a	112.00a	153.67a	3.30a	35.50a	26.00a	24.67bcd
22	TSS 79	3.33bc	96.67a	102.33a	104.33a	109.00a	152.33a	2.33a	31.83a	18.17d	8.67d
23	NGB01349	2.00c	96.33a	100.67a	103.33a	109.33a	147.33a	2.43a	30.60a	25.93a	7.17d
	Mean of parents	3.83	98	102.75	105.75	110.25	153.17	2.54	32.94	23.91	12
	Mean of mutants	9.33	90.43	95.47	97.68	102.52	144.95	2.33	30.05	20.98	23.43
	Overall mean	8.78	95.68	100.88	103.33	108.32	152.68	2.47	31.86	22.4	22.46
	SE(0.05)	1.57	0.41	0.43	0.43	0.43	0.59	0.06	0.28	0.39	2.88
	%CV	141.81	3.55	3.57	3.45	3.29	3.23	21.13	7.35	14.39	90.96

Means with the same letter(s) in the same column or row are not significantly different from each other at p=0.05

Agronomic performance of AYB M_2 mutant lines showed that the mutant lines, along with their parents, reached first flowering, 50% flowering, first podding, 50% podding, and 70% physiological maturity in 90 days after planting (DAP), 93 DAP, 95 DAP, 100 DAP, and 147 DAP, respectively (Table 2). On the other hand, M_2 mutant lines reached first flowering, 50% flowering, first podding, and 70% physiological maturity earlier than their parents and outyielded their parents by 62.64% (Table 3). Significant phenotypic differences were also recorded among the mutant lines, where line IART-1 had the highest seed yield of 33.50 g/plant and reached first flowering, 50% flowering, first podding, and 50% podding earlier than the rest, while parent AYB 94 attained late first flowering, 50% flowering and 70% physiological maturity than the rest (Table 3).

3.2. Principal component analysis for agronomic characters of African yam bean lines

The principal component (PC) of yield and other agronomic characters in AYB lines showed that the first four PCs accounted for 75.54% of the total variation. The selected four PCs had Eigenvalues >1.0 with corresponding contributions of 34.32%, 19.15%, 11.27% and 10.79%, respectively to the total variations (Table 4). The first PC was associated with first flowering, 50% flowering, first podding, and 50% podding. The second PC was responsible for pod and seed yields, whereas peduncle and pod lengths were associated with the third PC, while the fourth PC was responsible for 70% physiological maturity (Table 5).

Table 4. Eigenvalues and variation associated with each component of agronomic characters in African yam bean lines

	PC 1	PC 2	PC 3	PC 4
Eigenvalues	3.43	1.92	1.13	1.08
Percentage of Variance	34.32	19.15	11.27	10.79
Cumulative %	34.32	53.47	64.75	75.54

PC: Principal component.

Table 5. Contributions of some agronomic characters in African yam bean lines based on principal component

Traits	PC 1	PC 2	PC 3	PC 4
First flowering	0.89*	0.14	-0.04	-0.10
50% flowering	0.88*	0.12	-0.04	-0.07
First podding	0.88*	0.25	0.06	0.11
50% podding	0.87*	0.26	0.09	0.05
70% physiological maturity	0.16	-0.17	-0.12	0.68*
Pods/peduncle	-0.07	-0.01	0.49	-0.56
Peduncle length (cm)	-0.08	-0.33	0.51	0.49
Pod length (cm)	0.08	0.06	0.77*	0.10
Pod yield/plant (g)	-0.35	0.91*	0.07	0.14
Seed yield/plant (g)	-0.41	0.89*	0.02	0.13

*Component contributors; PC: Principal component.

3.3. Clustering of African yam bean lines

The goodness of fit of the dendrogram based on cophenetic correlation (rcop) was 0.94. African. AYB M_2 mutant lines and their parents were delineated into three heterotic groups at a rescaled distance of 15 units (Figure 1); cluster I consisted of three lines (IART-1, IART-2, IART-3). The members of this group had the highest pod and seed yields/plant as well as reached first flowering, 50% flowering, and 70% physiological maturity earlier than the rest. Cluster II had 17 lines (including their four parents). The members of this cluster possessed moderate pod and seed yields/plant and the longest pod length. Cluster III was made up of three mutant lines (IART-4, IART-5, IART-6). The members of this cluster had the lowest pod and seed yields/plant and longest peduncle (Figure 1, Table 6, Table 7). According to inter-cluster distance, AYB lines in clusters 1 and 2 had the lowest inter-cluster distance of 16.95 units, whereas clusters 1 and 3 had the highest inter-cluster distance of 52.54 units (Table 8).

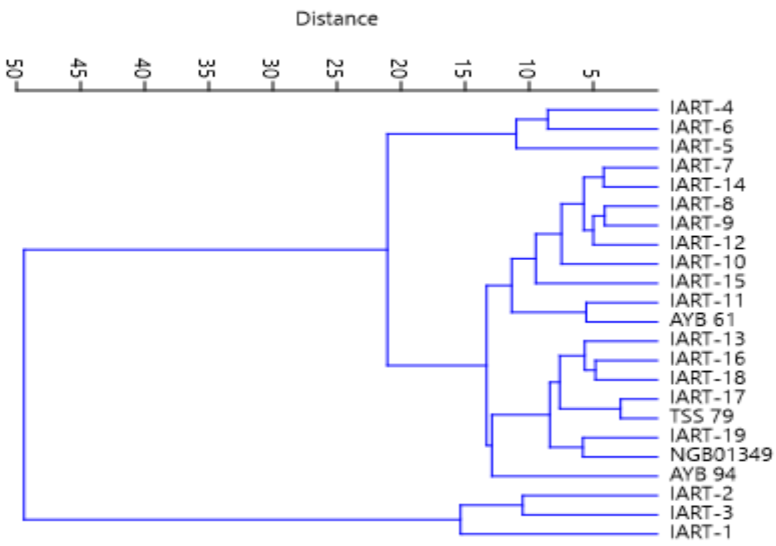

Figure 1. Dendrogram of the 23 African yam bean lines with three heterotic groups at the rescaled distance of 15 units.

Table 6. Means characteristics of African yam bean lines evaluated

Cluster	I	II	III
Member	3	17	3
Days to first flowering	93.67	94.89	96.18
Days to 50% flowering	99.67	100.44	101.18
Days to first podding	103.45	101.78	103.59
Days to 50% podding	108.67	107.11	108.47
Days to 70% physiological maturity	150.67	151.55	153.24
Number of pods per peduncle	2.29	2.63	2.48
Peduncle length (cm)	30.26	31.48	32.21
Pod length (cm)	22.28	23.42	22.24
Pod yield per plant (g)	60.22	31.98	14.12
Seed yield per plant (g)	27.33	11.43	5.04

Table 7. List of the members of each cluster

Cluster	1	2	3
Member	IART-1, IART-2, IART-3	NGB-01349, AYB-94, TSS-79, AYB-61, IART-7, IART-14, IART-8, IART-9, IART-12, IART-10, IART-15, IART-11, IART-13, IART-16, IART-18, IART-17, IART-19	IART-4, IART-5, IART-6

Table 8. Inter-cluster distance, according to K-mean clustering analysis

Cluster	1	2	3
1	-	16.95	52.54
2		-	36.32
3			-

3.4. Pearson correlation between agronomic characters of AYB lines

The association between agronomic characters revealed that seed and pod yields (r= 0.97**) had a significant and positive relationship but negatively correlated with first flowering (r= -0.23*) and 50% flowering (-0.24*). This suggests the increase in pod yield per plant and early flowering contributed to seed yield in AYB mutant lines. Positive and significant associations were obtained between first flowering with 50% flowering (r= 0.85**), first podding (r= 0.73**) and 50% podding (r= 0.68**). 50% flowering was positively and significantly correlated with first podding (r= 0.69**) and 50% podding (r= 0.68**). Also, there was a strong and positive correlation between the first podding and the 50% podding (r= 0.89**) (Table 9).

Table 9. Pearson correlation between pairs of seed yield and other agronomic characters

	SYPP	DFF	50DF	DFP	50DP	MAT	NPPED	PEDL	PODL	PYPP
SYPP	-	-0.23*	-0.24*	-0.14	-0.16	-0.11	0.00	-0.14	0.00	0.97**
DFF		-	0.85**	0.73**	0.68**	0.09	0.01	-0.13	0.02	-0.19
50DF			-	0.69**	0.68**	0.10	-0.04	-0.14	0.06	-0.19
DFP				-	0.89**	0.11	-0.08	-0.01	0.06	-0.06
50DP					-	0.05	-0.07	-0.08	0.13	-0.06
MAT						-	-0.08	0.09	-0.02	-0.10
NPPED							-	0.02	0.07	0.02
PEDL								-	0.10	-0.12
PODL									-	0.03
PYPP										-

*, ** Significant at ($p < 0.05$) and ($p < 0.01$), respectively.

SYPP: seed yield/plant (g); DFF: first flowering; 50DF: 50% flowering; DFP: first podding; 50DP: 50% podding; MAT: 70% physiological maturity; NPPED: pods/peduncle; PEDL: Peduncle length (cm); PODL: Pod length (cm); PYPP: Pod yield/plant (g).

4. Discussion

In this study, there was significant variability among the agro-morphological traits. The presence of significant variability in pod and seed yields/plant of AYB, as evidenced by coefficients of variation (CV) in this study, had been earlier reported in pod and seed yields per plant of AYB in M_1 generation (Akinyosoye *et al.*, 2021). High CVs (>90%) indicate that significant variation existed in pod and seed yield per plant. Thus, the mutant lines can be adequately distinguished based on pod and seed yields. The low CV values (<22%) obtained in other traits indicate phenotypic uniformity within the lines in this study. This provides an ample opportunity for the selection of promising lines for the traits of interest by the plant breeder for further improvement.

The results obtained for flowering and maturity were lower than the information obtained on them in the M_1 generation of AYB in the previous study, whereas the seed yield obtained in this was higher than that of the M_1 generation in the previous study (Akinyosoye *et al.*, 2021). The M_2 mutant lines reached first flowering, 50% flowering, first podding, and 70% physiological maturity earlier than their parents and outyielded their parents by 62.64%. This phenomenon of induction of early flowering and maturity in mutant lines than their parents had earlier been reported by others in some crops such as AYB (Akinyosoye *et al.*, 2021); Arabidopsis (Onouchi *et al.*, 2000); barley (Matyszczak *et al.*, 2020); wheat (Laghari *et al.*, 2012). Similarly, reports of higher grain yield in mutant lines than their parents had also been reported by others in wheat (Morad *et al.*, 2011; Laghari *et al.*, 2012). Flowering or maturity time is a key factor for adaptation to natural and agricultural settings and directly influences yield (Turner *et al.*, 2005). Also, Nigeria is already plagued with climate change assoicated with biotic (pests and diseases) and abiotic stresses (drought) (Olajide and Adeyinka 2021; Akinyosoye 2022). Thus, the cultivation of early maturing genotypes helps the plants to escape the vagaries of weather due to the short life cycle, especially when there is rain cessation or unexpected drought. The observed phenotypic differences were recorded among the mutant lines. This could be due to the inherent genetic potential of the lines.

The principal component (PC) showed that the first four PCs accounted for 75.54% of the total variation. A similar result was reported by Olomitutu *et al.* (2022) who obtained 70.2% of the variation in the first four principal components in AYB lines. The relative discriminating power of the PCA determines character contribution to the total variation, and its discriminating power is dependent on the strength of the axis as measured by their eigenvalues (Idehen *et al.*, 2016; Akinyosoye *et al.*, 2017). Some traits such as first flowering, 50% flowering, first podding and 50% podding, 70% physiological maturity, pod length, and pod and seed yields had PC values ≥ 0.6 and were adjudged as the most important contributors to the variation in this study. This assertion is corroborated by the findings of Matus *et al.* (1999), who reported that any character having PC greater than or equal to 0.6 is regarded as the most contributor to the variation. Therefore, identified agronomic characteristics could assist in the effective selection in AYB improvement programmes (Akinyosoye *et al.*, 2017).

The results obtained from cluster analysis indicated that 73.9% of the lines were found in cluster II. This indicates that most of the lines in this cluster were homogenous. Also, the moderate pod and seed yields/plant obtained in cluster II could be due to low variability among the lines in this cluster, whereas members in cluster I were heterogeneous due to high phenotypic variation existing in the cluster with good yield potentials. Adewale *et al.* (2012) reported that selections can be made for promising genotypes exhibiting unique phenotypic characters in a cluster. For instance, all the members in cluster I can be selected for the pod, seed yields/plant, and earliness to flowering and maturity. Few members in cluster II, especially parents AYB 61 and NGB01349 can be selected for longer pod length, whereas all the members in cluster III can only be selected for longer peduncle length. Classification of AYB into different heterotic groups in this study was in line with the findings of Adewale et al. (2012), who opined that breeding for genetic improvement of AYB requires an understanding of the genotype's classification pattern and intra-specific variability. As a result, the presence of genetic variations among AYB genotypes should be taken advantage of in breeding programs.

The significant and positive correlation recorded between pair of seed yield and other agronomic characters suggests that these traits could be governed by similar genes with pleiotropic effect or closely linked genes (Brown and Caligari, 2008). The significant and positive correlation between yield-related traits suggested that the traits could be improved simultaneously (Olomitutu *et al.*, 2022). Hence, any of these characters could be used in indirect selection to increase yield.

Conclusion

This study revealed that M_2 mutant lines flowered and matured earlier than their parents and outyielded their parents. Some traits such as first flowering, 50% flowering, and pod yield/plant were adjudged as the most contributors to the total variation. All the members in cluster I (IART-1, IART-2, IART-3) can be selected for the pod, seed yields/plant, and earliness to flowering and maturity. Few members in cluster II (AYB 61, NGB01349, IART-4, AYB 94, IART 12) can be selected for longer pod length, whereas all the members in cluster III (IART-4, IART-5, IART-6) can only be selected for longer peduncle length. Also, an increase in pod yield per plant and early flowering contributed to seed yield. Therefore, pair of traits that showed a significant and positive association with seed yield could be used for indirect selection to increase yield. AYB breeding lines identified in this study could be utilized by plant breeders/geneticists to develop AYB varieties that are early maturing and high yielding in improvement programs.

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