Evaluation of elite and local African yam bean cultivars for yield and yield-related traits

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The variability in African yam bean (AYB) accessions with respect to yield and other agronomic traits were studied for two cropping seasons (2012 and 2013) in field experiments to evaluate the growth, yield and yield components of 36 AYB accessions. The accessions differed significantly ($P \leq 0.05$) in the traits studied. In 2012 Pearson correlation coefficients indicated that seed yield had significant ($P \leq 0.01$) and positive relationships with total pod weight per plant (r = 0.80), number of filled pods (r = 0.90**) and total number of pods per plant (r = 0.73**). Total pod weight per plant recorded significant and positive relationships with total number of pods per plant (r = 0.88**) and number of filled pods (r = 0.90**). In the 2013 cropping season, seed yield had positively significant ($P \leq 0.01$) relationships with total pod weight per plant (r = 0.96**), number of pods per plant (r = 0.89**), number of filled pods (0.92**) and shrivelled pods (r = 0.72**). Total pod weight per plant had positively significant ($P \leq 0.01$) relationships with number of pods per plant (r = 0.93**), number of filled pods (r = 0.92**) and shrivelled pods (r = 0.78**). Principal component analysis results identified seed yield, total pod weight, number of filled pods, percentage filled pods, number of days to first emergence, number of days to 50% emergence and number of seeds per pod as the most discriminating traits among the accessions. TSs 137, TSs 111, TSs 118, Tseagbaragba, TSs 60 and TSs 93 were the best performing accessions for seed yield. The evident variability in the AYB accessions evaluated should be made use of in developing improved African yam bean varieties.**

Keywords: African yam bean, accessions, variability, biodiversity, *Sphenostylis stenocarpa*

African yam bean, *Sphenostylis stenocarpa* (AYB), a tropical legume, produces grains and tubers (Baiyeri et al. 2016) which are consumed by humans and livestock in Nigeria and other African countries. It is adapted to various agro-ecologies in both southern and northern parts of Nigeria and has the potential through research to become an important legume for sustainable food and nutrition security due to its high protein and energy, dietary fibre, iron, zinc, and selenium, high dry matter and low fat contents (Baiyeri et al. 2018a).

In Nigeria, AYB grain yields are low and vary per locality 205 - 631 kg ha^{-1} in Abakaliki (Ogah 2013), 440 kg ha^{-1} in Mokwa and 749 kg ha^{-1} in Ibadan (Adewale et al. 2017), because yield is largely dependent on the genotype, environment and crop management practices. In southeastern Nigeria, high costs in acquiring the stakes necessary for good yields (Baiyeri et al. 2018b) has further resulted in lower production and only a few traditional farmers are able to cultivate the crop according to their traditional cropping systems.

There is a thrust to revitalize commercial production of AYB through breeding. A necessary first step is to evaluate available AYB accessions for yield and its associated traits. The International Institute of Tropical Agriculture (IITA) has a large collection of AYB accessions, from various locations in Africa. A small subset of these accessions have been evaluated in southwestern Nigeria (Popoola et al. 2011; Adewale et al. 2012); the accessions evaluated showed significant differences in the morphological traits. However, it is necessary to evaluate a larger subset of accessions to select enough parents for a breeding programme aimed at improving

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yield in AYB for commercial production in southeastern Nigeria.

Materials and methods

The field evaluation was carried out at the research field of the Department of Crop Science, University of Nigeria, Nsukka, Nigeria during the 2012 and 2013 cropping seasons. Nsukka is of the derived savannah agro-ecology, characterised by lowland and humid tropical conditions with annual rainfall of about 1500 mm. During the rainy season the temperature ranges between 20 – 30ºC and the relative humidity ranges between 70 – 80% (Baiyeri et al. 2008). The soil is acidic and classified as an ultisol. In the study, 36 African yam bean accessions were evaluated with 32 originating from the Genetic Resources Center (GRC) of IITA (TSs 1, TSs 9, TSs 10, TSs 23, TSs 24, TSs 33, TSs 48, TSs 49, TSs 57, TSs 60, TSs 61, TSs 69, TSs 79, TSs 82, TSs 84, TSs 86, TSs 89, TSs 93, TSs 94, TSs 95, TSs 96, TSs 101, TSs 109, TSs 111, TSs 116, TSs 118, TSs 125, TSs 137, TSs 138, TSs 139, TSs 156, TSs 349), three accessions (Adikpo, Tesagbaragba and Zak Biam) from Benue State, Nigeria and one accession (Ondo) from Ondo State, Nigeria. The land preparation included ploughing, followed by harrowing and ridging. Two seeds were planted per hole on the crest with a plant spacing of 1 m x 1 m. The experimental design was a randomised complete block with four replications. Each replicate had 36 single row plots (each being a single row of 5 m long) and each plot had six plants. Thinning of the AYB seedlings from two to one was done at 5 weeks after planting. Each AYB plant was staked on a bamboo about 3 m long. The AYB seedlings received 100 kg/ha of NPK (15:15:15) fertilizer (Notore brand). The field was weeded regularly to ensure there was no competition between the crops and the weeds. Data were collected from the four middle plants in the net plot. These included days to first seedling emergence, days to 50% seedling emergence, number of days to first flowering, number of days to 50% flowering, number of pods per plant, number of filled pods per plant, number of shrivelled pods per plant, total pod weight per plant, pod length, shelling percentage, 100-seed weight, and seed (grain) yield. Analyses of variance were done to partition the total source of variation for each of the cropping years and over the two cropping years while principal component analysis (PCA) was performed, to identify key traits that are most discriminatory among the accessions, using GENSTAT Discovery Edition 3.0 7.2DE (GENSTAT, 2007). Significance of the treatment means was determined by Fisher's least significant difference (LSD) at the 5% probability level. Pearson's correlation analysis was performed, to understand the strength of relationships that existed among the agronomic traits studied in the AYB accessions during each cropping year, using SPSS 17.0. (2008). Accession by trait analysis was performed to identify association between the AYB accessions and the agronomic traits. Accession by environment interaction analysis was performed using GGE biplot to assess the performances of the AYB accessions over the two years.

Results

Results of the yield and yield-related traits in AYB accessions evaluated in trial 1 (2012 cropping season)

The seedling emergence and flowering traits of the AYB seedlings were significantly ($P \leq 0.05$) influenced by accessions (Table 1). TSs 60, TSs 156 and Ondo were the earliest to emerge at 6 days after planting (DAP), while TSs 138 (8.50 DAP) took the longest time to emerge. TSs 60 (7.00 DAP) was also the earliest accession to attain 50% emergence followed closely followed by TSs 1, TSs 101, TSs 156 and Tseagbaragba. TSs 138 (11 DAP) was the latest to attain 50% emergence. TSs 95 (87.25 DAP), TSs 33 (90.50 DAP) and TSs 60 (93.25 DAP) were the earliest to flower while Adikpo (111.0 DAP), TSs 109 (110.8 DAP), and TSs 138 (110.5 DAP) were the latest to flower. TSs 60 (99.5 DAP) was the earliest to 50% flowering while TSs 139 (117.5 DAP) and TSs 109 (117.3 DAP) were the latest to attain 50% flowering. The pod length of the AYB accessions were significantly ($P \leq 0.05$) influenced by accessions. TSs 60 produced the longest pods (31.96 cm) while TSs 111 (17.27 cm) produced the shortest pods. The total number of pods per plant, number of filled pods per plant, number of shrivelled pods per plant and pod weight per plant were not significantly ($P > 0.05$) influenced by accession (Table 2). The AYB accessions were however, significantly ($P \leq 0.05$) different in their percentage filled pods. TSs 156 (42.47%), TSs 137 (39.14%), Tseagbaragba (37.80%) recorded the highest percentages for filled pods while TSs 109 (7.73%) poorest for the same trait. The number of seeds per pod, shelling percentage and 100-seed weight were significantly influenced by accession and year (Table 3). TSs 61 (17.29 seeds), TSs 23 (16.25 seeds) produced a higher number of seeds per pod than the rest of the accessions while the fewest number of seeds per pod were recorded in TSs 1 (13.25 seeds). TSs 111 (63.33%), Tseagbaragba (61.20%), TSs 156 (60.75%) and TSs 137 (59.89%) were the most prominent accessions for shelling percentage. Ondo (23.25%) recorded the poorest shelling percentage. Ondo (29.55 g) and TSs 69 (28.78 g) produced the heaviest weights of 100 seeds. The grain yield performance of the accessions was significantly ($P \leq 0.05$) influenced by year but was not significantly influenced by accession. Tseagbargba (765 kg/ha), TSs 60 (735 kg/ha), TSs 137 (619.3 kg/ha), TSs 118 (515 Kg/ha), TSs 93 (503.8 kg/ha) were the best performing accessions for seed yield. TSs 109 (116 kg/ha), TSs 86 (137.5 kg/ha), Ondo (144.8 kg/ha), were the poorest accessions for seed yield in the first trial.

The results of the Pearson's correlation analysis showed that seed weight (grain yield) was positively and significantly ($P \leq 0.01$) associated with number of filled pods ($r = 0.90$**), total pod weight ($r = 0.80$**) and total number of pods ($r = 0.73$**) (Table 4). Total pod weight per plant had a positive and significant ($P \leq 0.01$) relationship with the total number of pods per plant ($r = 0.88$**), number of filled pods ($r = 0.89$**), and seed weight ($r = 0.80$**). Percentage filled pods also showed a significant positive ($P \leq 0.01$) relationship with shelling percentage ($r = 0.86$**).

The result of the principal component analysis in the first year of the evaluation is shown in Table 6. The first four principal components explained 71.68% of the total variation. Number of filled pods, seed yield, total pod weight, number of pods per plant and percentage filled pods had the highest eigenvalues on the first principal component that explained 36.95% of the total variation. The number of shrivelled pods and number of pods per plant had the highest eigenvector values on the second principal component, which explained 14.27% of the total variation. Number of days to 50% emergence had the highest eigenvector value on the third principal component, which explained 12.53% of the total variation while number of days to first flowering had the highest eigenvector value on the fourth principal component, which explained 7.93% of the total variation. Seed yield, total pod weight, number of pods per plant, percentage filled pods, number of shrivelled pods, days to 50% emergence and days to first flowering were the most discriminating traits among the African yam bean accessions evaluated.

Figure 1 shows the biplot of the first two principal components. This helps to identify which wins where or which is best for what; it shows that total pod weight and number of seeds per plant are positive traits of TSs 60 and TSs 89; Tseagbaragba is favoured for seed yield and number of filled pods; TSs 137 was prominent for percentage filled pods and shelling percentage.

Table 1: Effects of accession, year and accession x year interaction on the emergence, flowering and pod length of 36 African yam bean accessions during the 2012 and 2013 cropping seasons

Accession	DTFE			DT50E			DTFF			DT50F			PDL		
	2012	**2013**	**Mean**	**2012**	**2013**	**Mean**	**2012**	**2013**	**Mean**	**2012**	**2013**	**Mean**	**2012**	**2013**	**Mean**
TSs 1	6.50	7.00	6.75	7.25	8.50	7.88	96.25	90.25	93.25	105.6	93.25	99.25	19.09	20.71	19.90
TSs 9	7.25	6.00	6.63	8.00	7.25	7.63	97.25	88.00	92.62	108.3	90.75	99.50	21.85	23.94	22.89
TSs 10	7.50	7.75	7.63	8.25	10.75	9.50	95.50	89.50	92.50	107.5	92.00	99.75	20.07	23.44	21.75
TSs 23	7.00	8.25	7.63	7.50	13.75	10.63	103.8	93.00	98.38	112.8	96.00	104.4	21.77	25.01	23.39
TSs 24	7.25	7.25	7.25	8.25	8.25	8.25	96.25	91.50	93.88	111.5	93.75	102.6	22.01	21.85	21.93
TSs 33	6.75	7.00	6.88	8.00	8.50	8.25	90.50	85.25	87.88	106.5	92.00	99.12	20.70	22.48	21.59
TSs 48	7.75	6.50	7.13	8.78	7.75	8.26	106.0	88.75	97.38	110.5	92.50	101.5	20.83	21.12	20.97
TSs 49	7.50	6.25	6.88	9.00	7.75	8.38	105.8	88.00	96.88	114.0	93.25	103.6	22.12	23.61	22.87
TSs 57	7.25	7.00	7.13	7.75	9.50	8.63	104.3	89.50	96.88	110.8	92.98	101.9	22.41	21.17	21.79
TSs 60	6.25	6.00	6.13	7.00	8.00	7.50	93.25	85.00	89.12	99.50	88.50	94.00	31.96	20.81	26.39
TSs 61	7.50	7.00	7.25	8.25	8.50	8.38	102.0	88.00	95.00	110.8	92.25	101.5	22.26	23.04	22.65
TSs 69	7.25	7.00	7.13	9.00	9.75	9.38	103.8	91.00	97.38	115.8	94.75	105.3	21.83	26.87	24.35
TSs 79	6.75	6.75	6.75	7.75	8.50	8.13	107.0	93.00	100.0	115.3	95.50	105.9	20.57	20.40	20.48
TSs 82	7.75	6.75	7.25	8.25	9.00	8.63	107.5	92.75	100.1	114.8	98.00	106.4	20.27	21.47	20.87
TSs 84	7.00	6.50	6.75	8.00	7.75	7.88	98.25	88.75	93.50	109.5	91.75	100.6	21.17	23.85	22.51
TSs 86	8.00	6.75	7.38	8.25	8.50	8.38	93.75	89.75	91.75	110.5	93.50	102.0	21.32	22.26	21.79
TSs 89	7.25	6.00	6.63	9.00	7.25	8.13	106.0	92.00	99.00	113.0	95.25	104.1	23.62	24.10	23.86
TSs 93	8.00	6.50	7.25	8.25	8.50	8.38	103.3	92.75	98.00	112.5	96.50	104.5	22.94	23.61	23.28
TSs 94	7.75	6.50	7.13	8.25	7.50	7.88	101.0	90.75	95.88	114.8	94.00	104.4	19.19	21.57	20.38
TSs 95	7.25	8.25	7.75	9.43	11.67	10.55	87.25	91.94	89.59	103.8	98.00	100.9	20.05	23.86	21.95
TSs 96	7.75	6.75	7.25	8.00	8.25	8.13	97.50	87.75	92.62	104.3	90.50	97.38	22.76	23.48	23.12
TSs 101	6.50	7.00	6.75	7.25	9.25	8.25	101.3	89.50	95.38	112.8	92.00	102.4	21.77	22.65	22.21
TSs 109	7.25	7.00	7.13	8.00	10.25	9.13	110.8	91.75	101.3	117.3	96.50	106.9	22.30	24.30	23.30
TSs 111	6.75	7.00	6.88	7.75	12.25	10.00	100.0	90.75	95.38	108.0	92.75	100.4	17.27	19.16	18.21
TSs 116	6.75	7.25	7.00	7.50	10.50	9.00	102.8	93.50	98.12	111.3	97.75	104.5	20.83	21.66	21.24
TSs 118	7.75	6.75	7.25	8.25	10.21	9.23	102.3	88.00	95.12	111.0	90.75	100.9	21.23	20.31	20.72
TSs 125	6.75	6.75	6.75	8.25	8.50	8.38	96.50	88.00	92.25	110.0	92.75	101.4	20.19	37.40	28.79
TSs 137	7.00	7.50	7.25	8.75	11.25	10.00	102.5	91.00	96.75	107.8	93.50	100.6	18.87	19.71	19.29
TSs 138	8.50	6.25	7.38	11.00	8.50	9.75	110.5	91.00	100.8	114.8	95.50	105.1	19.69	16.78	18.24
TSs 139	7.75	6.75	7.25	8.00	10.75	9.38	109.8	94.75	102.3	117.5	98.75	108.1	22.33	25.14	23.74
TSs 156	6.25	7.75	7.00	7.25	11.25	9.25	98.50	91.27	94.88	110.5	95.48	103.0	19.05	19.06	19.05
TSs 349	6.75	6.75	6.75	7.75	9.25	8.50	96.50	90.25	93.38	112.0	94.00	103.0	22.27	21.91	22.09
Adikpo	7.25	8.06	7.66	8.25	12.76	10.51	111.0	94.10	102.6	114.3	101.0	107.6	19.45	21.35	20.40
Ondo	6.25	6.75	6.50	7.50	9.75	8.63	102.8	87.75	95.25	114.3	91.75	103.0	22.81	25.73	24.27
Tseagbaragba	6.75	7.75	7.25	7.25	12.50	9.88	101.3	95.60	98.43	110.3	99.46	104.9	20.04	19.35	19.69
Zak Biam	7.00	6.50	6.75	7.75	9.50	8.63	96.25	91.50	93.88	110.0	94.25	102.1	18.15	20.66	19.40
Mean	7.18	6.93	7.06	8.13	9.49	8.13	101.07	90.44	95.76	110.9	94.20	102.6	21.25	22.60	21.93
	$LSD_{(0.05)}$			$LSD_{(0.05)}$			$LSD_{(0.05)}$			$LSD_{(0.05)}$			$LSD_{(0.05)}$		
	Accession: 0.77			Accession: 1.13			Accession: 4.91			Accession: 3.55			Accession: 1.73		
	Year: 0.18			Year: 0.27			Year: 1.15			Year: 0.84			Year: 0.41		
	Accession x year: 1.08			Accession x year: 1.60			Accession x year: 6.94			Accession x year: 5.02			Accessions x year: NS		

NS = not significant (P > 0.05) **DTFE** = days to first emergence **DT50E** = days to 50% emergence **DTFF** = days to first flowering **DT50F** = days to 50% flowering **PDL** = pod length (cm)

Table 2: Effects of accession, year and accession x year interaction on the pod-related traits of 36 African yam bean accessions during the 2012 and 2013 cropping seasons

Accession	NPDP			NFPD			NSPD			PFPD			TPWT		
	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
TSs 1	37.8	22.7	30.2	10.94	5.560	8.250	26.81	17.23	22.02	30.55	21.21	25.88	61.30	37.90	49.60
TSs 9	43.1	36.1	39.6	9.960	14.06	12.01	33.12	21.00	27.06	25.60	27.55	26.58	76.90	109.3	93.10
TSs 10	48.7	40.4	44.5	10.06	16.75	13.41	38.65	24.25	31.45	23.00	38.63	30.82	67.80	115.6	91.70
TSs 23	30.9	34.4	32.6	6.230	13.67	9.950	24.62	21.56	23.09	19.10	35.24	27.17	53.00	119.5	86.20
TSs 24	41.6	25.8	33.7	13.75	8.080	10.92	27.87	18.69	23.28	32.69	27.56	30.12	79.80	44.40	62.10
TSs 33	39.8	30.8	35.3	13.00	11.60	12.30	27.44	19.19	23.31	32.59	35.88	34.24	83.60	77.40	80.50
TSs 48	47.1	28.8	37.9	15.46	8.270	11.86	31.62	20.52	26.07	32.58	28.34	30.46	100.4	60.7	80.60
TSs 49	40.3	45.8	43.0	8.750	12.60	10.68	31.50	33.27	32.39	18.65	29.42	24.03	74.70	94.40	84.50
TSs 57	47.6	14.2	30.9	13.25	3.290	8.270	34.40	10.88	22.64	29.36	20.98	25.17	96.50	26.80	61.60
TSs 60	65.1	35.4	50.2	24.69	10.62	17.66	40.38	25.37	32.87	33.72	23.10	28.41	120.2	65.80	93.00
TSs 61	44.1	34.9	39.5	8.190	14.77	11.48	35.81	20.37	28.09	18.82	39.91	29.36	77.30	102.6	90.00
TSs 69	29.2	39.7	34.5	4.000	11.16	7.580	25.23	28.43	26.83	14.88	17.90	16.39	45.80	116.0	80.90
TSs 79	26.2	30.2	28.2	6.690	10.79	8.740	19.54	18.54	19.04	21.55	37.84	29.70	48.40	73.50	61.00
TSs 82	24.0	22.2	23.1	2.810	4.500	3.660	21.23	17.94	19.58	9.880	20.70	15.29	29.10	37.20	33.20
TSs 84	40.4	22.1	31.3	12.12	7.940	10.03	28.31	14.25	21.28	31.90	33.32	32.61	79.60	57.50	68.60
TSs 86	38.2	28.1	33.1	5.870	12.56	9.220	32.33	17.75	25.04	13.00	34.22	23.61	53.90	66.60	60.20
TSs 89	58.7	27.8	43.2	20.25	10.17	15.21	38.44	17.81	28.12	35.05	28.92	31.99	159.0	64.10	111.5
TSs 93	53.1	41.4	47.2	14.81	13.69	14.25	37.88	27.69	32.78	25.99	26.42	26.20	105.7	122.6	114.1
TSs 94	27.5	43.2	35.4	4.620	13.90	9.260	21.40	29.35	25.38	12.69	29.13	20.91	36.10	104.9	70.50
TSs 95	27.1	38.2	32.7	8.560	12.42	10.49	18.58	24.56	21.57	25.87	30.67	28.27	66.20	113.1	89.60
TSs 96	36.4	33.2	34.8	8.750	11.60	10.18	27.69	21.69	24.69	23.28	33.98	28.63	68.50	76.40	72.50
TSs 101	41.3	31.1	36.2	10.75	9.440	10.09	30.50	22.31	26.41	24.54	29.06	26.80	82.30	75.70	79.00
TSs 109	26.4	34.8	30.6	2.310	14.62	8.470	24.04	19.62	21.83	7.730	38.60	23.17	40.50	91.00	65.80
TSs 111	35.6	35.1	35.3	15.69	16.90	16.29	20.80	18.19	19.49	36.72	39.13	37.93	76.00	93.00	84.50
TSs 116	52.1	34.8	43.5	14.17	16.31	15.24	37.35	18.50	27.93	26.33	44.45	35.39	91.10	98.00	94.50
TSs 118	55.0	46.7	50.9	13.23	21.19	17.21	41.88	29.19	35.53	23.62	42.62	33.12	102.0	117.5	109.7
TSs 125	28.7	25.7	27.2	8.690	8.500	8.590	20.00	17.81	18.91	20.40	30.26	25.33	59.40	55.20	57.30
TSs 137	50.6	43.0	46.8	22.77	20.19	21.48	27.69	23.90	25.79	39.14	44.03	41.59	104.0	113.7	108.9
TSs 138	28.9	27.1	28.0	10.73	9.190	9.960	18.21	17.94	18.07	36.30	26.24	31.27	61.30	54.20	57.80
TSs 139	41.7	32.6	37.1	4.100	8.690	6.400	37.56	24.56	31.06	11.73	24.63	18.18	74.90	95.00	84.90
TSs 156	34.8	14.0	24.4	14.94	4.440	9.690	19.73	9.560	14.65	42.47	27.49	34.98	71.70	21.20	46.50
TSs 349	44.2	28.1	36.1	10.85	8.060	9.460	33.31	18.94	26.12	19.12	27.66	23.39	83.70	51.60	67.70
Adikpo	32.3	26.3	29.3	11.69	14.60	13.14	20.62	11.70	16.16	35.15	44.73	39.94	68.20	91.70	79.90
Ondo	36.6	32.3	34.4	4.120	7.220	5.670	32.44	25.90	29.17	10.71	22.30	16.50	56.60	94.80	75.70
Tseagbaragba	57.9	20.5	39.2	22.06	12.12	17.09	35.25	8.370	21.81	37.80	56.60	47.20	124.4	64.50	94.40
Zak Biam	38.1	28.4	33.3	15.63	13.08	14.35	22.60	15.33	18.97	33.30	40.30	36.80	93.10	81.40	97.30
Mean	40.3	31.5	35.9	11.24	11.46	11.35	29.02	20.34	24.68	25.44	32.20	28.82	77.0	80.1	78.6
	$LSD_{(0.05)}$			$LSD_{(0.05)}$			$LSD_{(0.05)}$			$LSD_{(0.05)}$			$LSD_{(0.05)}$		
	Accession: NS			Accession: NS			Accession: NS			Accession: 13.91			Accession: NS		
	Year: 4.47			Year: NS			Year: 2.94			Year: 3.27			Year: NS		
	Accession x year: NS			Accession x year: NS			Accession x year: NS			Accession x year: NS			Accession x year: NS		

NS = Not significant (P > 0.05) **NPDP** = number of pods per plant **NFPD** = number of filled pods **NSPD** = number of shrivelled pods
PFPP = percentage filled pods **TPWT** = pod weight per plant (g)

Table 3: Effects of accession, year and accession x year interaction on the seed-related traits and grain yield of 36 African yam bean accessions during the 2012 and 2013 cropping seasons

Accession	NSP			SHLP			HSWT			SWKGH		
	2012	**2013**	**Mean**	**2012**	**2013**	**Mean**	**2012**	**2013**	**Mean**	**2012**	**2013**	**Mean**
TSs 1	13.25	13.85	13.55	54.85	50.52	52.69	23.48	20.07	21.77	335.0	222.5	278.8
TSs 9	15.93	15.06	15.50	50.53	36.72	43.62	24.28	24.52	24.40	372.0	506.8	439.3
TSs 10	14.67	14.37	14.52	57.42	52.23	54.82	23.70	24.23	23.97	373.8	641.3	507.5
TSs 23	16.25	15.81	16.03	44.17	55.97	50.07	24.80	25.01	24.90	176.5	700.0	439.0
TSs 24	15.79	11.87	13.83	55.16	38.71	46.93	25.83	26.24	26.03	451.8	203.0	327.3
TSs 33	14.94	14.56	14.75	57.01	61.09	59.05	24.95	24.44	24.69	478.8	581.8	530.3
TSs 48	14.33	12.90	13.61	52.82	53.55	53.18	27.15	21.79	24.47	492.5	341.3	416.8
TSs 49	15.50	14.04	14.77	43.36	60.54	51.95	25.63	25.71	25.67	384.3	565.5	475.0
TSs 57	15.79	11.58	13.69	53.87	33.47	43.67	25.13	22.48	23.80	475.8	97.8	286.8
TSs 60	14.94	15.01	14.97	57.38	46.84	52.11	20.48	19.72	20.10	735.0	387.5	561.3
TSs 61	17.29	14.12	15.71	43.16	52.06	47.61	25.95	24.49	25.22	326.0	573.0	449.5
TSs 69	15.12	15.32	15.22	42.17	34.41	38.29	28.78	32.75	30.76	158.0	565.3	361.5
TSs 79	15.69	14.04	14.86	42.88	57.83	50.36	22.05	19.97	21.01	225.3	423.5	324.5
TSs 82	13.56	14.00	13.78	26.92	46.47	36.70	22.85	22.10	22.47	97.5	197.3	147.5
TSs 84	15.06	12.21	13.64	50.76	48.29	49.53	24.15	24.76	24.45	317.5	282.3	299.8
TSs 86	16.00	14.85	15.43	32.10	40.42	36.26	23.98	21.08	22.53	137.5	311.8	224.8
TSs 89	16.06	13.69	14.87	53.18	31.85	42.51	27.08	23.76	25.42	347.3	286.3	316.8
TSs 93	15.71	17.12	16.42	51.41	36.62	44.01	23.65	25.96	24.80	503.8	615.5	559.8
TSs 94	13.56	12.90	13.23	35.37	44.87	40.12	23.53	23.79	23.66	161.3	539.8	350.5
TSs 95	14.42	15.17	14.79	47.65	46.79	47.22	22.20	26.26	24.23	174.5	625.5	400.0
TSs 96	16.04	15.00	15.52	50.63	56.94	53.79	26.73	26.26	26.49	391.5	424.8	408.0
TSs 101	15.71	14.94	15.32	47.02	48.37	47.69	25.60	26.11	25.85	398.8	415.8	407.3
TSs 109	14.05	16.17	15.11	21.88	44.95	33.41	23.08	24.56	23.82	116.0	468.3	292.0
TSs 111	13.69	14.02	13.85	63.33	57.78	60.56	23.30	22.85	23.07	475.3	741.5	599.3
TSs 116	15.96	15.19	15.57	56.90	53.55	55.22	21.53	20.75	21.14	466.5	580.8	523.5
TSs 118	14.81	11.94	13.37	47.69	56.25	51.97	25.38	28.26	26.82	515.0	646.3	580.5
TSs 125	15.06	10.94	13.00	45.04	54.73	49.89	24.85	23.36	24.10	323.5	325.5	324.5
TSs 137	13.92	15.15	14.53	59.89	57.53	58.71	22.80	23.04	22.92	619.3	625.8	622.5
TSs 138	15.35	10.50	12.93	56.50	62.23	59.36	24.80	24.10	24.45	267.0	433.8	350.5
TSs 139	13.37	14.83	12.81	40.07	37.49	38.78	31.75	22.12	26.93	256.5	318.0	287.3
TSs 156	14.83	12.94	13.89	60.75	41.74	51.25	23.80	20.18	21.99	383.0	99.8	241.3
TSs 349	14.83	12.94	13.88	37.95	42.85	40.40	22.93	23.07	23.00	413.8	268.0	341.0
Adikpo	14.31	14.18	14.25	56.81	46.56	51.68	26.08	27.24	26.66	302.0	553.0	427.5
Ondo	13.51	14.15	13.83	23.25	43.65	33.45	29.55	39.84	34.69	144.8	435.0	289.8
Tseagbaragba	15.94	13.85	14.90	61.20	62.91	62.05	25.90	24.41	25.15	765.0	394.5	579.8
Zak Biam	13.73	13.50	13.61	56.49	50.39	53.44	25.00	29.28	27.14	456.3	408.8	432.5
Mean	14.97	13.89	14.43	48.27	48.53	48.40	24.80	24.57	24.68	361.1	439.1	400.1
	$LSD_{(0.05)}$			$LSD_{(0.05)}$			$LSD_{(0.05)}$			$LSD_{(0.05)}$		
	Accessions: 2.02			Accessions: 5.03			Accessions: 3.58			Accessions: NS		
	Year: 0.476			Year: NS			Year: NS			Year: 3.27		
	Accessions x Year: NS			Accessions x Year: NS			Accessions x Year: 5.06			Accessions x Year: NS		

NS = Not significant ($P > 0.05$) **NSP** = number of seeds per pod **SHLP** = shelling percentage **HSWT** = 100-seed weight (g) **SWKGH** = Grain yield (kg/ha)

Table 4: Correlation coefficients among the yield and yield-related traits of 36 African yam bean accessions evaluated in 2012

Parameters	TPWT	NPDP	NFPD	NSPD	PDL	NSP	SWKGH	HSWT	SHLP	PFPD	DTFE	DT50% E	DTFF	DT50%FF
TPWT	1													
NPDP	0.88**	1												
NFPD	0.89**	0.75**	1											
NSPD	0.63**	0.89**	0.37**	1										
PDL	0.24**	0.30**	0.19*	0.30**	1									
NSP	0.21*	0.20*	0.15	0.18*	0.18*	1								
SWKGH	0.80**	0.73**	0.90**	0.40**	0.18*	0.15	1							
HSWT	0.23**	0.18*	0.02	0.23**	0.00	0.04	0.09	1						
SHLP	0.51**	0.35**	0.65**	0.04	0.04	0.18*	0.68**	0.09	1					
PFPD	0.60**	0.34**	0.79**	-0.07	0.04	0.10	0.72**	0.05	0.86**	1				
DTFE	-0.00	0.00	-0.10	0.08	-0.05	-0.05	-0.07	0.24**	-0.11	-0.11	1			
DT50% E	-0.02	-0.08	-0.04	-0.08	-0.12	-0.06	-0.03	0.19*	0.07	0.06	0.54**	1		
DTFF	-0.19*	-0.18*	-0.24**	-0.10	-0.08	0.02	-0.27**	0.08	-0.23**	-0.21*	0.11	0.16	1	
DT50%FF	-0.34**	-0.27**	-0.44**	-0.08	-0.08	-0.12	-0.44**	0.09	-0.45**	-0.44**	0.14	0.10	0.58**	1

** Correlation is significant at the 0.01 level * Correlation is significant at the 0.05 level

TPWT = total pod weight **NPDP** = total number of pods per plant **NFPD** = number of filled pods **NSPD** = number of shrivelled pods **PDL** = pod length **NSP** = number of seeds per pod **SWKGH** = seed weight **HSWT** = 100 seed weight **SHLP** = shelling percentage **PFPD** = percentage filled pods **DTFE** = days to first emergence **DT50%E** = days to 50% emergence **DTFF** = days to first flowering **DT50%F** = ays to 50% flowering

Table 5: Correlation coefficients among the yield and yield-related traits of 36 African yam bean accessions evaluated in 2013

Parameters	TPWT	NPDP	NFPD	NSPD	PDL	NSP	SWKGH	HSWT	SHLP	PFPD	DTFE	DT50% E	DTFF	DT50%FF
TPWT	1													
NPDP	0.93^{**}	1												
NFPD	0.92^{**}	0.88^{**}	1											
NSPD	0.78^{**}	0.93^{**}	0.66^{**}	1										
PDL	0.18^{*}	0.17^{*}	0.11	0.21^{*}	1									
NSP	0.37^{**}	0.33^{**}	0.32^{**}	0.29^{**}	0.24^{**}	1								
SWKGH	0.96^{**}	0.89^{**}	0.92^{**}	0.72^{**}	0.11	0.33^{**}	1							
HSWT	0.37^{**}	0.28^{**}	0.27^{**}	0.25^{**}	0.11	0.13	0.36^{**}	1						
SHLP	0.42^{**}	0.41^{**}	0.50^{**}	0.29^{**}	-0.01	0.09	0.58^{**}	0.16	1					
PFPD	0.58^{**}	0.46^{**}	0.75^{**}	0.17^{*}	0.05	0.30^{**}	0.62^{**}	0.17	0.63^{**}	1				
DTFE	-0.05	-0.08	-0.10	-0.04	-0.01	0.01	-0.08	-0.01	-0.05	0.01	1			
DT50% E	-0.05	-0.12	-0.08	-0.12	-0.10	0.05	-0.06	0.01	-0.04	0.05	0.69^{**}	1		
DTFF	-0.15	-0.23^{**}	-0.17^{*}	-0.25^{**}	-0.05	-0.03	-0.19^{*}	-0.17	-0.12	0.05	0.23^{**}	0.35^{**}	1	
DT50%FF	-0.21^{*}	-0.31^{**}	-0.27^{**}	-0.28^{**}	-0.09	-0.07	-0.22^{*}	-0.10	-0.15	-0.08	0.35^{**}	0.40^{**}	0.69^{**}	1

****** Correlation is significant at the 0.01 level ***** Correlation is significant at the 0.05 level

TPWT = total pod weight **NPDP** = total number of pods per plant **NFPD** = number of filled pods **NSPD** = number of shrivelled pods **PDL** = pod length **NSP** = number of seeds per pod **SWKGH** = seed weight **HSWT** = 100 seed weight **SHLP** = shelling percentage **PFPD** = percentage filled pods **DTFE** = days to first emergence **DT50%E** = days to 50% emergence **DTFF** = days to first flowering **DT50%F** = days to 50% flowering

Table 6: Eigenvector values of the agronomic traits of 36 African yam bean accessions evaluated in 2012 cropping season

Agronomic traits	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Days to 50% flowering	0.239	0.327	0.073	0.487
Days to 50% emergence	0.033	0.166	0.592	-0.201
Days to first emergence	0.052	0.320	0.455	-0.375
Days to first flowering	0.155	0.265	0.198	0.664
Number of filled pods	-0.415	-0.038	0.054	0.144
Hundred seed weight	-0.057	0.313	0.255	-0.112
Number of pods per plant	-0.365	0.333	-0.163	0.017
Number of seeds per pod	-0.101	0.031	-0.001	-0.141
Pod length	-0.120	0.186	-0.269	-0.088
Percentage filled pods	-0.334	-0.290	0.283	0.197
Shelling percentage	-0.314	-0.275	0.271	0.134
Number of shrivelled pods	-0.223	0.501	-0.272	-0.086
Seed yield	-0.402	-0.029	0.064	0.098
Total pod weight	-0.400	0.189	0.004	0.076
Latent roots	5.173	1.998	1.754	1.110
Percentage of the total variation explained	36.95	14.27	12.53	7.93

PC = principal component

Table 7: Eigenvector values of the agronomic traits of 36 African yam bean accessions evaluated in 2013 cropping season

Agronomic traits	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Days to 50% flowering	0.167	-0.432	-0.209	0.284
Days to 50% emergence	0.084	-0.559	0.195	0.176
Days to first emergence	0.094	-0.479	0.322	-0.210
Days to first flowering	0.169	-0.388	-0.242	0.308
Number of filled pods	-0.385	-0.091	-0.051	-0.078
Hundred seed weight	-0.185	-0.041	0.080	0.236
Number of pods per plant	-0.379	-0.034	0.194	-0.049
Number of seeds per pod	-0.136	-0.110	0.213	0.350
Pod length	-0.060	0.070	0.179	0.735
Percentage filled pods	-0.263	-0.210	-0.400	-0.064
Shelling percentage	-0.228	-0.135	-0.353	-0.100
Number of shrivelled pods	-0.312	0.003	0.364	-0.014
Seed yield	-0.392	-0.124	0.0043	-0.006
Total pod weight	-0.390	-0.108	0.098	0.011
Latent roots	5.864	2.170	1.632	1.038
Percentage of the total variation explained	39.09	14.47	10.88	6.92

PC = principal component

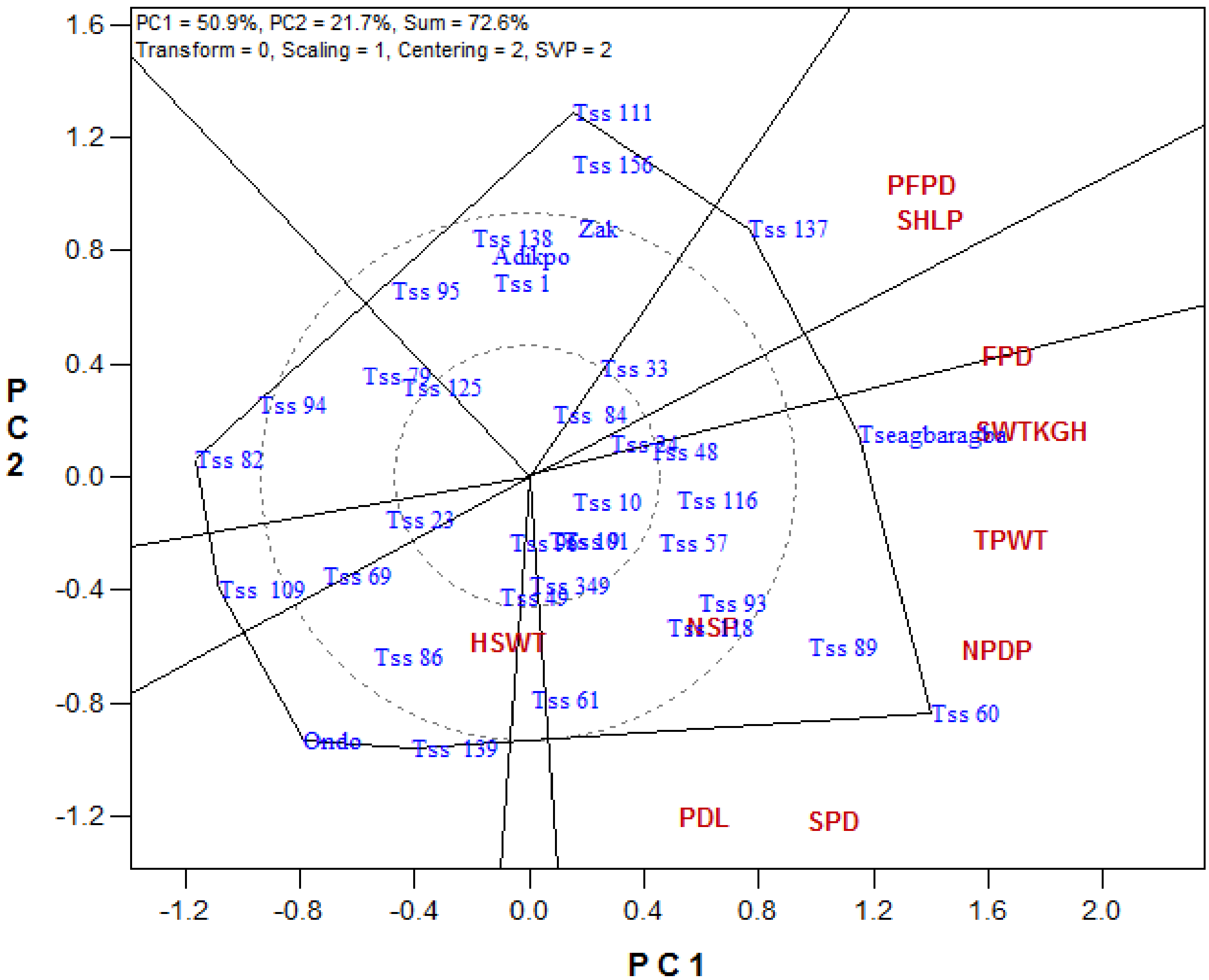

Figure 1: Genotype by trait analysis of agronomic traits in 36 African yam bean accessions evaluated in 2012

TPWT = total pod weight **NPDP** = number of pods per plant **NFPD** = number of filled pods **SPD** = number of shrivelled pods **PDL** = pod length **NSP** = number of seeds per pod **SWKGH** = seed yield **HSWT** = 100 seed weight **SHLP** = shelling percentage **PFPD** = percentage filled pods **PC** = principal component

Results of the yield and yield-related traits in AYB accessions evaluated in trial 2 (2013 cropping season)

Again, seedling emergence and flowering traits were significantly ($P \leq 0.05$) influenced by accession. TSs 60, TSs 9 and TSs 89 were the earliest accessions to emerge at 6 DAP during the 2013 cropping season (Table 1) while Adikpo (8.09 DAP), TSs 23 (8.25 DAP) and TSs 95 (8.25 DAP) took the longest number of days to emerge. At 7.25 DAP, 50% seedlings of TSs 9 and TSs 89 had emerged while it took as long as 12.75 DAP and 13.75 DAP for 50% of the seedlings of Adikpo and TSs 23, respectively, to emerge. TSs 60 (85.00 DAP) and TSs 33 (85.25 DAP) were the earliest to flower while Tseagbaragba (95.60 DAP), TSs 139 (94.75 DAP) and Adikpo (94.10 DAP) took the longest number of days to flower. AYB stands of TSs 60 (88.50 DAP), TSs 96 (90.50 DAP), TSs 9 (90.75 DAP) and TSs 118 (90.75 DAP) were earliest to attain 50% flowering while Adikpo was the latest at 101 DAP. TSs 125 (37.40 cm) had the longest pods while TSs 138 (16.78 cm) produced the shortest pods. The AYB accessions were statistically similar ($P > 0.05$) for total number of pods per plant, number of filled pods per plant, number of shrivelled pods and pod weight per plant. The accessions differed significantly in percentage filled pods. Tseagbaragba (56.60%) recorded the highest percentage for filled pods followed closely by Adikpo 44.73%, TSs 116 (44.45%) and TSs 137 (44.03%) while TSS 69 (17.90%) was poorest for percentage filled pods. The grain yield performance of the accession was significantly ($P \leq 0.05$) influenced by year but was not significantly influenced by accession (Table 2). Number of seeds per pod varied from 10.50 seeds in TSs 138 to 17.12 seeds in TSs 93 (Table 3). Shelling percentage ranged from 31.85% in TSs 89 to 62.91% in Tseagbaragba. The weight of 100 seeds varied from 19.72 g in TSs 60 to 39.84 g in Ondo; these traits were significantly influenced by accession. The grain yield of the AYB accessions varied from 97.8 kg/ha in TSs 57 to 741.5 kg/ha in TSs 111 (Table 3).

Pearson's correlation analysis showed that seed weight had positively significant ($P \leq 0.01$) relationship with total pod weight per plant ($r = 0.96^{**}$), total number of pods per plant ($r = 0.89^{**}$), number of filled pods ($r = 0.92^{**}$) and shrivelled pods ($r = 0.72^{**}$). Total pod weight per plant had positively significant ($P \leq 0.01$) relationships with total number of pods per plant ($r = 0.93^{**}$), number of filled pods ($r = 0.92^{**}$) and shrivelled pods ($r = 0.78^{**}$). Number of pods per plant also showed positive and highly significant ($P \leq 0.01$) relationships with number of filled pods ($r = 0.88^{**}$) and shrivelled pods ($r = 0.93^{**}$) (Table 5).

The result of the PCA in the second year of the evaluations is shown in Table 7. A similar trend in the variation with respect to the traits measured in the first year was observed in the second year of the evaluation. The first four principal components explained 71.36% of the total variation. Seed yield (seed weight) and total pod weight had the highest eigenvalues on the first principal component which explained 39.09% of the total variation. Number of days to 50% emergence and number of days to first emergence had the highest eigenvector values on the second principal component, which explained 14.47% of the variation. Percentage filled pods had the highest eigenvector values on the third principal component (10.88% of the variation) while pod length had the highest eigenvector value on the fourth principal component (6.92% of the variation.

Seed yield, total pod weight, number of filled pods, percentage filled pods, number of days to first emergence, number of days to 50% emergence and pod length were the most discriminating traits among the African yam bean accessions evaluated.

The accession by trait analysis (Figure 2) showed that Tseagbaragba was prominent for percentage filled pods and shelling percentage while TSs 137 and TSs 111 ranked highest for number of filled pods. TSs 118 and TSs 10 were noted for being the best accession for seed yield, total pod weight and number of pods per plant. TSs 69 was highest for number of shrivelled pods. The biplot showed that TSs 156, TSs 57, TSs 82 and TSs 1 were the poorest performing accessions for seed yield and yield components studied in 2013.

Year significantly ($P \leq 0.05$) influenced number of days to first emergence, number of days to 50% emergence, days to first flowering, days to 50% flowering, pod length, number of pods per plant, number of seeds per pod and grain yield. The 2013 trial was significantly higher than the 2012 trial in percentage filled pods, pod length and grain yield. Accession by year interaction significantly influenced the emergence and flowering traits of the accessions and 100-seed weight. The accession by environment interaction analysis of agronomic traits (Figure 3) showed Tseagbaragba and TSs 60 were best performing accessions for seed yield in the first year of the evaluation while TSs 111 and TSs 118 were best performing accessions for the seed yield in the second year of the evaluation. For the two cropping seasons, TSs

137 was the most prominent accessions for seed yield. The biplot also clearly showed TSs 57, TSs 156, TSs 82 and TSs 1 as the poorest performing accessions for seed (grain) yield. Over the two years, six best performing accessions for seed yield were; TSs 137 (622.5 kg/ha), TSs 111 (599.3 kg/ha), TSs 118 (580.5 kg/ha), Tseagbaragba (579.8 kg/ha), TSs 60 (561.3 kg/ha) and TSs 93 (559.8 kg/ha) while the poorest performing accessions for seed yield were; TSs 82 (147.5 kg/ha), TSs 156 (241.3 kg/ha), TSs 86 (224.8 kg/ha), TSs 1 (278.8 kg/ha) and TSs 139 (287.3 kg/ha) (Table 3).

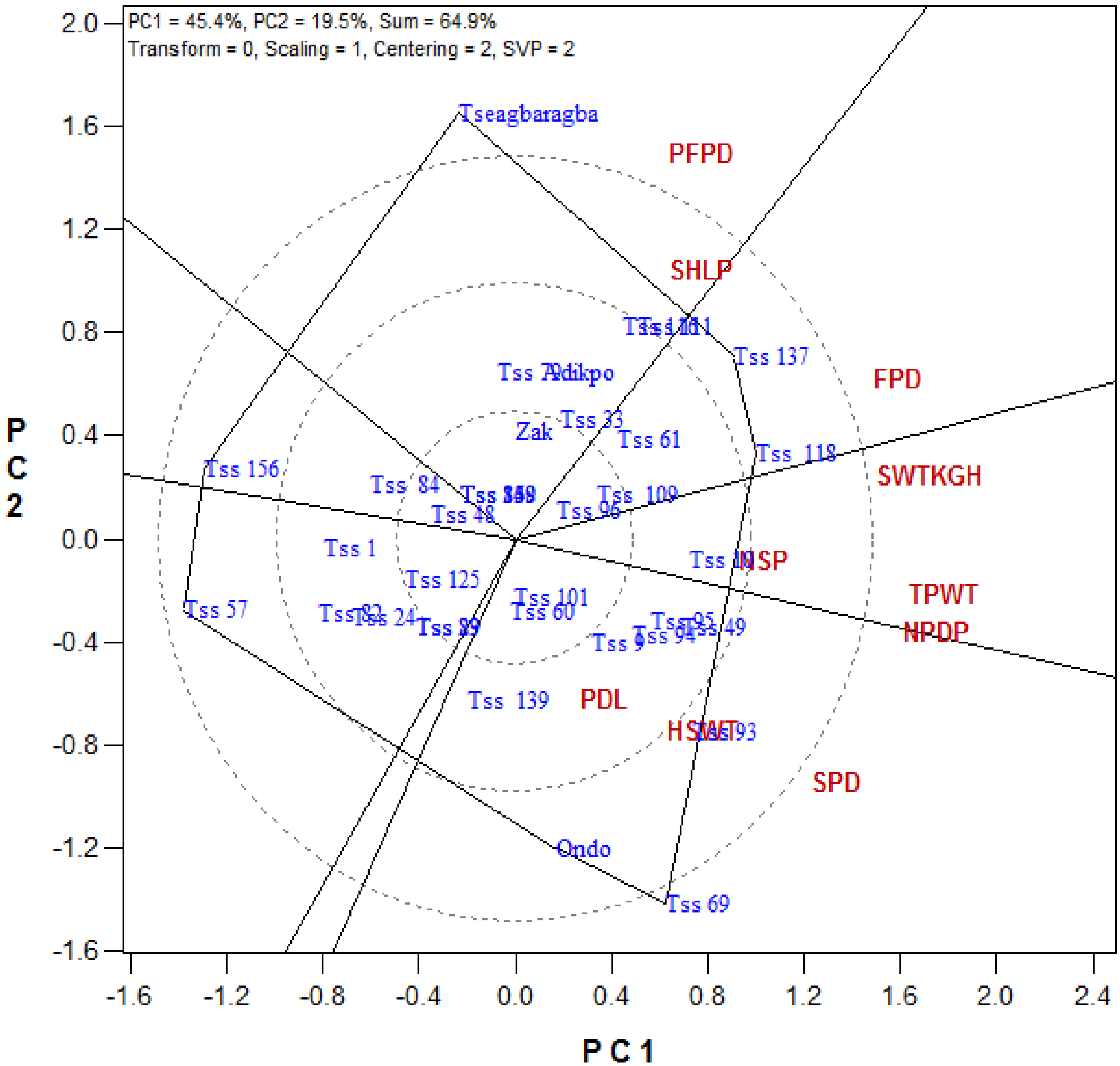

Figure 2: Genotype by Trait analysis of agronomic traits in 36 African yam bean accessions evaluated in 2013

TPWT = total pod weight **NPDP** = number of pods per plant **NFPD** = number of filled pods **SPD** = number of shrivelled pods **PDL** = pod length **NSP** = number of seeds per pod **SWKGH** = seed yield **HSWT** = 100 seed weight **SHLP** = shelling percentage **PFPD** = percentage filled pods **PC** = principal component

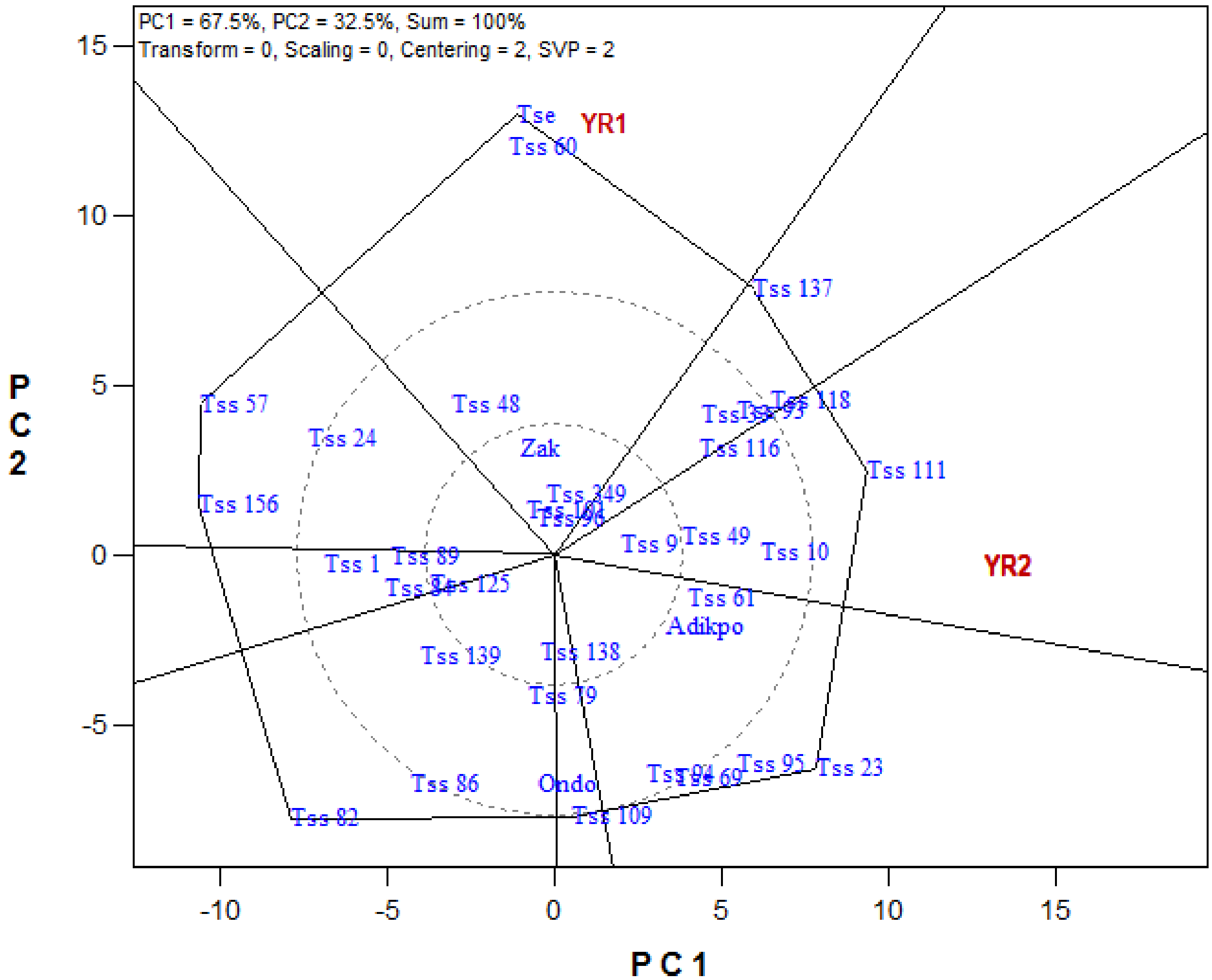

Figure 3: Genotype x Environment interaction analysis of yield in 36 African yam bean accessions in 2012 & 2013 cropping seasons

YR1=Year 1 of the evaluation (2012 cropping season) **YR2**=Year 2 of the evaluation (2013 cropping season) Tse=Tseagbaragba **Tss**=TSs

Discussion

The results of the analyses for the two cropping seasons revealed significant variations in the 15 traits studied in the 36 AYB accessions, suggesting genotypic distinction, which could permit selection for desirable traits. Genetic differences observed in a population of a crop is of great value to the geneticists and plant breeders for the improvement of such a crop plant (Hayward and Breese 1993) while an effective crop improvement strategy largely relies on the level of variation in a base population (Adebisi, et al. 2001). The AYB accessions showed variation in seed yield and best performing (TSs 137, TSs 111, TSs 118, Tseagbaragba, TSs 60 and TSs 93) accessions for seed yield were identified and could be used as parents in breeding for seed yield. The best performing accessions for AYB grain yield also demonstrated good performance for other important traits that contributed significantly to their yield performances.

Pearson's correlation analysis showed interesting significant relationships among the yield and yield-related traits studied. These associations have important implications for AYB selection and crop management. African yam bean grain yield was positively and strongly related with number of filled pods, total pod weight, total number of pods per plant and was moderately and positively associated with shrivelled pods, suggesting that yield is largely associated with these traits. Crop management practices that will enhance any of these traits could significantly increase seed yield in African yam bean. Our results agree with Ojuederie et al. (2015) who reported similar results in their work on AYB evaluations in southwestern Nigeria. The strong and positively significant relationships between yield and these yield-related traits indicate that the improvement in any of these traits results in the improvement of seed yield in AYB. Directly selecting for yield in a number of cases has proven to be misleading due to it being largely influenced by yield components (Chowdhury et al. 2019). For a sound improvement in AYB seed yield, it is therefore important to consider all the seed yield-related traits rather than just considering traits that have high correlation values.

Number of shrivelled pods was also positively and significantly correlated with seed yield. The accessions generally produced a higher number of shrivelled pods than filled pods. The higher number of shrivelled pods could have resulted from the limitation in the strength of the reproductive sinks for dry matter partitioning in favour of pod filling and seed setting. Mechanisms for photoassimilate partitioning for enhanced pod filling are yet to be understood in African yam bean. A clear insight into the mechanisms of the allocation and partitioning of photosynthates in the entire plant basis is useful in enhancing crop yield (Smith et al. 2018). There is, therefore, the need for research efforts for the manipulations of sink dynamics in African yam bean. Enhanced pod filling which results from increased photosynthate partitioning and allocation to the pods and seeds should be selected for in future AYB breeding programmes. Crop management practices for pod filling and seed setting are also needed to increase grain yield in AYB. A lot of floral abscission was observed in the studied accessions. The cause of huge floral abscission in AYB has not been clearly understood and needs further investigation.

Whenever phenotypic evaluation of crop genotypes is performed, a number of traits are simultaneously evaluated, evaluating all the traits is costly and may not enhance selection response (Placide et al. 2015). The principal component analysis is a powerful data analysis tool widely used to classify phenotypic traits in a germplasm into groups and guides the choice of parents for genetic improvement (Afuape et al. 2011; Beheshtizadeh et al. 2013, Placide et al. 2015). It enhances selection efficiency by aiding the identification of key traits that are most discriminatory among the genotypes. The principal component analysis in this study revealed that seed yield, total pod weight, number of filled pods, percentage filled pods, number of days to first emergence, number of days to 50% emergence and number of seeds per pod are the most discriminating agronomic traits in the classification of the African yam bean accessions studied.

The accession by environment interaction and accession by trait biplots clearly show the best and poor performing accessions for various traits studied over the two cropping seasons. The accession by environment interaction biplot for yield performance of the accessions showed that TSs 60 and Tseagbaragba and TSs 111 and TSs 118 were most prominent for seed yield in the first and second years of the evaluation, respectively, while TSs 137 was the overall best performing accession for the two cropping seasons. These excellent accessions that combine good grain yields with other yield-related traits are promising parents that could be used for hybridization purposes by AYB breeding programmes. The evident genotypic variability revealed in this study suggests the possibility of improving grain yield in African yam bean. The variability could be utilized by future AYB improvement programs in developing high yielding AYB varieties.

Conclusion

This study has revealed some degree of exploitable variability among the 36 African yam bean accessions studied. TSs 137 and TSs 118 were the best performing accessions for yield at the Nsukka environment and can be grown by prospective AYB farmers. Breeders with interest in improving grain yield could use TSs 137, TSs 118, Tseagbaragba, TSs 60 and TSs 93 as parents. The best performing accessions for grain yield should be evaluated across different agro-ecologies to ascertain their yield stability.

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