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## GGE BIPLLOT APPLICATION FOR ADAPTABILITY OF AFRICAN YAM BEAN GRAIN YIELD TO FOUR AGRO-ECOLOGIES IN NIGERIA

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### ABSTRACT

Genotypes respond to environments differently; therefore it is important that their response to growing environment should be investigated in order to identify most suitable genotype(s) for specific environment. The objective of this study was to understand the adaptability of some accessions of African yam bean to different agro-ecologies of Nigeria. Thirty African yam bean (AYB) (*Sphenostylis stenocarpa* (Hochst ex. A. Rich) Harms) accessions were evaluated for grain yield adaptability to four agro-environments in Nigeria. Genotype by environment (GE) interaction was significant ( $P < 0.01$ ) for grain yield, with a range of 239.29 kg ha<sup>-1</sup> (TSs 89) to 4130.46 kg ha<sup>-1</sup> (TSs 33). Two principal component axes generated in the biplots explained 70.9% of the total variation due to the accessions and their interaction with the environments. The superior genotypes for each location were TSs82 (Ibadan), TSs116 (Mokwa), TSs24 (Ikenne) and TSs33 (Ubiaja). Three mega-environments arose from the study; namely Ikenne, Ubiaja and Mokwa (Ibadan merged with Mokwa to form a single mega-environment). Ikenne was a more representative environment for AYB production, having a mean grain yield of 1074.53 kg ha<sup>-1</sup>, closest to the grand mean of 1075.57 kg ha<sup>-1</sup>. However, Ubiaja was most supportive for grain production of AYB. Some of the accessions identified with high yielding, adaptable/stable in the study included TSs101, TSs111, TSs93, TSs94, TSs57, TSs104B and TSs109.

**Key Words:** Accessions, mega-environment, principal components, *Sphenostylis stenocarpa*

### RÉSUMÉ

Les génotypes répondent différemment aux environnements, donc il importe que leur réponse à l'environnement de production soit investiguée dans le but d'identifier les génotypes appropriés à l'environnement spécifique. L'objectif de cette étude était de comprendre l'adaptabilité de quelques accessions du pois tubéreux africain aux différentes agro-écologies du Nigéria. Trente accessions du pois tubéreux africain (AYB) (*Sphenostylis stenocarpa* (Hochst ex. A. Rich) Harms) étaient évaluées pour l'adaptabilité du rendement en graines à quatre agro-environnements au Nigéria. L'interaction du génotype avec l'environnement (GE) était significative ( $P < 0,01$ ) pour le rendement en graines, avec une marge de 239,29 kg ha<sup>-1</sup> (TSs 89) à 4130,46 kg ha<sup>-1</sup> (TSs 33). Les deux axes de composantes principales générés dans les biplots, ont expliqué 70,9% de la variation totale due aux accessions et à leur interaction avec les environnements. Les génotypes supérieurs pour chaque location étaient TSs82 (Ibadan), TSs116 (Mokwa), TSs24 (Ikenne) et TSs33 (Ubiaja). Trois méga-environnements étaient obtenus dans l'étude ; à savoir Ikenne, Ubiaja et Mokwa (Ibadan s'est fusionné avec Mokwa pour former un simple méga-environnement). Ikenne était un environnement plus représentatif pour la production de AYB, en ayant un

rendement moyen en graines de 1074,53 kg ha<sup>-1</sup>, proche du plus grand rendement moyen de 1075,57 kg ha<sup>-1</sup>. Néanmoins, Ubiaja était plus favorable pour la production en graines de AYB. Les quelques accessions identifiées avec un rendement élevé, adaptable/stable dans cette étude comprennent: TSs101, TSs111, TSs93, TSs94, TSs57, TSs104B et TSs109.

*Mots Clés:* Accessions, composantes principales, méga-environnement, *Sphenostylis stenocarpa*

## INTRODUCTION

Genotype-by-environment data from multi-environment trials (METs) are valuable for identifying superior genotypes and evaluating the test environments (Yan and Kang, 2003). Much effort has been made to interpret G x E interaction in multi-environment trial of genotypes (Lin *et al.*, 1986). For every MET variance, components include that of genotypes (G), environment (E) and the interaction of the two. GGE biplot only considers G and GE in a MET data because they are the only sources of variation that are relevant for cultivar evaluation (Gauch and Zobel, 1996; Yan *et al.*, 2000; Yan and Kang, 2003). In typical METs, the E accounts for  $\leq 80\%$  of the total variance; G and G x E or GE each account for about 10% (Gauch and Zobel, 1996; Yan *et al.*, 2000; Ortiz *et al.*, 2001).

GGE biplot is a user-friendly software (Yan *et al.*, 2000), working on environment-centre data, which removes the environment main effect and integrates the genotypic main effect with the genotype-by-environment interaction effect of a genotype-by-environment dataset. It displays results of the relationship of the genotypes and the environments in simple, descriptive and explanatory visual graphics. GGE biplot explains the performance of genotypes and the interaction of the same with its environment within a two-dimensional scattered plot based on the scores of the first two principal components (PC) axes (Yan, 2001). Within the GGE biplot the power to discriminate the genotypes is measured by the vector length in the biplot and the representativeness of other test environments is measured by the angle of the test

environment with the “average” environment (Yan, 2001).

The visual descriptive statistical tool, according to Yang *et al.* (2009), has some limitations. GGE biplot software can generate different biplots, depending on the type of scale applied to the data prior to singular value decomposition or principal component analysis (PCA) (Yan and Kang, 2003). Therefore, caution is necessary to avoid indistinct result generation. Miranda *et al.* (2009) stated that the GGE biplot model diagnosis for MET dataset was useful, but cautioned that the accuracy gained from model diagnosis should not be overstated. The two PC axes, which form the biplot frame do not usually account for the total (100%) variability; hence the accuracy of the visual result is relative to the proportion explained by PC1 and PC2 of the total variability.

The understanding and the use of the right scale determines the effectiveness and proper interpretation of GGE biplot results (Yan and Kang, 2003). The most commonly used data scaling methods include (a) no scaling, (b) scaling by the standard deviation of genotype means within environments (SD-scaled), and (c) scaling by the standard error within environments (SE-scaled) (Yan *et al.*, 2000). The SE-scaled GGE biplot has been identified as most appropriate for genotype and test environment evaluation because it accounts for heterogeneity among environments in experimental errors (Yan *et al.*, 2000; Yan and Kang 2003; Blanche and Myers, 2006).

The GGE Biplot software has received widespread use by researchers (Naro *et al.*, 2003; Butron *et al.*, 2004; Ma *et al.*, 2004; Kaya *et al.*, 2006; Aremu *et al.*, 2008; Akande and Balogun, 2009; Alake and Ariyo, 2012).

The multi-facet graphical statistical tool (GGE biplot) informatively explains a higher proportion of the sum of squares of the GxE interaction with regards to environments and cultivar performance (Namorato *et al.*, 2008; Miranda *et al.*, 2009) and makes visualisation more logical and biological for practice than AMMI (Rao *et al.*, 2011). The objective of this study was to assess the grain yield performance of African yam bean (*Sphenostylis stenocarpa* (Hochst ex. A. Rich) Harms) accessions evaluated in four distinct agro-ecologies of Nigeria.

## MATERIALS AND METHODS

Thirty accessions of African yam bean, previously reported for genetic variability (Adewale *et al.*, 2012), were evaluated for grain yield in four environments of Nigeria, namely: Ibadan, Ikenne, Mokwa and Ubiaja agro-ecologies during 2007 growing season. The geographical locations and distinguishing climatic features of the four sites are presented in Table 1. Treatments included thirty accessions of African yam bean and four environments. The experimental design was a randomised complete block (RCB) with three replications. Each replicate had 30 single row plots of 15 metres long and distance between rows was one metre. Three seeds were planted per hill on the ridges at 1 metre apart. The thirty accessions were obtained from the Genetic Resources Centre, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

At planting, a mixture of Premextra and Gramoxone at 80 and 70 ml, respectively; in 20 litres of water, was applied to control pre and post-emergent weeds. Thinning of the seedlings was carried out two weeks after planting (WAP), and staking at 3 WAP. Sixty kilogrammes of NPK (15:15:15) fertiliser was applied in two splits, by ring application, at 4 and 8 WAP. Insecticide (Nuvacron at 2.5 ml

l<sup>-1</sup>) was applied at intervals of 2 weeks, from flowering inception to control floral and pod pests. Subsequently, manual weeding was carried out regularly, to keep the field free of weeds.

Grain yield data from the four locations were obtained. Grain yield per hectare (kg ha<sup>-1</sup>) was calculated as the product of the mean seed yield of 15 plants per plot and 10,000 plants (plant population per hectare). The plot means of grain yield for each replication was subjected to Analysis of Variance (ANOVA) using PROC GLM in SAS for the combined locations. The means of accessions were compared using critical difference (CD), following Singh and Chaudhary (1985):

$$CD = (2 MS_e/r)^{1/2} \times t$$

Where:

$MS_e$  = the error mean square,

$r$  = the number of replicates, and

$t$  = the tabulated value at 5% level of significance for the degree of freedom of error mean square.

Based on ANOVA, the interaction between the accessions and the environment was significant for grain yield; therefore, the genotype by environment (GE) interaction source of variation was partitioned as recommended by Samonte and Hernandez (1990). The GE variance was partitioned using GGE Biplot Software. Detailed description of the basic model for the GGE biplot was described in Yan (2001) and Yan *et al.* (2007). From our genotype-by-environment two-way table, different GGE biplots were generated, depending on the scaling factor. In each case, a two-dimensional GGE biplot was constructed with the first two principal components (PC1 and PC2).

TABLE 1. Coordinates, agro-ecology and total monthly rainfall of the four locations in 2007 cropping season in Nigeria

Locations	Ibadan	Ikenne	Mokwa	Ubiaja
Coordinates	7.5°N, 3.9°E	6.9°N, 3.7°E	9.3°N, 5.05°E	6.65°N, 6.38°E
Agro-ecology	Forest-savanna transition zone	Lowland humid forest	Southern guinea savanna	Humid rainforest
Months	----- Total monthly rainfall (mm) -----			
January	-	-	-	-
February	0.05	-	-	42.0
March	15.9	38.4	10.0	71.8
April	70.7	16.0	116.0	111.3
May	201.27	141.0	202.5	215.2
June	308.25	409.7	127.5	205.4
July	145.5	286.8	106.0	298.2
August	121.55	144.4	414.0	150.1
September	264.75	313.6	363.0	416.8
October	203.95	170.2	39.5	185.2
November	9.85	70.1	-	0.7
December	0.05	4.5	-	21.5
Total	1341.82	1594.7	1378.5	1718.2
Mean	111.82	132.89	114.88	143.18

Source: Geo-Spatial Laboratory at IITA, Ibadan, Nigeria

## RESULTS

There were significant differences ( $P < 0.01$ ) among the locations, accessions and the interaction of both (Table 2). The highest mean grain yield ( $2037.74 \text{ kg ha}^{-1}$ ) of the thirty accessions was recorded at Ubiaja; followed by Ikenne with a mean of  $1074.53 \text{ kg ha}^{-1}$ . The poorest grain yield ( $440.78 \text{ kg ha}^{-1}$ ) was recorded at Mokwa (Table 3). Overall, grain yield ranged between  $239.29$  (TSs89, Mokwa) to  $4130.46 \text{ kg ha}^{-1}$  (TSs33, Ubiaja).

The GGE biplot for grain yield data of the 30 AYB accessions is presented in Figure 1. The biplot consists of PC1 scores, plotted against PC2 scores for both accessions and environments. The two axes explained 70.9% of the total variation relative to the accessions and their interaction with the environment (i.e. G + GE). PC1 scores greater than 0.0 detected the accessions with good adaptability and high yields. Moreover, PC1 with less than 0.0 discriminated the poorly-adapted and low yielding accessions (Fig. 1). Unlike the PC1, PC2 measures genotypic stability or instability. Two groups evolved based on the values ( $= 0$  or  $\neq 0$ ) along the PC2 axis; the stable and the unstable accessions. Accessions found along 0.0 on the PC2 were stable. Accessions farther away from PC2 at 0.0 were less stable. Therefore, TSs111 was a good and stable yielder; while TSs118 was a poor but stable yielder (Fig. 1).

GGE biplot analysis specifically revealed the performances of the different accessions in each environment (Figs. 2 - 5). The arrow-head thick line in Figures 2 - 5 are the axes of each environment (environmental axis) in the increasing order of accessions yield. In Figures 2 - 5, PL which is perpendicular to each environmental axis separated the thirty accessions differently into two groups: below average (behind the arrow-head) and above average (toward the arrow-head) accessions.

Mean grain yield for the thirty AYB accessions at Ibadan was  $749.22 \text{ kg ha}^{-1}$  (Table 3). Accessions with below mean yield (Fig. 2) (featuring at the North of PL) included TSs81, TSs96, TSs109, TSs94, TSs93, TSs23, TSs58, TSs67, TSs118, TSs89, TSs87, TSs48, TSs49 and TSs69. Other accessions to the South of PL (Fig. 2) had higher than mean yield ( $749.22 \text{ kg ha}^{-1}$ ), TSs82 ranked top and was the best genotype in Ibadan. TSs84 had the shortest environmental axis projection in Fig. 2; therefore, it is the most adapted accession in Ibadan.

In Figure 3, sixteen accessions had above-average yield. Mean grain yield at Ikenne was  $1074.53 \text{ kg ha}^{-1}$  (Table 3). TSs24 had the highest yield (about 1.8 tonnes of grain per hectare, Table 3); and was well adapted to the location because of its closeness (short projection) to the environmental axis of Ikenne. TSs82 trailed behind the fourteen accessions (Fig. 3).

TABLE 2. Summary of the analysis of variance for a grain yield

Sources of variation	Degree of freedom	Mean squares
Locations	3	43057348.2***
Accessions	29	570650.4***
Accession x Location	87	349735.8**
Error	232	215360.8
Mean		1075.57
CV (%)		43.15

TABLE 3. Grain yield (kg ha<sup>-1</sup>) of the thirty accessions of African yam bean in the four environments in Nigeria

Accessions	Environments				Mean
	Ibadan	Ikenne	Mokwa	Ubiaja	
TSs9	803.35	1036.10	374.28	1993.69	1051.86
TSs10	736.03	954.46	374.28	2819.51	1221.07
TSs23	661.57	1070.96	259.88	1553.79	886.55
TSs24	809.93	1770.93	616.96	2780.66	1494.62
TSs33	946.65	1450.97	514.48	4130.46	1760.64
TSs48	582.66	989.25	343.67	1505.07	855.16
TSs49	640.01	790.04	336.68	2028.93	948.92
TSs57	723.97	1267.80	629.86	2094.04	1178.92
TSs58	614.46	1053.45	334.11	1197.00	799.76
TSs61	716.85	1168.02	449.03	1598.66	983.14
TSs67	441.71	1007.96	391.16	1290.25	782.77
TSs69	463.00	845.90	283.05	2308.82	975.19
TSs81	758.91	883.13	248.00	1739.12	907.29
TSs82	1471.44	784.62	429.41	1217.61	975.77
TSs84	1022.05	941.37	578.59	2273.48	1203.87
TSs86	1425.26	1008.32	295.43	1416.01	1036.26
TSs87	547.22	830.12	328.64	1303.36	752.34
TSs89	614.36	973.10	239.29	1920.43	936.80
TSs91	833.33	1022.90	331.81	1881.42	1017.37
TSs93	643.10	1168.83	492.20	2062.69	1091.71
TSs94	513.14	1082.82	635.79	1685.47	979.31
TSs95	647.76	1172.51	411.88	2071.22	1075.84
TSs96	586.26	1218.06	374.38	3232.16	1352.72
TSs101	744.61	1157.50	471.82	1936.31	1077.56
TSs104B	918.06	961.49	609.79	2438.80	1232.04
TSs109	590.15	1135.60	596.09	2656.59	1244.61
TSs111	783.28	1340.52	408.42	1600.36	1033.15
TSs116	895.63	1291.46	1086.91	2028.20	1325.55
TSs118	478.62	796.14	462.70	1942.27	919.93
TSs125	863.35	1061.50	314.68	2425.95	1166.37
Mean	749.22	1074.53	440.78	2037.74	1075.57
CD (5%)	562.09	386.12	304.19	1301.50	638.48
CV (%)	46.41	22.23	42.69	39.51	37.71

CD = Critical differences, mean difference between two accessions that exceeds the critical difference value (CD (5%)) is significant at P = 0.05

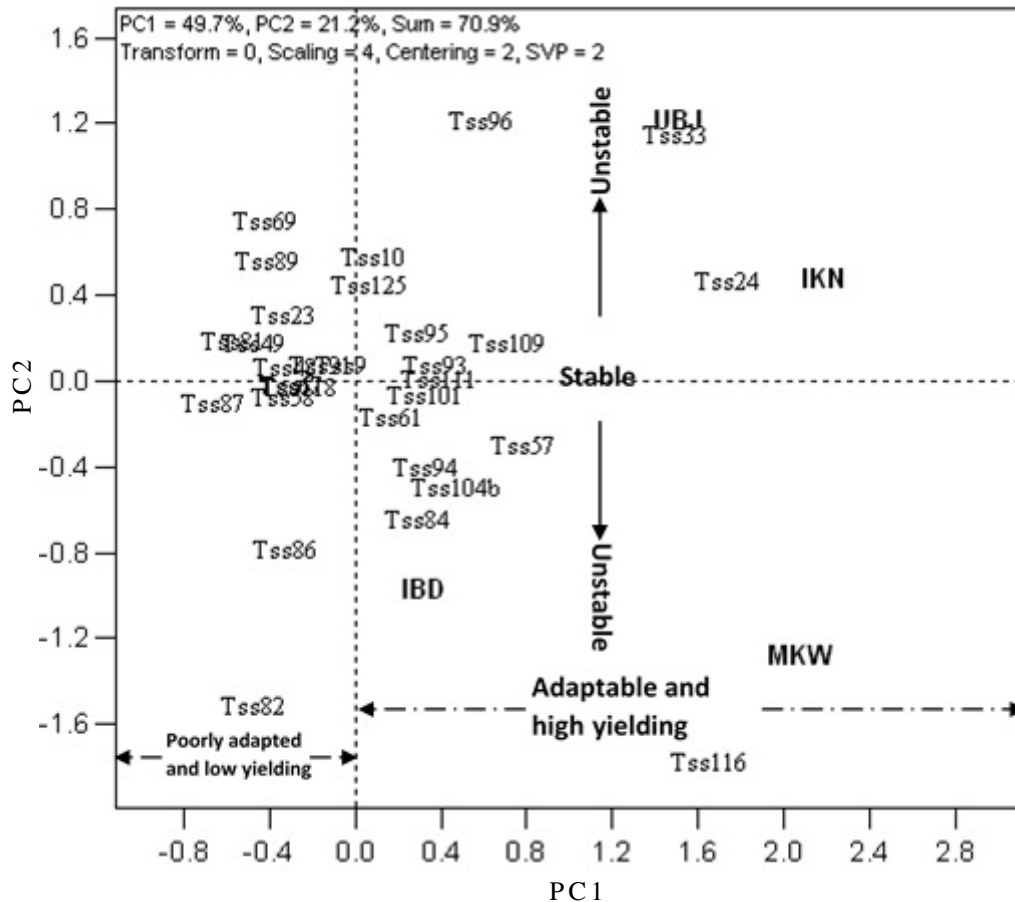


Figure 1. GGE biplot of the grain yield of thirty accessions of African yam bean in a trial across four locations in Nigeria. IBD = Ibadan, IKN = Ikenne, MKW = Mokwa and UBJ = Ubiaja.

In Figure 4, Mokwa environment enhanced the above mean ( $> 440.78 \text{ kg ha}^{-1}$ ) performance of 15 accessions. The remaining half of the accessions had grain yield lower than  $440.78 \text{ kg ha}^{-1}$ . The higher yielders in Mokwa were to the west of PL. The highest grain yield ( $1086.91 \text{ kg ha}^{-1}$ , Table 3) was obtained in TSS116. TSS69 was the lowest grain yielder in Mokwa.

Mean yield in Ubiaja was  $2037.74 \text{ kg ha}^{-1}$  (Table 3). Twelve accessions (to the west of PL) had above mean grain yield (Fig. 5). TSS33 had the best performance and was equally the most adapted accession in the agro-ecology because of the proximity of the accession to the environmental axis of the location. TSS82

again trailed behind the remaining 18 poor yielders in Ubiaja.

The polygon view of the GGE biplot gives a visualisation pattern, which reveals the accession that was superior in a specific environment, “which-won-where”. Figure 6 presented a GGE biplot, where all the accessions were enclosed within a heptagon. The vertexes were named after the seven accessions at each vertex. Seven projecting lines (OA, OB, OC, OD, OE, OF and OG) from the origin (O), further divided the heptagon into seven sectors, cutting the sides of the heptagon perpendicularly. The four environments fell in three of the seven sectors (Fig. 6). Sector 1 was AOB, which had Ubiaja



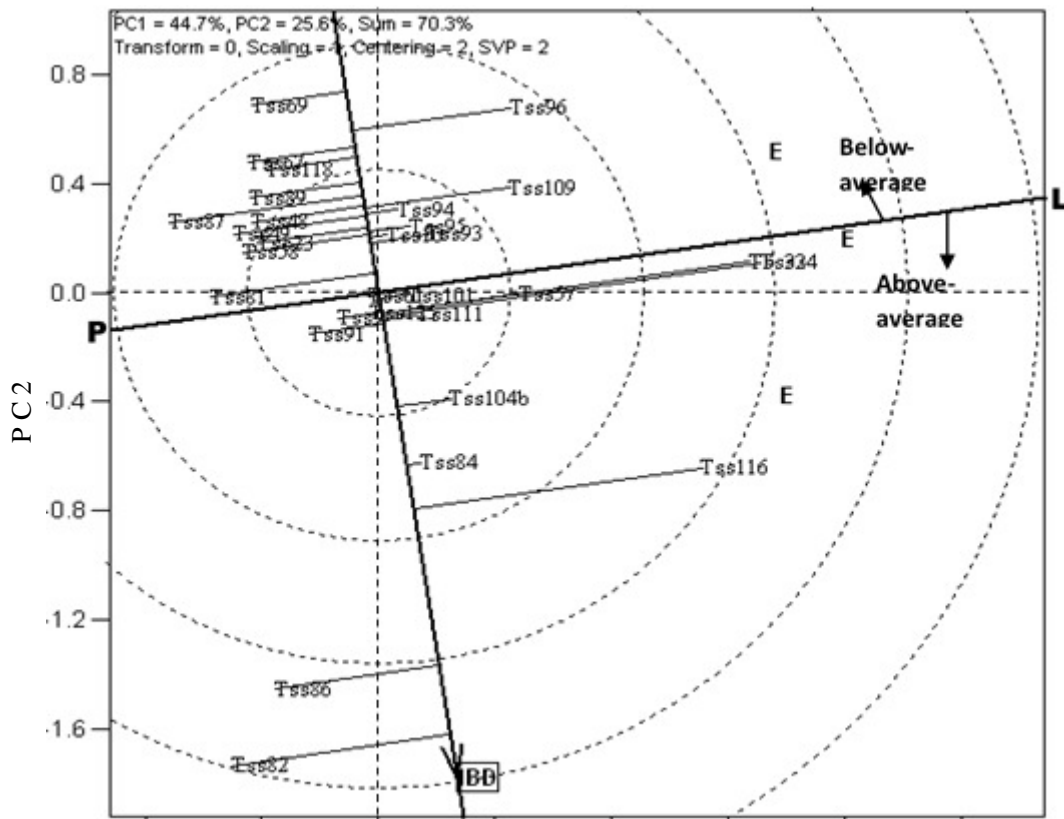


Figure 2. A biplot for grain yield profiles of the thirty accessions of African yam bean at Ibadan, Nigeria.

as the only environment. The two accessions in the sector were TSs33 and TSs96, and both were most adaptable to Ubiaja; but TSs33 (the vertex accession) was superior in grain yield.

BOC was sector 2, in which Ikenne was located. TSs24 was the vertex accession, and had the highest yield in the environment. Mokwa and Ibadan came under sector 3; TSs116 was the vertex accession with the highest yield. The vertex accessions for sectors 4, 5 and 6 were TSs82, TSs87 and TSs69, respectively. These accessions were unstable; with poor yield and low adaptability with respect to the four tested environments. Sector 7 had no representative accession.

The AEC ordinate and AEC abscissa passed through the origin, and aligned perpendicularly to each other. The AEC ordinate separated the

accessions with poor yielders from those with good yielders. Furthermore, the average yield of accessions was approximated by the projections of their markers to the AEC abscissa. Therefore, accessions with good yield, irrespective of their location along the AEC abscissa; included TSs116, TSs96, TSs33, TSs24, TSs95, TSs104B, TSs84 and TSs109; while those with poor yield were TSs87, TSs82, TSs86, TSs69, TSs89, TSs23, TSs10 (Fig. 7). The AEC abscissa, which passed through the biplot origin and along the average environment, had its arrow head at the spot represented by the small circle. This spot approximated the mean and stable yield of the 30 accessions. It could otherwise be called the ideal AYB accession. TSs57 had the highest proximity to the ideal AYB accession.



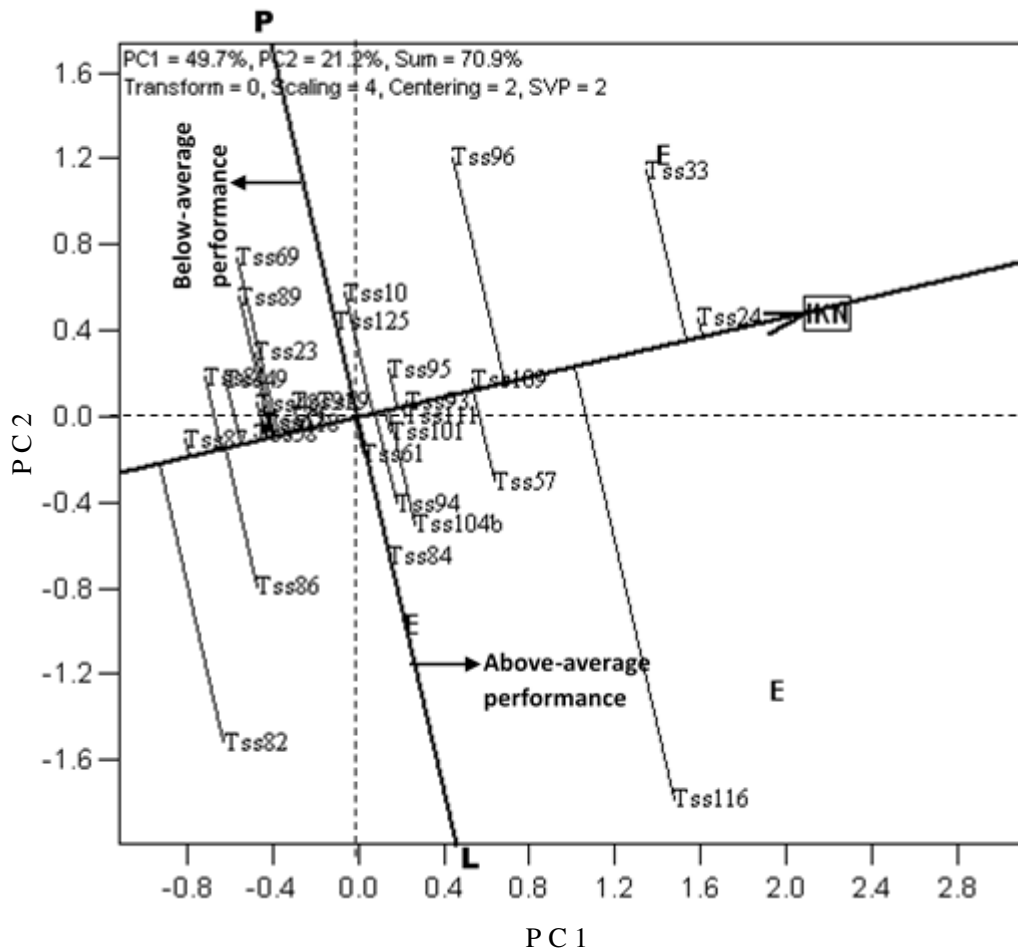


Figure 3. Grain yield performance of the thirty accessions of African yam bean at Ikenne in Nigeria.

Figure 8 displayed the average environment coordinate using the environment-focused scaling in GGE biplot, to test how distinct and representative each environment was. Discriminating ability is based on the vector length of each environment; the longer the more discriminating. A highly discriminating environment provides distinctive information with high genotypic inference on the tested genotypes. Hence, Mokwa, Ikenne and Ubiaja were most discriminating for the thirty AYB accessions than Ibadan. The average environment is indicated by the small circle to which the AEC abscissa axis, passing through

the biplot origin, pointed in Figure 8. Therefore, Ikenne was more representative, having a mean grain yield ( $1074.53 \text{ kg ha}^{-1}$ ) closest to the grand mean ( $1075.57 \text{ kg ha}^{-1}$ ). Moreover, Ikenne and Mokwa were near the ideal environment because of the low acute angle of their vector to the AEC abscissa. Ubiaja and Ibadan with larger acute angle to AEC axis were less representative.

## DISCUSSION

The significant differences observed among locations (Table 2) can be attributed to

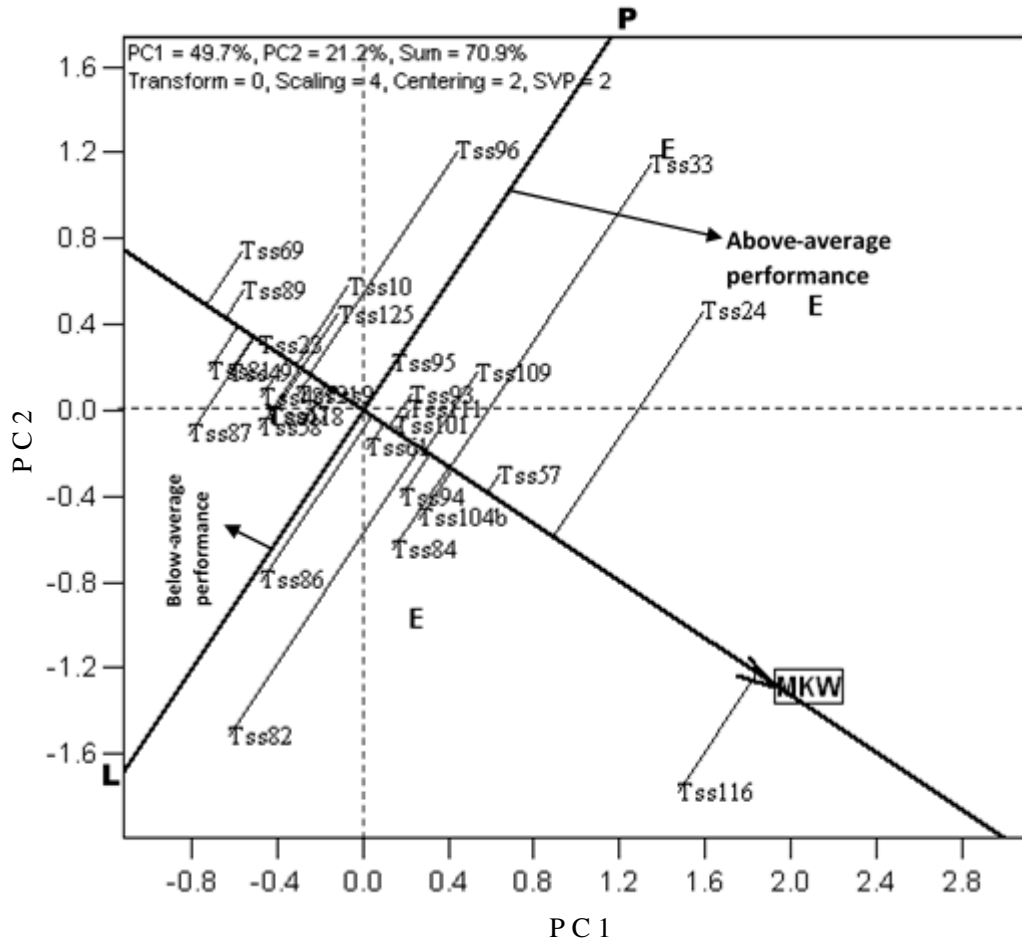


Figure 4. Grain yield performance of the thirty accessions of African yam bean at Mokwa in Nigeria.

differences in rainfall precipitation, with Ibadan having the lowest amount of annual precipitation for the year of study. The wide range in grain yield among the 30 accessions (Table 3) and their significant inconsistent performances in each of the four locations (Table 2) depict the crossover genotype by environment interaction and significant differences among the four environments. The high yields of the thirty accessions in Ubiaja (Table 3) could be linked to the high amount and distribution of rainfall. Lower rainfall as obtained in Mokwa (Southern Guinea Savanna) and Ibadan (Forest-Savanna transition zone) in 2007 may not be supportive to AYB's productivity. Adewale and Odoh (2013)

reported that AYB matures within five to seven months. Due to photoperiodic sensitivity, flowering in AYB starts from late September. Hence, the lower yields of the 30 accessions, especially in Mokwa, could be explained by the inadequacy of moisture shortly after flowering. This seems to reflect that moisture availability supports grain filling. Our result concurs with earlier findings (Baigorri *et al.*, 1999; Costa-Franca *et al.*, 2000; Ghassemi-Golezani *et al.*, 2009) that water deficit during the reproductive growth tends to have the most adverse effect on crop productivity.

Partitioning of the GGE component through GGE biplot analysis (Fig. 1) showed that PC1 and PC2 were the most significant axes,



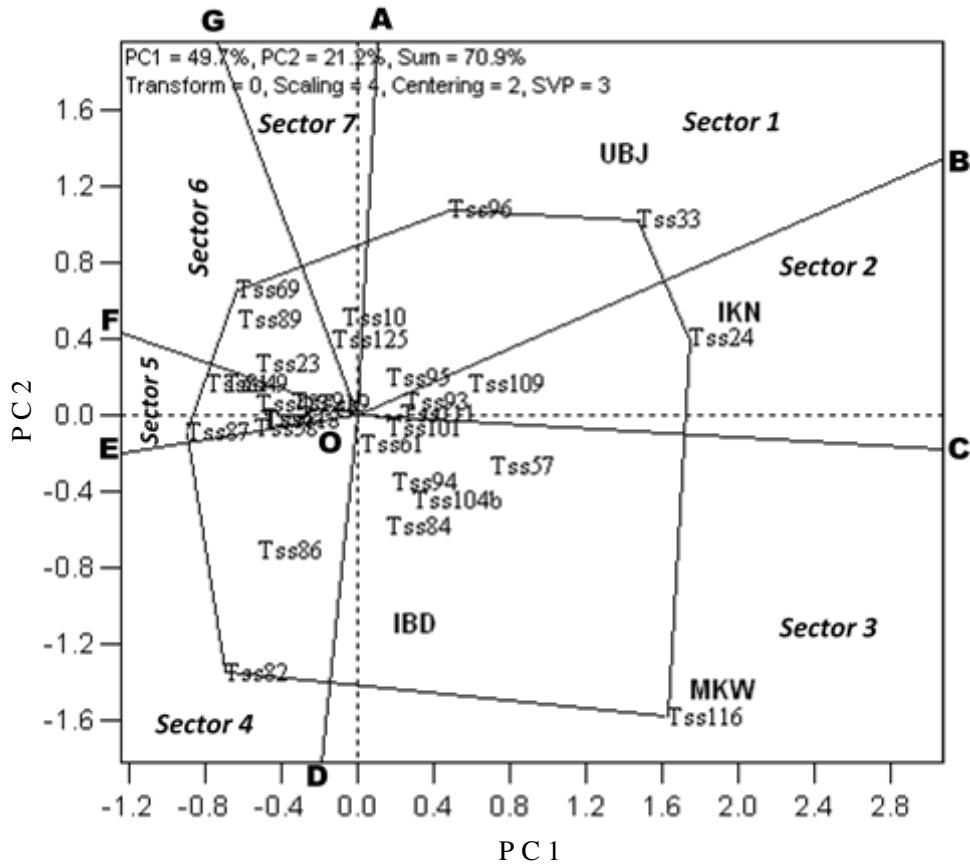


Figure 6. Polygon view of GGE biplot showing which accession had the best grain yield in which environment in Nigeria. IBD – Ibadan, IKN –Ikenne, MKW –Mokwa and UBJ – Ubiaja.

of Ubiaja seems to offer a productive environment for AYB in Nigeria.

The GGE biplot identified three mega environments, namely, Ubiaja, Ikenne and Mokwa for their uniqueness and representativeness in discriminating the thirty accessions of AYB. It, therefore, implied that Ibadan can be classified a microenvironment within Mokwa or *vice-versa* according to the procedure of Yan *et al.* (2000); Yan and Kang (2003). Ibadan (forest-savanna transition ecology) and Mokwa (southern guinea savanna ecology) are locations within the Nigerian savanna. Interestingly, the mean annual rainfall for Ibadan in 2007 was lowest (111.82 mm) among the other environments and this may have impaired performance of the accessions

in Ibadan in 2007. Ikenne and Ubiaja are locations within the forest zone with differing annual rainfalls (Table 1); the differing rainfall could be implicated for the varied performances of the accessions in the two locations.

High PC1 score of an environment makes it highly discriminating among accessions, yet the nearness of the site to zero PC2 scores make it more representative of an average environment (Yan *et al.*, 2001). Ikenne is the nearest to the ideal environment in the present study and, therefore, could be considered to be the most favourable environment for at least an average performance of the 30 tested AYB accessions. Grain yield from Ikenne was 1074.53 kg ha<sup>-1</sup> compared to the overall mean

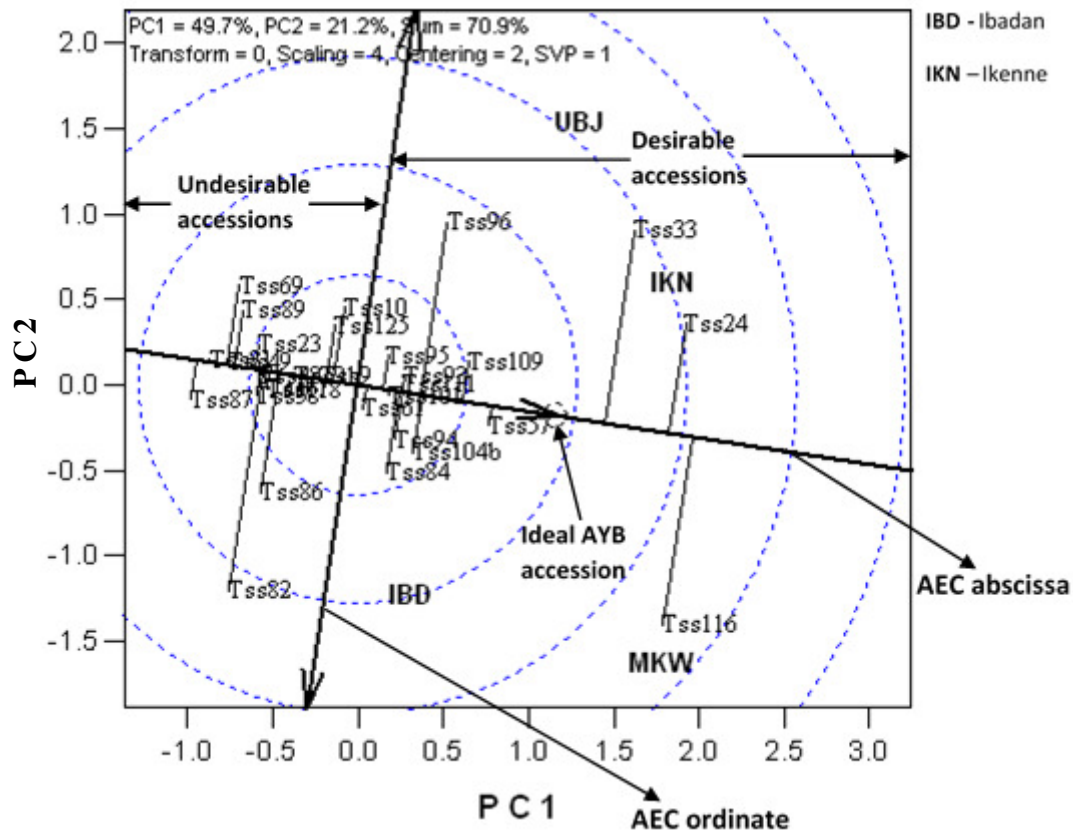


Figure 7. Mean environment coordinates (AEC) view of the GGE biplot based on the accession-focused scaling, showing the mean yield and stability of accessions. IBD – Ibadan, IKN –Ikenne, MKW –Mokwa and UBJ – Ubiaja.

grain yield of 1075.57 kg ha<sup>-1</sup>. The present study did not identify Ibadan as a mega-environment; however, further studies with many years' data (Yan and Kang, 2003) would be needed to authenticate the relevance of Ibadan as a testing site for AYB evaluation in Nigeria.

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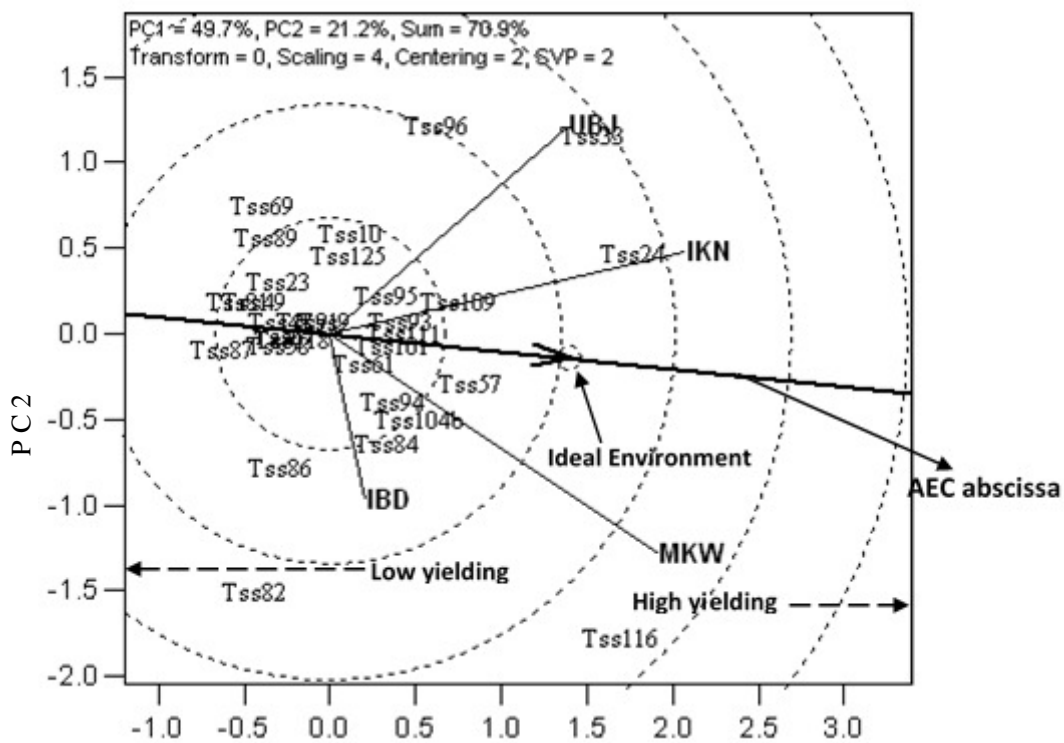


Figure 8. Mean environment coordinates (AEC) view of the GGE biplot based on the environment-focused scaling, showing the ideal environment for AYB along the AEC abscissa. IBD = Ibadan, IKN = Ikenne, MKW = Mokwa and UBJ = Ubiaja.

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