Research Article

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Assessing yield stability in African yam bean (*Sphenostylis stenocarpa*) performance using year effect

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Abstract: Maintaining yield stability in the African yam bean (AYB) (*Sphenostylis stenocarpa*) under year-to-year variability is crucial to its sustained productivity. Exploring yield stability in crops is vital in identifying how stable and consistent the yield of such crops is. Cultivation of AYB, an underutilized traditional legume in a specific environment, will further popularize the crop and enhance the acceptance as a cheap protein source thereby reducing hunger and malnutrition especially in regions where climate change has negatively affected legume crop production. Field trials were carried out to study the performance of 23 AYB genotypes in four-year environments. Two seeds of each genotype were sown in a single 5 m row plot spaced at 1 m between and within rows; the trial was conducted during the cropping season of 2011, 2012, 2013, and 2014 and was laid out in a randomized complete block design (RCBD) with three replications. At harvesting, five plants from each row were separately harvested; seeds of all the sampled plants in each plot were bulked and weighed, and the seed yield per plant was then determined. A combined analysis of variance (ANOVA) was performed to test for the significance of genotypes, year, and genotype by year interaction. Before

combined ANOVA, a test for homogeneity of residual variances was performed using Bartlett's test; stability of the genotypes over the years was ascertained numerically and graphically using additive main effects and multiplicative interaction and Genotype X Genotype X Environment interaction (GGE) biplot analyses. Rainfall distribution between 680 and 1,700 mm with an average temperature of 28.50°C under sandy-clay soil type supported high and stable seed yield production in AYB. This environment was found adequate during the 2014 (E1) growing season. Genotypes TSs118, TSs12, TSs109, TSs148, TSs5, TSs61, and TSs69 produced an above-average mean yield across the years and were found to be productive and stable in all the year environments. TSs82 and TSs6 with above-average mean seed and tuber yield can be considered for cultivation where seed and tuber dual-purpose production is to be maximized, while TSs111, TSs49, and TSs96 with high tuber yield ranking above average total tuber yield can be further enhanced for tuber production.

Keywords: African yam bean, weather environment, year effect, productivity, GGE biplot, additive main effects and multiplicative interaction analysis, selection accuracy

1 Introduction

Achieving yield stability under increased year-to-year yield variation is an important breeding goal for indigenous legumes as their relevance for food security is becoming more prominent in Africa (Thiyagu et al. 2012). Again, the use of stability parameters is important in defining and identifying crop genotypes with consistent yield production (Clarkea et al. 2019). African yam bean (AYB) (*Sphenostylis stenocarpa*) is an important pulse crop grown predominantly in the South Western parts of Nigeria and some African nations. Aside from producing seeds, some accessions also bear tubers (Apata and Ologhobo 1990; Ikhajagbe et al. 2007). Recently, the crop has gained a renewed interest by

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researchers, not because of its high-nutritional value alone, but also the ability of the crop to grow over a wide range of climatic and soil conditions (Aremu et al. 2007; Arogundade et al. 2014; Malumba et al. 2016). Furthermore, AYB contributes to soil fertility improvement through atmospheric nitrogen fixation (Assefa and Kleiner 1997). Despite these advantages in recent years, the total acreage for AYB production is on a constant declining trend, leading to low productivity (Linneman 1995; Aremu and Ibirinde 2012; Arogundade et al. 2016) when compared with other grain legumes. This is ascribed to yield instability, particularly in AYB producing areas, characterized by high interannual yield variability (Sood et al. 2011). This emphasizes the need for developing high yield stable genotypes to survive the challenges of meteorological factors fluctuation. Similarly, this will help developing economies that are characterized by low income and high unemployment rates such as Nigeria to improve their food nutritional qualities (Adama et al. 2018; Asaleye et al. 2018; Popoola et al. 2018). The fact that the performance of AYB is strongly influenced by variability in the environments, at the very least, and those representing yearly weather variation, makes it a barrier for improving yield potential (Yadava et al. 2011). Multi-environment trials are typically used in plant breeding programs to evaluate genetic materials over a range of years in a target environment (Holtsford and Ellstrand 1992; Odeseye et al. 2018; Ibrahima et al. 2019). However, when comparing these genetic materials, their interaction with the environment is often expected to a certain degree.

Genotype by environment interaction ($G \times E$) usually refers to the differential response of genotypes for a given trait across environments and is considered an important source of year-to-year variation in crop yield (Owusua et al. 2018; Seyouma et al. 2019). Therefore, the most trustworthy approach to manage $G \times E$ interaction is the adoption of stable cultivars in a cropping system (Adeniyen et al. 2007). For developing high-yield stable cultivars, it becomes imperative to identify stable sources through the analysis of $G \times E$ interaction in cultivar evaluation trials conducted over the years. The development of high yielding stable AYB cultivars is itself a strenuous task due to the influence of several factors that affect plant growth, which is documented to be compounded by year-to-year variability in weather (Kang and Pham 1991; Adewale and Dumet 2011). Therefore, understanding changes in yield are important for harnessing genotypic stability. To understand the influences of year-to-year variability in weather on genotype yield stability, a repetitive field testing and trait evaluation are conducted while employing statistical tools that directly test for the presence of $G \times E$ and measure individual genotype stability. The existence of $G \times E$ and yield stability can be

evaluated using various multivariate techniques (Ene-Obong and Okoye 1992; Farias et al. 2017). A number of outstanding reviews of most of the current statistical tools to test and measure genotypic stability have been published (Baye 2002; Adewale et al. 2010; Aremu et al. 2018). Among them, the most widely used is the additive main effects and multiplicative interaction (AMMI) analysis, which is a hybrid model that incorporates both analyses of variance and principal component analysis, has been considered as a powerful statistical tool for interpreting $G \times E$ interaction and extensively used in plant breeding research (Cornelius et al. 1992; Das et al. 2010).

The attainment of stable genotypes and identification of testing/breeding environments with respect to targeted traits is the ultimate goal of any breeding program (Adewale and Dumet 2011). On this basis, estimating the magnitude of $G \times Y$ interaction on yield stability in AYB has a crucial role to play here because yield stability acts as a buffer against crop failure for resource-poor farmers in Africa. Thus, the exploration of considerable variation among cultivars to identifying stable genotypes for seed yield is highly essential for the sustainability of the smallholder farming system in sub-Saharan Africa. It has previously been reported that the selection of AYB for yield stability is a complex process due to the influence of $G \times E$ that affect yield (Holts 1995). When unpredictable environmental factors, such as year-to-year variation results in significant $G \times E$ interaction, crop improvement scientists need to develop stable cultivars that perform reasonably well under a range of environmental conditions.

Consequently, genotype main effect plus genotype $\times$ environment interaction (GGE also called site regression analysis, a graphical analysis method of multi-environment data) has been widely exploited in the identification of most adapted stable genotypes in target environments (Gauch and Zobel 1996; Cartera et al. 2018; Ngailo et al. 2019). In the AYB cultivar breeding program, yield (pod or tuber) stability is an important breeding objective, next to yield potential (Cornelius et al. 1992). A multi-environment trial in plant breeding remains a challenge as a result of genotype $\times$ environment interaction (GEI). The choice of statistical analysis plays a key role in determining accuracy in the recommendation of both productive and stable test environments. To date, very few studies have been reported on performance trials of AYB, and the studies concluded that the selection of superior genotypes for yield is impacted by $G \times E$ (Anley et al. 2013). However, no stability study has been performed using a multiyear yield trial for a diverse range of AYB cultivars,

representing a large share of national genetic variation of AYB germplasm collections. The collections for this study are maintained in the gene bank of the International Institute of Tropical Agriculture (IITA). Hence, this study obtains information on seed yield performance of 23 AYB genotypes using $G \times Y$ interaction analysis and hence assesses the joint value of AMMI and GGE techniques for the identification of stable and high yielding AYB genotypes for the use of farmers and specific crop breeding research.

2 Material and methods

2.1 Genetic materials and field trials

Four field experiments were conducted between 2011 and 2014 at the Teaching and Research Farm of Ladoko Akintola University of Technology, Ogbomoso (longitudes 4°100E, Latitude 8°100 N, 149 masl), Nigeria. The study site is representative of the Guinea Savannah Zone of Southern Nigeria. The soil type of this site is sandy-clayey; there are two main cropping seasons, early cropping season (April–July) and late cropping season (August–November). AYB is mostly planted during the early cropping season. The weather parameters prevailing during the experimental years were taken and are presented in Table 1.

Twenty-three (23) accessions of AYB (presented in Table 2) obtained from diverse eco-geographical origins of Nigeria were sourced from the gene bank of the IITA, Ibadan, in 2010. These cultivars were selected for this study based on their diversity for various agronomic traits.

The experimental sites were cleared, plowed, and harrowed. Two seeds of each genotype were sown in single 5 m row plots spaced at 1 m between and within rows. This gives a population density of 10,000 plants per hectare. The trial was conducted at each year (April

30th, May 1st, May 31st, and June 20th during the cropping season of 2011, 2012, 2013, and 2014, respectively) and was laid out in a randomized complete block design (RCBD) with three replications. Due to the effect of climate change observed during the cropping season, the experiment was not carried out on the same date of each year. However, the early season was put into consideration to ensure little variation in the weather condition. This was done by planting the genotypes during the early cropping season between April and June for the four years considered. Likewise, this will also enhance the understanding of how climate and weather change affects legume crop production. The blocks were separated by a 2-m alley to reduce inter-block plant competition. Interplots were separated by 1-m spacing between and within rows. The four trials were conducted during the rainy season. Hand weeding was carried out as at when needed to maintain a clean field. Two seeds were sown per stand to give two-plant stands and a total of ten plants. Only one of each inner plant stand was harvested to give five plants from each row which were separately harvested. Seeds of all the sampled plants in each plot were bulked and weighed, and the seed yield per plant (g) was then determined by dividing by five.

2.2 Statistical analyses

A combined analysis of variance (ANOVA) for RCBD across the years (environments) was performed to test for the significance of genotypes, year, and genotype by year interaction using the general linear model (GLM) procedure of the Statistical Analysis System (SAS 9.1) statistical package (SAS, 2004). Before combined ANOVA, a test for homogeneity of residual variances was performed using Bartlett's test (Steel *et al.* 1996). The stability of the genotypes over the years was ascertained numerically and graphically using AMMI and GGE biplot

Table 1: Agro-meteorological and soil data characteristics of the experimental site (Ogbomoso, Nigeria)

Agroecology	Latitude (°N)	Longitude (°E)	Year	Annual rainfall (mm) Min–max	Temperature		R/Humidity (%)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)
					Min–max	Average				
Guinea savannah	8°100 N	4°100E	2011	530–1,100	30–35	32.5	61	810	90	100
			2012	590–1,200	29–32	30.5	65	810	90	100
			2013	608–1,500	34–37	35.05	71	810	90	100
			2014	680–1,700	26–31	28.5	78	810	90	100

Table 2: Description of the AYB genotypes as sourced in 2010

S/n	Genotype	Seed coat colour	Genetic code	Status/crop description	Source
1	TSs118	Yellowish grey	G1	Seed only	IITA
2	TSs10	Camel brown	G2	Seed and tuber	IITA
3	TSs12	Brown	G3	Seed and nodule	IITA
4	TSs109	Tan brown	G4	Seed and tuber	IITA
5	TSs111	Sun – burn brown	G5	Seed and nodule	IITA
6	TSs148	Mottled brown	G6	Seed and nodule	IITA
7	TSs45	Sahara brown	G7	Seed and nodule	IITA
8	TSs47	Sun – burn brown (V)	G8	Seed and nodule	IITA
9	TSs6	Cocoa brown	G9	Seed and nodule	IITA
10	TSs93	Agate	G10	Seed and tuber	IITA
11	TSs95	Light brown	G11	Seed and tuber	IITA
12	TSs96	Light brown	G12	Seed and tuber	IITA
13	TSs116	Camel brown	G13	Seed and nodule	IITA
14	TSs48	Sahara brown	G14	Seed and nodule	IITA
15	TSs49	Sun – burn brown (V)	G15	Seed	IITA
16	TSs57	Reddish golden (V)	G16	Seed	IITA
17	TSs58	Light brown (V)	G17	Seed	IITA
18	TSs60	Reddish golden	G18	Seed	IITA
19	TSs61	Red – haired brown	G19	Seed	IITA
20	TSs69	Deep purple	G20	Seed	IITA
21	TSs79	Agate (V)	G21	Seed	IITA
22	TSs82	Sunburn brown	G22	Seed	IITA
23	TSs119	Brownish orange	G23	Seed	IITA

analyses. The AMMI was employed in this study. The grain yield data were subjected to AMMI analysis which combines ANOVA with additive and multiplicative parameters into a single model (Gauch 2013). In this study, the replicate effect was removed in combining the data. According to Gauch (1988), the replicate effect tends to make the data noisy, in which the estimated parameter may not reflect the actual mean. The main effect was partitioned into genotypic and environmental effects, while the nonadditive effect was due to genotype by environment interaction and is detailed in the AMMI equation used for analysis. This study follows Gauch (1988) and stated the AMMI model as follows:

$$Y_{ij} = \mu + G_i + E_j + \sum_{k=1}^n \lambda_k a_{ik} y_{jk} + \theta_{ij} \quad (1)$$

In equation (1), i = (AYB genotypes 1, 2, 3,...,23); j = (year environments) 1, 2,...,4; Y_{ij} is the observed mean yield of i th genotype in the j th environment; μ is the grand mean; G_i is the i th genotypic effect, E_j is the j th environment effect, n is the number of principal component analysis (PCA) axes considered, which is judged based on an empirical consideration of F -test of significance, λ_k is the eigenvalue of the PCA axis k ; a_{ik} and y_{jk} are the i th genotype j th environment PCA scores

for the PCA axis k , θ_{ij} is the residual; and n is the number of PCA axes retained in the model. The noise sum of the square in the interaction sum of square (SS) is estimated by multiplying $df\ G \times E$ by error mean square (MS).

AMMI stability value (ASV) was calculated using SAS 2.0 package of 2000 following the formula developed by Purchase (1997):

$$ASV = \sqrt{\left[\frac{SS_{IPCA1}}{SS_{IPCA2}} (IPCA1_{score}) \right]^2 + (IPCA2_{score})^2} \quad (2)$$

In equation (2), SS_{IPCA1} is the SSs of interaction principal component analysis 1; SS_{IPCA2} is the SSs of interaction principal component analysis 2; $IPCA1$ is interaction principal component analysis one, and $IPCA2$ is interaction principal component analysis two.

3 Presentation of results

3.1 Mean performance of genotypes

AYB flowering and pod formation start one-hundred days after germination. In this experiment, the dates to

flowering across the four environments were toward the end of early planting seasons (between July and end of August), when humidity is low and atmospheric temperature is also getting warm (27–35°C). Flowering marks the end of the accumulation of photosynthates from source to sink.

3.2 AMMI analysis

Consequent upon growing the 23 AYB genotypes in different cropping years, the $G \times E$ interaction effects from the combined AMMI analysis were statistically significant ($P < 0.001$) (Table 3). The environment had a higher variation and accounted for about 43.1% of the SS, while the interaction component accounted for only 22.65% and the genotypes accounting for 32.25% of the treatment SS. The $G \times E$ SS contains approximately 22,57,336 or 68.60% pattern with 10,33,164 or 32.40% noise. In Table 4, the first environment E1 (2011) recorded a mean yield performance of 251.8 kg/ha. Genotype (TSs116) G13 recorded the highest average mean seed yield of 465.4 kg/ha. This is followed by G19 (TSs61) (449.2 kg/ha) and G3 (TSs12) (417.3 kg/ha). G22 (TSs82) also recorded above-average mean seed yield (395.6 kg/ha). In all, E4 recorded the highest mean yield (635.8 kg/ha) when averaged over the four years. However, the soil data are the same in all the four environments with E4, which is the planting year of 2014. Most of the AYB produced high seed yield ranking above the overall mean seed yield across the growing years. Following Table 4, growing G9 (TSs6) under

temperature ranges of 27–35°C and low rainfall identify E1 to E3 (the year 2011–2013) as the best environments favorable to G9 (TSs-6), hence placing G9 (TSs6) as the most stable genotype. Where the economic target is seed yield, genotypes 10 (TSs93), 11 (TSs95), and 17 (TSs58) are not suitable to be grown within 27–35°C temperature with low rainfall distribution (Table 1) because the resultant seed yield is below the average. In addition to winning environment ranking, ASV and ranking analysis identified G1 (TSs118), G19 (TSs61), and G3 (TSs12) as having above-average mean yield and are, therefore, the most stable genotypes across the growing year seasons (Table 5). Better still, the 1PCA scores of these three AYB genotypes are between 0 (–0.76) and <2 (1.93) indicating small interaction effect with the environment, whereas G17 (TSs58) (11.87) followed by G20 (TSs69) (–9.51) and G5 (TSs111) (11.98) with first principal component analysis (1PCA) scores >2 are adjudged to be less stable and more sensitive to environmental changes.

3.3 GGE biplot analysis

Considering the GGE biplot analysis, 77.8 percent of the total variation was jointly explained by PC 1 and PC 2, accounting for 45% and 32.8% of the total variation, respectively. The interaction pattern based on genotype and environment is visualized in Figure 1. The genotype groups that were positioned farthest from the biplot origin were joined to form the polygon, with genotypes at the vertex contributing most to the interaction, and presenting the highest yielding genotypes (22, 20, 19) as also captured in Table 4 in the mean yield across the environments. Furthermore, the GGE biplot distributed the genotypes based on stability and seed yield (Figure 2). The average environment coordinates (AECs) (representing an average performance of the genotypes) and its ordinates (representing the stability of performance) indicated that genotypes 5, 18, 12, 7, and 15 on the left side of the AEC had a low yield in all the environments. Contrarily, genotypes (22, 20, and 19) on the right side had high yield across the environments. Genotype1 (TSs118), G3 (TSs12), G6 (TSs148), and 19 (TSs61) are most stable as they are located almost on the AEC ordinate.

Similarly, the GGE biplot revealed the associations among environments and identified potential mega-environments (Figure 3). The GGE biplot for seed yield in the 23 AYB genotypes showed that the four years/environments were distributed into two mega-environments,

Table 3: Combined analysis of AMMI model for seed yield (g/plant) in three environments and the proportion of the total variance attributable to the source of variation

Source	DF	SS	MS	SS (%)
Total	275	14,521,794	52,807	
Treatments	91	11,708,059	1,28,660***	
Genotypes	22	21,63,925	98,360***	32.25
Environments	3	62,536,324	20,84,545***	43.1
Block	8	58,643	7,330	0.4
Interaction($G \times E$)	66	32,90,500	49,856***	22.65
1PCA1	24	20,19,251	84,135***	
1PCA2	22	9,95,369	45,244***	
Residuals	20	2,75,880	13,794	
error	176	27,55,093	15,654	

*** significant at P -value < 0.001 ; DF, the degree of freedom; SS, the sum of the square; MS, mean square.

Table 4: Mean yield of AYB tested across the four-year environments

Genotypes	E1 (kg/ha)	E2 (kg/ha)	E3 (kg/ha)	E4 (kg/ha)	Mean seed yield (kg/ha)
G1	328.1	314.4	351.9	681.0	418.8
G2	224.6	258.2	375.9	847.3	426.5
G3	417.3	391.3	392.9	655.9	464.3
G4	292.5	138.5	198.5	605.2	308.7
G5	57.8	310.3	197.5	172.4	184.5
G6	341.7	391.0	382.3	607.1	430.5
G7	319.4	34.4	129.6	635.9	279.8
G8	225.2	117.3	203.5	649.3	298.8
G9	48.4	418.9	433.6	624.8	381.4
G10	331.1	360.0	304.9	445.4	360.3
G11	334.5	362.1	301.3	431.4	357.3
G12	53.3	202.8	271.4	620.2	286.9
G13	465.4	419.0	392.8	607.4	471.2
G14	357.7	261.7	328.4	733.5	420.3
G15	41.0	170.9	302.3	776.5	322.7
G16	391.2	412.1	380.7	568.7	438.2
G17	37.2	547.1	456.4	411.0	362.9
G18	51.1	146.4	214.5	575.7	246.9
G19	449.2	443.6	445.5	704.3	510.7
G20	315.2	316.5	473.1	1027.2	533.0
G21	144.0	169.9	288.6	764.1	341.7
G22	395.6	327.2	441.6	931.6	524.0
G23	169.4	379.1	367.6	547.6	365.9
Mean	251.8	299.7	331.9	635.8	379.8
IPCA1	0.63	17.02	4.86	-22.52	-0.003
IPCA2	20.72	-6.28	-8.44	-5.99	0.003

Note: E1, E2, E3 and E4 referred to 2011, 2012, 2013 and 2014 respectively.

based on the length of the vectors, which measures their similarity in discriminating the genotypes. The first mega-environment consisted of environment 2011, 2012, and 2013 respective years while the second mega-environment was the year 2014. Among the test year-environments, 2012 and 2014 had longer vectors than the other years-environments. The year-environments that form an acute angle among each other indicated a positive correlation. The most prominent relationships among environments were year/environment 2011, 2012 and 2013 which had acute angles among them and years 2012 and 2014 were slightly negatively correlated, which pointed to a cross over high $G \times E$. Considering the representativeness of the test environments, which is decided by the degree of the angle formed between environment vectors and the average tester coordination (ATC), the growing environment of the year 2011 is the most representative because of the smallest angle with the ATC axis. Furthermore, this year-environment was the closest to the ideal environment and, as a result, seemed the best of the four-year environments. It had the most discriminating and the most representative of the four-year environment, under study.

4 Discussion of findings

The combination of years using AMMI and GGE biplots identified the yield performance of the 23 genotypes as affected by the prevailing environmental factors (rainfall, temperature, humidity, etc.) in each of the four years of this study. The analysis revealed significant variations among the genotypes and years, which in turn explained a considerable degree of variation which can be exploited when selecting genotypes for specific environmental conditions. The differential response of AYB genotypes for seed yield to the differences in weather parameters across the four-year environments indicated the presence of $G \times E$, which justified further analysis of the stability of performance with yield and environment using AMMI and GGE.

From the AMMI analysis model, the fact that the yield pattern of each genotype accounted for a higher percentage of the $G \times E$ SS indicates that there is considerable selectivity pattern in the model using IPCA axis scores arising from individual genotype yield performance. These findings agree with the earlier report of Gauch (2006), which revealed that significant IPCA1 and successive axes in AMMI model captured interaction exclusively in a diatonic

Table 5: AYB genotypes mean performance ranking, IPCA 1 and 2 scores, and yield selection indices

Genotype	Ng	GM	Rank	IPCA1	IPCA2	ASV	Rank	YSI	Rank
G1	1	418.8	10	-0.76	1.82	0.97	1	11	3
G2	2	426.5	8	-6.42	-3.37	13.46	14	22	10
G3	3	464.3	5	1.84	3.85	5.36	3	8	2
G4	4	308.7	18	-3.26	5.49	8.60	8	26	13
G5	5	184.5	23	11.98	-0.30	24.32	22	45	23
G6	6	430.5	7	3.05	1.79	6.38	5	12	4
G7	7	279.8	20	-6.65	8.29	15.84	20	40	22
G8	8	298.8	19	-4.94	2.78	10.39	12	31	17
G9	9	381.4	11	3.22	-9.99	11.94	13	24	12
G10	10	360.3	14	6.38	4.57	13.72	16	30	16
G11	11	357.3	15	6.78	4.87	14.59	18	33	19
G12	12	286.9	21	-2.09	-5.03	6.58	6	27	15
G13	13	471.2	4	3.78	5.78	9.60	10	14	5
G14	14	420.3	9	-3.41	3.26	7.64	7	16	6
G15	15	322.7	17	-6.87	-7.21	15.69	19	36	20
G16	16	438.2	6	4.57	3.77	10.01	11	17	7
G17	17	362.9	13	11.87	-9.90	26.04	23	36	21
G18	18	246.9	22	-2.38	-3.20	5.79	4	26	14
G19	19	510.7	3	1.93	3.16	5.03	2	5	1
G20	20	533.0	1	-9.51	-4.04	19.70	21	22	11
G21	21	341.7	16	-6.55	-3.16	13.66	15	31	18
G22	22	524.0	2	-6.79	0.19	13.77	17	19	8
G23	23	365.9	12	4.22	-3.44	9.23	9	21	9

GM = grand mean; YSI = yield selection index; ASV = AMMI stability value.

Figure 1: Polygon view of the GGE biplot showing the superior AYB genotypes across the four-year environment. **Figure 2:** GGE biplot showing the ranking of AYB genotypes for both mean yield and stability across the four-year environments.

sequence that decreases from the first to the last component. This, therefore, provided the basis for considering the use of an AMMI biplot for visual assessment of the

performances of genotypes, environments, and their interactions (Gauch *et al.* 2008; Aremu and Ibirinde 2012; Clarke *et al.* 2019).

Figure 3: Discriminating and representativeness view of the GGE biplot and ranking of test environments relative to an ideal environment.

The E1 had near-zero IPCA scores of 0.631 indicated a small interaction effect but a below-average mean yield performance. Small interaction is an indication that the environment has little influence on the genotypes. Following the weather data in 2011 (Table 1), the near-zero 1PCA interpretation some of the genotypes recorded an above-average mean seed yield. According to Gauch et al. (2011) and Kuang et al. (2014), genotypes with above-average mean yield across growing environments can be adjudged as stable genotypes. This explains that the prevailing rainfall pattern, temperature, and humidity of the growing season did not significantly affect the performance of some of the AYB but affected 10 of the 23 genotypes, namely as follows: G1 (TSs118), G2 (TSs10), G3 (TSs12), G6 (TSs148), G9 (TSs6), G13 (TSs116), G14 (TSs48), G19 (TSs61), G20 (TSs69), and G22 (TSs82). These genotypes recorded an average mean yield above the grand mean (418.8 kg/ha) across the four years cropping environments and are therefore adjudged productive. This result criticizes the use of only mean performance across environments (Table 4) to adjudge genotype performance. No wonder the earlier research efforts of Yan (2002) and the later work on maize genotypes across nine environments (Mahalingam et al. 2006; Yan et al. 2007) stated that if a genotype or an environment has opposite directional signs with the PCA score, their interaction is negative no matter the quantum of the yield value.

On the genotype and environment AMMI stability ranking, the use of the GGE biplot and PCA scores further identified the winning genotype in the year environment.

Mean yield ranking and scores using IPCA1 and IPCA2 (Table 5) ranked G20 (TSs69), G22 (TSs82), and G19 (TSs61) as best seed yielding genotypes. That G20 and G22 recorded high yield of 533.0 kg/ha and 524.0 kg/ha, respectively, notwithstanding, the opposite signs on their IPCA scores (-9.51 ; -6.79) indicated negative interaction with the growing environments and therefore not winning in any of the four environments (Figure 1). Genotypes 13 (TSs116) and G19 (TSs61) demonstrated positive interaction when grown under specific rainfall of 608–1,500 and the environmental temperature not exceeding 34°C . These two specific genotypes are seen to have won in the 2013 environment and hence adjudged adaptable and stable for the environment. Kuang et al. (2014) found 3 genotypes of maize out of 9 in 20 environments to be productive and stable using AMMI analysis. This result further confirms the findings of Gauch and Zobel (1997) and also supported by the efforts of Purchase 1997 who emphasized that ASV gives a balance measurement between IPCA scores, such that the lower the IPCA scores, the more specifically adapted the genotype to the study year/environment. Again, the more recent work of Clarke et al. (2019), identified stability performance in the yield of commercial sorghum hybrids to be affected by stress (water and temperature) in the environment. The ranking patterns of ASV and yield stability (YSI) are almost the same (Table 5). This implies that genotype selection can follow either of both rankings patterns.

The scaling in Figure 2 centers on genotype mean yield and stability across the four-year environments. This agrees with Yan (2002) scaling, where singular values are partitioned into environment scores for comparing genotype relationships among year environments. Following Zobel et al. (1988), the main effect principal additive effects of genotypes and environment adequately explain the genotype means and environment means in relation to individual genotype mean performance across the four-year environments (Table 4). The differential seed yield performance may be attributed to the inconsistent lower rainfall distribution in the 2011 and 2013 growing years, which consequently determined the temperature and humidity flow (Table 1). No wonder, Silveira et al. (2013) reported that phenotypic stability is a function of both climatic and soil conditions. The GGE biplot analysis identified some genotypes as performing similarly in a given test year environment, the discriminating power of the genotypes relative to the ideal environment was revealed. Furthermore, the analysis suggested that the years/environments used for the evaluation of the AYB could be separated into two mega-environments, and where mega-environments

(large) are used, test environment representatives are identified. The similarity of the genotypes in their performance observed in the growing years of 2011 and 2013 suggested a positive correlation between them, which was also obvious from the acute angle formed between the vectors of the two years.

Even though the 2012 season is somewhat closer to the 2013 cosine angle, genotype performances within these two environments are not the same. Whereas 2014 and 2012 with the longest vectors in comparison with the remaining two years/environments suggested that these years/environments were the most effective for genotypic differentiation based on seed yield in AYB. From these observations, it is inferred that field trials with a few test years might give the same level of information, which was otherwise obtained by evaluating under the highly correlated years, thereby reducing the cost associated with field evaluation, without precision in identifying the best performance for seed yield (Popoola *et al.* 2011; Aremu *et al.* 2018). Furthermore, the year 2013 could be regarded as a redundant environment in evaluating yield stability in AYB because it is neither discriminating nor representative. Kuang *et al.* (2014) recorded a wide-angle relationship between two growing environments of maize in Ontario as discriminating. A near-zero IPCA1 score for G1 (TSs118; -0.76) followed by G12 (TSs96; -2.09) and G18 (TSs60; -2.38) genotypes with least contribution to the interaction component and mapped near the biplot origin indicated their adaptability and stability across any of the four-year weather environments. The ranking pattern of YSI also supports the selection of these AYB genotypes. According to Farshadfar *et al.* (2011) and Das *et al.* (2010), ASV and YSI comparatively support IPCA scores values in selecting stable genotypes and have been successfully used in the selection of wheat and corn for specific location adaptation. Following large IPCA scores, G5 (TSs-111; 11.98), G17 (TSs-58; 11.87), and G11 (TSs-95; 6.78) were the more responsive and contributed largely to the interaction component and may be considered for specific adaptation. Those with smaller IPCA scores G1 (TSs118), G3 (TSs12), G6 (TSs148), G19 (TSs61), and G20 (TSs69) are identified as the most stable genotypes across environments.

5 Conclusion

The study assessed the performance of 23 AYB genotypes for seed yields for four years (2011, 2012, 2013, and 2014) cropping seasons using Additive Main Effect and Multiplicative Interaction (AMMI) and GGE biplot to

determine the main effects due to genotype (G), environment (E) and GEI in varying year environments in one location. The use of AMMI in genotype yield analysis using single value-based data remains unique. This method separates genotype, environment, and the interaction components to showcase specific genotype productivity in a given environment. Genotype stability studies are important in classifying genotype adaptation and consistency in yield performance. Such studies will reduce efforts and save costs in engaging unpredictable field locations for farming and crop breeding research. The use of GGE and AMMI tools in this research identified G1 (TSs118), G3 (TSs12), G6 (TSs148), G19 (TSs61), and G20 (TSs69) as the most productive and adaptable to any range of the three weather characteristics within the cropping seasons of AYB. The year effect becomes relevant in multi-environment breeding, where weather reports are cumulatively harnessed. It is therefore important to collate accurate weather forecast decisions before engaging these seven genotypes for yield production, location notwithstanding. Better still, G4 (TSs-109), G9 (TSs-6), and G20 (TSs-69) have the dual-purpose production capacity to give an above-average mean seed and tuber yield. The weather factors in the growing seasons of 2011 and 2012 are almost the same and supported below-average mean yield performance (251.8 kg/ha; 299.7 kg/ha) as evident in the GGE–environment AMMI biplot (Figure 4) and therefore can be a representative of the year environment.

Figure 4: AMMI1 biplot of 23 AYB genotypes seed yield across the four environments.

The year 2014, with the highest rainfall, relative humidity, and lowest average temperature, is most productive and stable (635.8 kg/ha). A prevailing environment with high rainfall, with consequently high relative humidity and a prevailing low temperature, can be determined and utilized for growing the earlier identified stable genotypes (G1 (TSs-118), G3 (TSs-12), G4 (TSs-109), G6 (TSs-148), G9 (TSs-6), G19 (TSs-61), G20 (TSs-69)). In achieving a meaningful breeding program, precision in genotype yield stability performance selection using AMMI ranking and GGE biplots either ASV or YSI can be interchangeably engaged during genotype stability selection.

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