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Research Article

Genotype – genotype × environment (GGE) biplot analysis of winged bean for grain yield

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The winged bean is an underutilized legume that is adapted to the tropics. It has good prospects as a significant multi-purpose food crop including human nutrition, cattle feed, and environmental protection. However, little research attention has been given to the crop to address the identified constraints, especially low yield in Nigeria. To improve its yield potential, GGE biplot analysis was used to identify high-yielding and stable winged bean genotypes, previously collected from the continent of Asia, and Nigeria for yield improvement. Twenty winged bean genotypes were being evaluated under the rainfed condition at three locations (Ibadan, Ile-Ife, and Kishi) for two years, comprising six environments. The obtained results showed that the seed yield (SY) ranged from 805.61 kg.ha^{-1} (Ibadan) to 1,096.35 kg.ha^{-1} (Kishi), with SY of 988.42 kg.ha^{-1} across the locations. The winged bean reached its first flowering, 50% flowering, 50% podding, and 70% physiological maturity in 74, 80, 93, and 137 days after being planted, respectively across the locations. The GGE biplot analysis showed that the principal component (PC) axes captured 71.5% of the total variation, where PC1 and PC2 were responsible for 36.6% and 34.9%, respectively. Genotype, environment, and their interaction had a significant effect on SY. Environments IB20 and IF20 were adjudged the most ideal environments to discriminate between the genotypes. Genotype Tpt-12 was identified as high-yielding and stable. Tpt-12 would be recommended for commercial farming in southwestern Nigeria. The selected high-yielding winged bean genotypes are hereby recommended as promising parental lines for the grain yield improvement in the winged bean improvement programs.

Keywords: winged bean, GGE biplot analysis, genotype x environment interaction, agronomic traits, agro-ecologies of Nigeria

1 Introduction

The winged bean which belongs to the Fabaceae family (*Psophocarpus tetragonolobus* (L.) DC.) is an underutilized leguminous crop in Sub-Saharan Africa. The winged bean was identified for the first time in South East Asia, namely between Papua New Guinea and India. It was also detected in various African countries, most notably Ghana and Nigeria (Bassal et al., 2020). It grows well in different soil types, including marginal soil. It may be cultivated in the tropics at altitudes up to 2,000 m a. s. l. (Mohanty et al., 2013). A self-pollinated plant known as "winged bean" has a twining vine pattern and both annual and perennial growth forms. It is a dual crop, with seeds developing in longitudinal pods above the soil surface, and tubers growing as the root sinks underground (Koshy, et al., 2013; Vatanparast, et al., 2016).

Winged bean plant has a good prospect as a significant multi-purpose food crop in the tropics, including Asia, Africa, and Latin America, providing human nutrition, cattle feed, and environmental protection (Alalade et al., 2016,). Additionally, every component of the crop, including its flowers, leaves, green pods, and tubers, can be consumed raw or cooked (Mohanty et al., 2015). Winged beans have a protein content that is comparable to that of soybeans (32–38%) and is roughly 50% higher than that of the majority of other edible legumes (Adegboyega et al., 2019; Amoo et al., 2006). Boils and ulcers can be treated using its pod extract (Perry & Metzger, 1980). Its extracts have both

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antioxidant and antimicrobial properties (Khalili et al., 2013). When combined with water and emulsifier, winged beans can be used to make milk that is similar to soy milk (Yang & Tan, 2011). This suggests that it can effectively treat protein deficiency or malnutrition in Africa in place of soybean. Low yield, high labour costs, anti-nutritional factors, pod breaking, late maturity, and scandent behaviour are the main constraints to the widespread utilization of the winged bean (Popoola et al., 2019). The crop has been given little research attention to address the identified constraints, particularly the low grain yield in Africa, especially Nigeria. Although there are few data on the winged bean yields, matured seed yield of 2,000 kg.ha^{-1}, and green pod yield of up to 10,000 kg.ha^{-1} was reported (Tanzi et al., 2019).

The study of genotype by environment interaction (G × E) is vital for the selection of genotypes for specific environments or broad adaptation across environments (Baye et al., 2011). The interaction between genotype and environment may be explained by environmental factors like temperature and rainfall patterns etc (Ewool, 2004). It is possible to visually analyse the connections between the test environments, genotypes, and their interactions based on GGE biplot analysis (Yan et al., 2000). Hence, the GGE-Biplot is based on a principal component analysis with first two major components (Sousa et al., 2018). The "which-won-where" pattern of the GGE biplot is a fantastic method for mega-environment analysis, allowing for the nomination of promising genotypes based on yield potential and stability for cultivation in either broad mega-environments or specific environments (Yan & Kang, 2003; Yan & Tinker, 2005). Furthermore, the GGE biplot analysis is a useful technique for identifying locations that can distinguish between genotypes (Dehghani et al., 2009). The GGE biplot has been used to evaluate various crops such as winged bean (Tiwari et al., 2022), Bambara groundnut (Olanrewaju et al., 2021), lentil (Rahmatollah et al., 2013), and maize (Akinyosoye, 2022). For instance, Tiwari et al. (2022) carried out the GGE biplot analysis on winged bean. The findings from the work revealed that the winged bean genotype 'AKWB-1' was the most stable genotype in all the test environments in terms of mean yield, and it would be recommended for commercial cultivation. Also, in the Fabaceae family, Olanrewaju et al. (2021) conducted the GGE biplot analysis on Bambara groundnut. The findings showed that the stable genotypes included TVSu-1589, TVSu-1905, and TVSu-2048.

Although there are few studies on yield stability and adaptability of winged bean in various agro-ecologies of Nigeria, they have hampered sustainability of sufficient grain production of winged bean in Nigeria. In addition, Nigeria still lacks any known varieties of underutilized legumes like winged bean, Bambara groundnut, mung bean, sword bean, kidney bean, etc. that have been registered and released. Potential farmers cannot access to access the few genotypes of underutilized legumes that are kept in gene banks of some of the country's agricultural research institutions (Akinyosoye et al., 2021). In order to select the high-yielding and most stable winged bean genotypes at each location and also across locations for eventual access to the farmers, it is necessary to evaluate the winged bean genotypes for agronomic performance in multiple environments using the GGE biplot analysis. Therefore, this study sought to identify high-yielding and stable winged bean genotypes among twenty winged bean genotypes previously collected from the continent of Asia, and Nigeria for adaptation and yield improvement in southwestern agro-environments of Nigeria.

2 Material and methods

Genetic Resource Center of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, provided the twenty wings bean genotypes, previously collected from the continent of Asia, and Nigeria (Table 1). The experiment was carried out at three locations in 2019 and 2020, comprising of six environments. The experimental sites were: Ile-Ife (Rain Forest ecology), Ibadan (Rainforest-Savanna transition), and Kishi (Southern Guinea Savanna ecology). The three locations represent the major agro-ecologies in humid agro-environments of Southwestern Nigeria. The average annual temperature across the three locations was roughly 27 °C in 2019, and 20 °C in 2020. Nigeria is a tropical country with mean annual rainfall of 0.09308 m in Ibadan, 0.09550 m in Ile-Ife, and 0.07725 m in Kishi in the year 2019, and 0.07717 m in Ibadan, 0.07508 m in Ile-Ife, and 0.04683 m in Kishi in the year 2020 (Akinyosoye et al., 2021). In Kishi, ferric lixisol was the most prevalent soil type, while in Ibadan and Ile-Ife, only ferric lixisols were found there (Sonneveld, 2006).

The experiment was laid out in a randomised complete block design with three replications at all the locations. The plot dimensions were 4 m by 1 m with a 1 m inter- and intra-row spacing at each location. Regular weeding and other cultural practices were performed when necessary, and Magic Force (Lambda-cyhalothrin 15% + Dimethoate 300 g.L^{-1}) was used to control field insect pests. Data were collected on the first flowering, 50% flowering, 50% podding, pods/peduncle, pods/plant, 70% maturity, pod length (m), seeds/pod, pod weight/plant (g), seed weight/plant (g) and seed yield (kg.ha^{-1}) (Agbeleye et al., 2020).

Table 1 Source and seed coat colour of twenty winged bean genotypes used in this study

SN	Genotype	Origin	Seed colour
1	TPt- 2	no passport data	light brown
2	TPt- 3	no passport data	brown
3	TPt- 6	indonesia	light brown
4	TPt- 9	no passport data	brown
5	TPt-10	Sri Lanka	brownish grey
6	TPt-11	Nigeria	greyish orange
7	TPt-12	Sri Lanka	brown
8	TPt-14	no passport data	brown
9	TPt-15	no passport data	dark brown
10	TPt-16	Indonesia	greyish orange
11	TPt-18	no passport data	brown
12	TPt-19	Nigeria	dark brown
13	TPt- 26	Nigeria	brown
14	TPt- 30	no passport data	brownish orange
15	TPt- 31	Indonesia	brown
16	TPt- 33	no passport data	light brown
17	TPt- 43	Bangladesh	dark brown
18	TPt- 48	no passport data	greyish yellow
19	TPt- 51	Bangladesh	greyish orange
20	TPt-125	no passport data	light brown

Source: genetic resource unit of the International Institute of Tropical Agriculture (IITA)

2.1 Data analysis

Three locations researched for two years were understood as six environments. Using Plant Breeding Tools software (Version 1.4, 2014), grain yield data were subjected to the analysis of variance (ANOVA) across environments to find high-yielding and stable winged bean genotypes that are suited to a particular environment or mega-environment.

3 Results and discussion

The measured agronomic traits varied across three locations mentioned in this study, where seed yield ranged from 805.61 kg.ha^{-1} (Ibadan) to 1,096.35 kg.ha^{-1} (Kishi). Moreover, most of the measured agronomic traits such as pods/plant, pod length, and seeds/pod had far better performance in Kishi than at other locations. On the other hand, the first flowering, 50% flowering, 50% podding, and 70% physiological maturity varied from 70, 77, 85 and 124 days after planting (DAP), respectively (Ibadan), to 81, 86, 101 and 165 DAP for the first flowering, 50% flowering, 50% podding, and 70% physiological maturity, respectively (Kishi) (Table 2). In addition, the coefficient of variation (CV) ranged from 4.54% for 70% maturity to 72.11% for seed yield, whereas moderate variability was observed for pods/plant (37.59%) and pods/peduncle (42.7%) across locations (Table 3). The seed yield reached across locations was 988.42 kg.ha^{-1}, and the winged bean reached first flowering, 50% flowering, 50% podding, and 70% physiological maturity in 74, 80, 93 and 137 DAP, respectively (Table 3). Genotypic variation existed among the winged beans examined in this study, where genotype Tpt-33 provided the highest seed yield (1,372.22 kg.ha^{-1}), followed by Tpt-48 (1,328.16 kg.ha^{-1}), and Tpt-43 (1,256.11 kg.ha^{-1}). The first nine genotypes had reached greater seed yield than the grand mean (988.42 kg.ha^{-1}) (Table 3). Investigation of the genotype by environment interaction is critical to identifying and selecting lines that perform better results in different environmental conditions. To accomplish this, plant breeders evaluate the performance of genotypes in various agro-environments. Thus, the significant variation in the grain yield observed in this study across the three locations clearly indicated that there was sufficient genetic diversity, which will aid selecting the right genotypes for improvement. This finding is consistent with the findings of Adegboyega et al. (2021) and Mohanty et al. (2013), who found significant

Table 2 Mean, minimum and maximum values of the agronomic traits of twenty genotypes of winged bean, evaluated in Ibadan, Ile-Ife and Kishi, in humid agro-environments of Nigeria in 2019 and 2020

Traits	Minimum	Maximum	Mean	StdDev	SE (0.05)
			Ibadan		
Seed yield (kg.ha^{-1})	8.89	6,320.00	805.61	814.00	74.31
First flowering	60.00	89.00	70.22	5.79	0.53
50% flowering	63.00	93.00	76.55	7.57	0.69
50% podding	63.00	113.00	85.22	12.31	1.12
Pods/peduncle	1.00	2.00	1.12	0.19	0.02
Pods per plant	7.50	29.50	14.36	3.66	0.33
70% physiological maturity	93.00	138.00	121.47	12.17	1.11
Pod length (cm)	11.70	24.10	18.61	2.18	0.20
Seeds per pod	9.00	15.50	12.03	1.44	0.13
			Ile-Ife		
Seed yield (kg.ha^{-1})	50.00	4,666.67	1,063.29	987.35	90.13
First flowering	58.00	98.00	70.91	9.98	0.91
50% flowering	65.00	108.00	78.41	11.36	1.04
50% podding	68.00	122.00	92.22	12.09	1.10
Pods/peduncle	1.00	6.50	2.73	1.42	0.13
Pods/plant	0.00	33.50	18.02	6.14	0.56
70% physiological maturity	80.00	145.00	124.26	12.15	1.11
Pod length (cm)	9.00	28.50	17.32	2.26	0.21
Seeds per pod	5.00	12.00	7.88	1.30	0.12
			Kishi		
Seed Yield (kg.ha^{-1})	142.14	2,840.00	1,096.35	563.26	51.42
First flowering	66.00	99.00	81.00	11.27	1.03
50% flowering	68.00	106.00	86.06	11.56	1.05
50% podding	80.00	118.00	101.11	5.91	0.54
Pods/peduncle	1.00	3.00	1.73	0.69	0.06
Pods/plant	1.25	50.00	18.61	9.27	0.85
70% physiological maturity	121.00	168.00	164.96	4.60	0.42
Pod length (cm)	13.00	24.48	18.79	1.91	0.17
Seeds/pod	7.00	28.75	11.93	2.67	0.24

variation among the winged bean genotypes tested in various environments. The winged bean genotypes evaluated in Kishi had the highest grain yield, pods/plant, pod length, seeds/pod, pod weight, and seed yield/plant values compared to those in Ibadan and Ile-Ife because there were the best weather conditions during the cropping season. This supports the findings of Akinyosoye (2022), who reported that during the maize hybrid cropping season in Kishi, there was more solar radiation and adequate rainfall distribution than in Ibadan and Ile-Ife.

Table 4 shows the mean seed yield across the twenty genotypes of winged bean observed in six environments. The seed yields of twenty genotypes varied significantly across the six environments, with the environment KI19 having the highest seed yield (1,154.14 kg.ha^{-1}), and IB20 having the lowest (532.29 kg.ha^{-1}). In four (IB19, IF19, KI19, and KI20) out of six environments, we have recorded the greater seed yield than the grand mean (988.42 kg.ha^{-1}). The result of the ANOVA and percentage variance for the seed yield showed the effect of the environment (E), Genotype (G), and Genotype by Environment (G × E) with the residual effect, as it is presented in Table 5. The results showed that

Table 3 Mean performance of the agronomic traits of twenty genotypes of winged bean, evaluated across the three locations between 2019 and 2020, in humid agro-environments of Nigeria

Genotype	Seed yield (kg.ha^{-1})	First flowering	50% flowering	50% podding	Pods/peduncle	Pods/plant	70% maturity	Pod length (cm)	Seeds/pod
TPt-33	1,372.22	75.06	82.17	94.72	1.7	17.11	136.83	18.6	10.73
TPt-48	1,328.16	73.39	78.28	92.67	1.74	16.86	139.56	18.39	11.13
TPt-43	1,256.11	73.06	81.33	90.94	1.84	18.82	139.72	18	10.32
TPt-6	1,242.13	74.56	81.56	94.89	2.06	18.28	136.72	19.41	10.59
TPt-10	1,232.17	74.11	79.5	91.78	1.82	16.63	139.33	17.6	10.27
TPt-12	1,123.06	73.22	79.83	93.22	2.11	18.72	130.39	18.05	10.7
TPt-11	1,119.64	73.56	78.94	90.83	1.75	16.4	126	16.88	10.98
TPt-9	1,112.73	72.67	78.94	93.17	2.19	20.61	138.89	18.35	11.5
TPt-31	1,056.3	75.11	80.56	94.11	1.9	16.23	139.56	18.6	10.6
TPt-18	980.15	75.78	80.22	91.61	1.68	15.71	139.78	17.98	10.31
TPt-14	976.41	76.33	82.39	93.44	1.84	18.32	136.44	18.3	10.38
TPt-125	874.43	72.78	78.72	92.56	2.35	17.89	132.11	18.12	10.61
TPt-15	871.22	77.22	82.89	95.44	1.63	16.06	136	18.29	9.67
TPt-16	867.57	73.56	79.22	91.83	1.61	15.23	136.72	18.24	10.81
TPt-2	838.34	74.06	81.11	95.72	1.9	16.4	139.17	18.76	10.75
TPt-51	837.15	68.94	74.67	88	1.58	17.79	142.5	16.63	10.76
TPt-19	813.16	74.5	81.33	92.5	2.31	17.12	140.33	18.74	10.52
TPt-3	625.13	72.83	80.17	93.33	2.06	15.36	135.94	18.09	10.65
TPt-30	621.31	77.22	83.5	93.72	1.79	15.98	133.67	18.8	10.71
TPt-26	620.96	72.94	81.44	92.5	1.39	14.46	138.22	19.03	10.33
Mean	988.42	74.05	80.34	92.85	1.86	17	136.89	18.24	10.62
SE(0.05)	42.98	0.55	0.58	0.65	0.06	0.37	1.18	0.12	0.14
Prob.(GEN)	*	ns	ns	ns	*	*	Ns	*	ns
Prob.(ENV.)	*	*	*	**	**	*	**	*	*
Prob. (G×E)	*	ns	ns	Ns	*	*	Ns	*	ns
LSD(0.05	256.37	2.42	2.74	2.49	0.28	2.29	10	1.79	0.66
CV%	72.11	9.1	9.49	7.47	42.7	37.59	4.54	10.6	17.32

Table 4 Mean seed yield (kg.ha^{-1}) of twenty genotypes of winged bean evaluated in six environments, in humid agro-environments of Nigeria

SN	Genotype	Environments					
		Ibadan 2019	Ibadan 2020	Ile-Ife 2019	Ile-Ife 2020	Kishi 2019	Kishi 2020
1	TPt-33	2,204.92	837.67	1,444.44	397.78	1,731.74	1,616.74
2	TPt-48	1,880.50	575.74	1,666.67	553.93	1,703.56	1,588.56
3	TPt-43	393.85	766.67	2,111.11	697.37	1,841.33	1,726.33
4	TPt-6	1,261.78	843.84	2,500.00	448.82	1,206.67	1,291.67
5	TPt-10	1,048.33	796.33	1,311.11	1,683.78	1,334.22	1,219.22
6	TPt-12	1,126.67	428.52	1,366.67	534.81	1,698.33	1,583.33
7	TPt-11	1,555.62	362.86	2,072.22	654.82	1,093.67	978.67
8	TPt-9	1,076.07	449.70	2,833.33	316.80	1,057.74	942.74
9	TPt-31	2,911.57	574.91	1,316.67	432.13	608.78	493.78
10	TPt-18	967.22	576.11	1,955.56	876.71	810.16	695.16
11	TPt-14	578.48	653.90	1,555.56	747.73	1,218.89	1,103.89
12	TPt-125	681.63	477.85	1,400.00	722.13	1,040.00	925.00
13	TPt-15	776.94	828.61	1,000.00	597.33	1,075.56	948.89
14	TPt-16	372.12	408.48	1,355.56	648.72	1,267.78	1,152.78
15	TPt-2	864.52	476.90	1,100.00	934.70	884.44	769.44
16	TPt-51	466.67	477.33	660.89	946.33	1,293.33	1,178.33
17	TPt-19	824.41	285.84	1,733.33	531.70	809.33	694.33
18	TPt-3	627.58	280.34	1,333.33	357.86	633.33	518.33
19	TPt-30	991.82	197.49	718.22	499.30	718.00	603.00
20	TPt-26	1,468.00	346.67	305.56	208.52	756.00	641.00
Mean		1,103.94	532.29	1,487.01	639.56	1,154.14	1,038.56
Prob (0.05)		*	*	*	**	*	*
SE (0.05)		812.77	235.35	957.66	207.35	382.05	382.14

* significant at $p = 0.05$, ** significant at $p = 0.01$ level of significance

Table 5 Analysis of variance and variation of the grain yield of twenty genotypes of winged bean evaluated in six environments, in humid agro-environments of Nigeria

Source	Df	Sum of squares (10^6)	Mean square (10^6)	Variation explained (%)
Environment (E)	5	38.71	7.74**	28.10
REP within E	12	18.11	1.51**	13.15
Genotype (G)	19	18.59	0.98**	13.50
G × E	95	51.10	0.54*	37.10
Residual	228	11.22	0.49	8.15
Total	359	137.73		

* significant at $p = 0.05$; ** significant at $p = 0.01$ level of significance, df: degree of freedom

genotype, environment, and their interaction (G × E) had significant effects on the seed yield, where G, E, and G × E accounted for 13.5%, 28.1%, and 37.1%, respectively of the variation, while the residual effect reached 8.15% of the variation (Table 5). This clearly shows that some winged bean genotypes performed differently in each of the six test environments because of the variations in the environmental conditions. As a result, genotypes can be chosen based on their suitability for a particular environment or multiple mega-environments. This result is in accordance with the findings of Sriwichai et al. (2021), who observed a significant G × E effect in their study of the yield stability in the winged bean genotypes.

Fig. 1 shows visualization of the "what-won-where" biplot for the seed yield of the twenty genotypes in six environments.

The GGE biplot enables evaluation of the environment based on the discriminating ability and representativeness of the GGE view (Sharma et al., 2020). The principal component axes captured 71.5% of the variation, with PC1 and PC2 accounted for 36.6%, and 34.9% of the variation, respectively. This demonstrates that the model's use of the GGE biplot to explain variation caused by G + E + GEI across environments was effective. The environments were grouped in a polygon into five sectors. Thus, three environments IF20, KI19, and KI20 were clustered in the first sector (mega-environment). Environments IB20 and IF19 were grouped in the second sector, while the environment IB19 comprised the third sector. However, none of the other sectors had environment representation. In each sector, the vertex genotypes or the genotypes at the corners of the

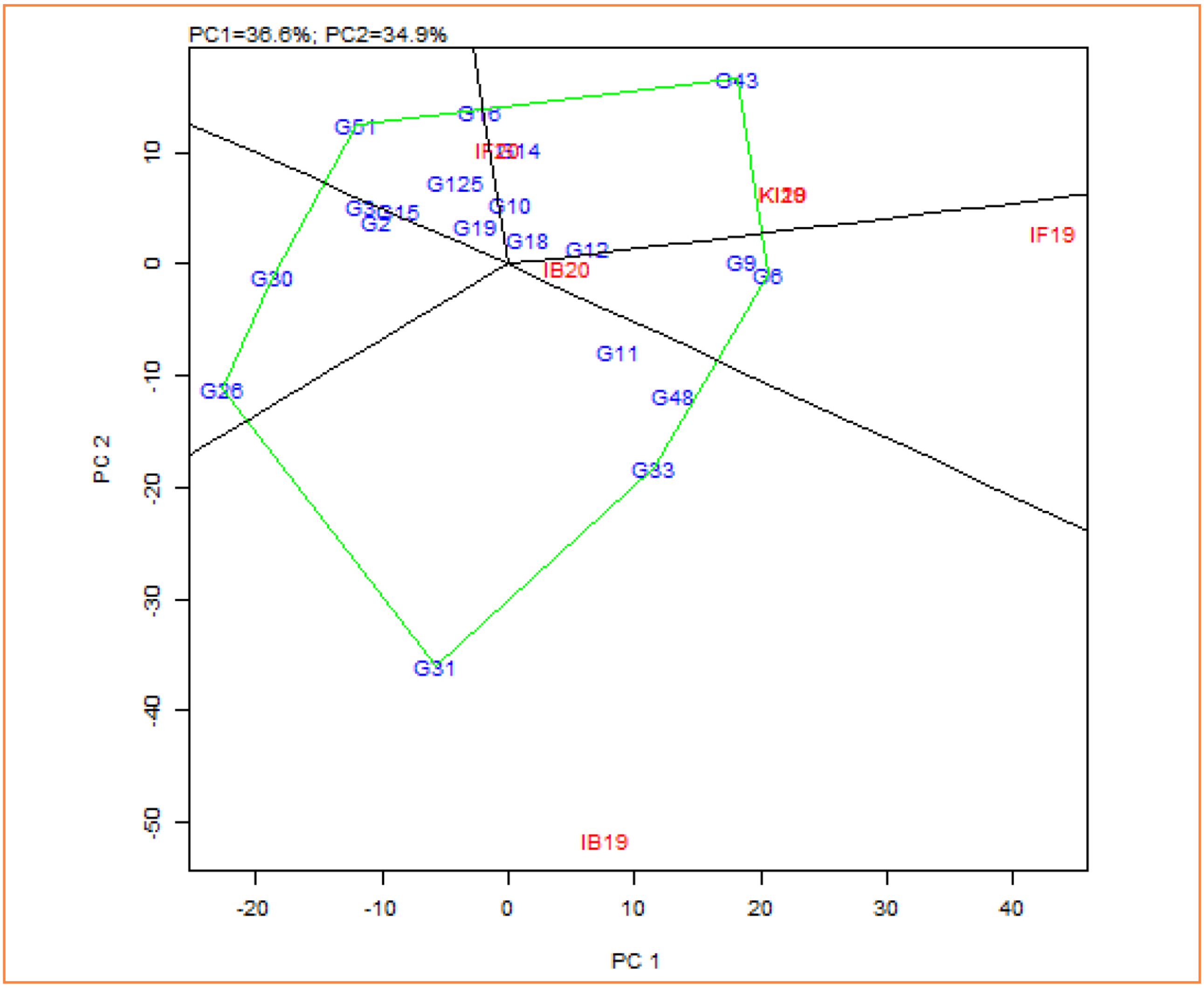

Figure 1 The "which-won-where" view of the GGE biplot for the seed yield of the twenty winged bean genotypes in six environments, in humid agro-environments of Nigeria (seed·kg·ha^{-1})
G2:Tpt-2; G3: Tpt-3; G6: Tpt-6; G9: Tpt-9; G10: Tpt-10; G11: Tpt-11; G12: Tpt-12; G14: Tpt-14; G15: Tpt-15; G16: Tpt-16; G18: Tpt-18; G19: Tpt-19; G26: Tpt-26; G30: Tpt-30; G31: Tpt-31; G33: Tpt-33; G43: Tpt-43; G48: Tpt-48; G51: Tpt-51;G125: Tpt-125. IF19, 20: Ile-Ife 2019, Ile-Ife 2020; IB19, 20: Ibadan 2019, Ibadan 2020; KI19, 20: Kishi 2019, Kishi 2020

polygons in a "which-won-where" polygon are the high-yielding or outstanding genotypes in such environment (Yan & Tinker, 2006). Hence, the genotype Tpt-43 was the highest yielder in the mega-environments. In addition, genotypes Tpt-6 and Tpt-9 were the highest yielder in the second sector, while Tpt-31 was adjudged the highest yielder in the third sector (Fig. 1).

The biplot of the environment view for the seed yield is presented in Fig. 2: Environments IB19 and IF19 were the only two that were found outside the concentric circles, they both had the longest projection along the average environment axis (AEA). The environment IB20 was found in the innermost part of the concentric circles with the shortest projection or vector on the direction of AEA (Fig. 2). The results obtained in this study agree with those of Akinyosoye (2022), Yan (2001), and Ebadi et al. (2010), who concluded that the vortex genotype in each sector could be grown at each of the locations where they demonstrated comparative advantages in seed production. Genotypes that did not fit into any of the sectors which the environment was represented by are not appropriate for cultivation in any of the investigated environments.

Fig. 3 presents the "mean vs. stability" of the GGE biplot using the average principal component axes (PC1 and PC2 scores) of the six environments. The result disclosed that the line perpendicular to the average environment axis (AEA) separated the genotypes into two groups (i.e. those above the average and those below the average). The genotypes found above the average included Tpt-6, Tpt-9, Tpt-43, Tpt-33, Tpt-48, Tpt-11, Tpt-12 Tpt-31, and Tpt-18, and were regarded as high-yielding genotypes,

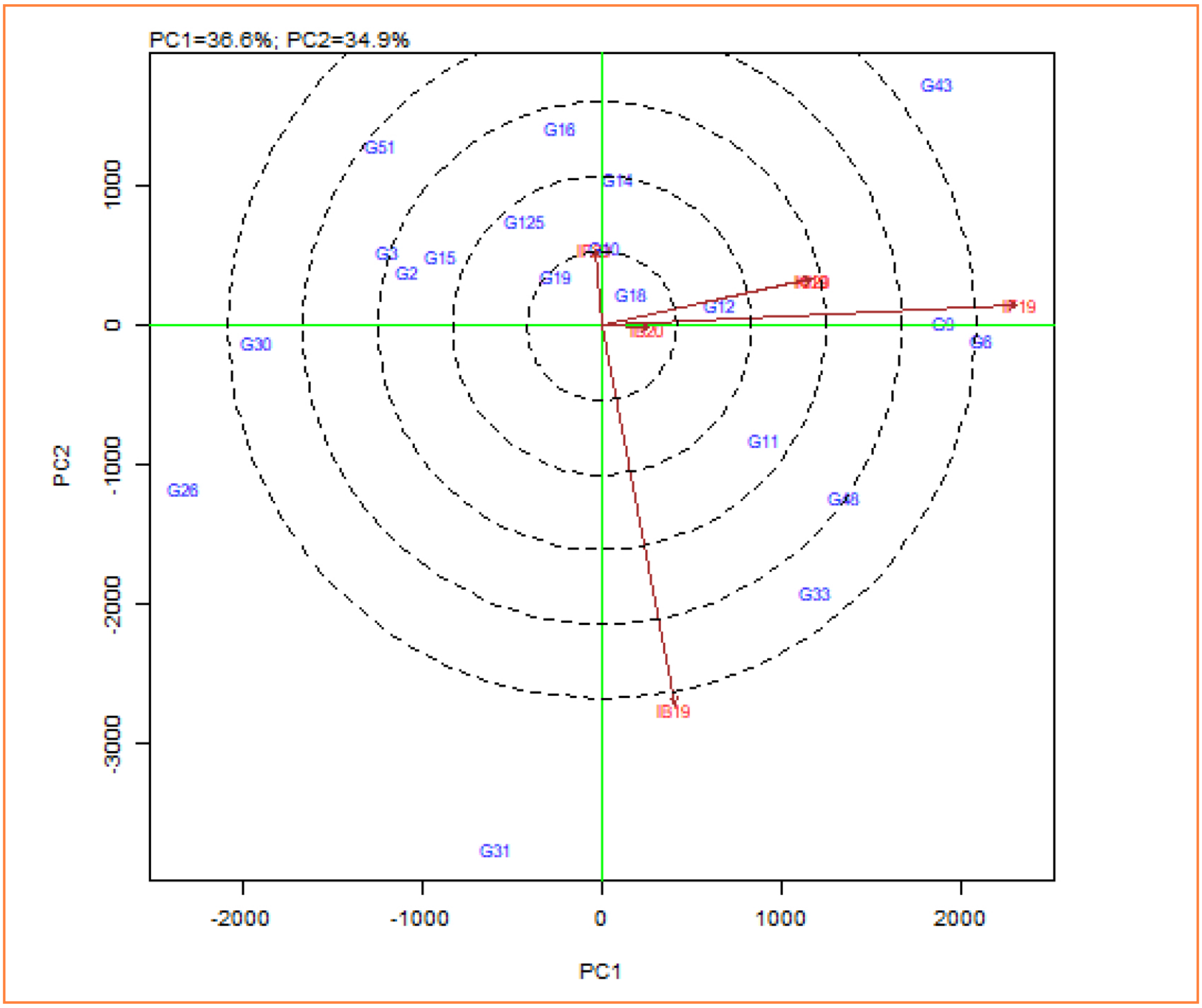

Figure 2 Ranking of the environments of the twenty genotypes of winged bean based on their yield performance (seed·kg·ha^{-1})
G2:Tpt-2; G3: Tpt-3; G6: Tpt-6; G9: Tpt-9; G10: Tpt-10; G11: Tpt-11; G12: Tpt-12; G14: Tpt-14; G15: Tpt-15; G16: Tpt-16; G18: Tpt-18; G19: Tpt-19; G26: Tpt-26; G30: Tpt-30; G31: Tpt-31; G33: Tpt-33; G43: Tpt-43; G48: Tpt-48; G51: Tpt-51;G125: Tpt-125. IF19, 20: Ile-Ife 2019, Ile-Ife 2020; IB19, 20: Ibadan 2019, Ibadan 2020; KI19, 20: Kishi 2019, Kishi 2020

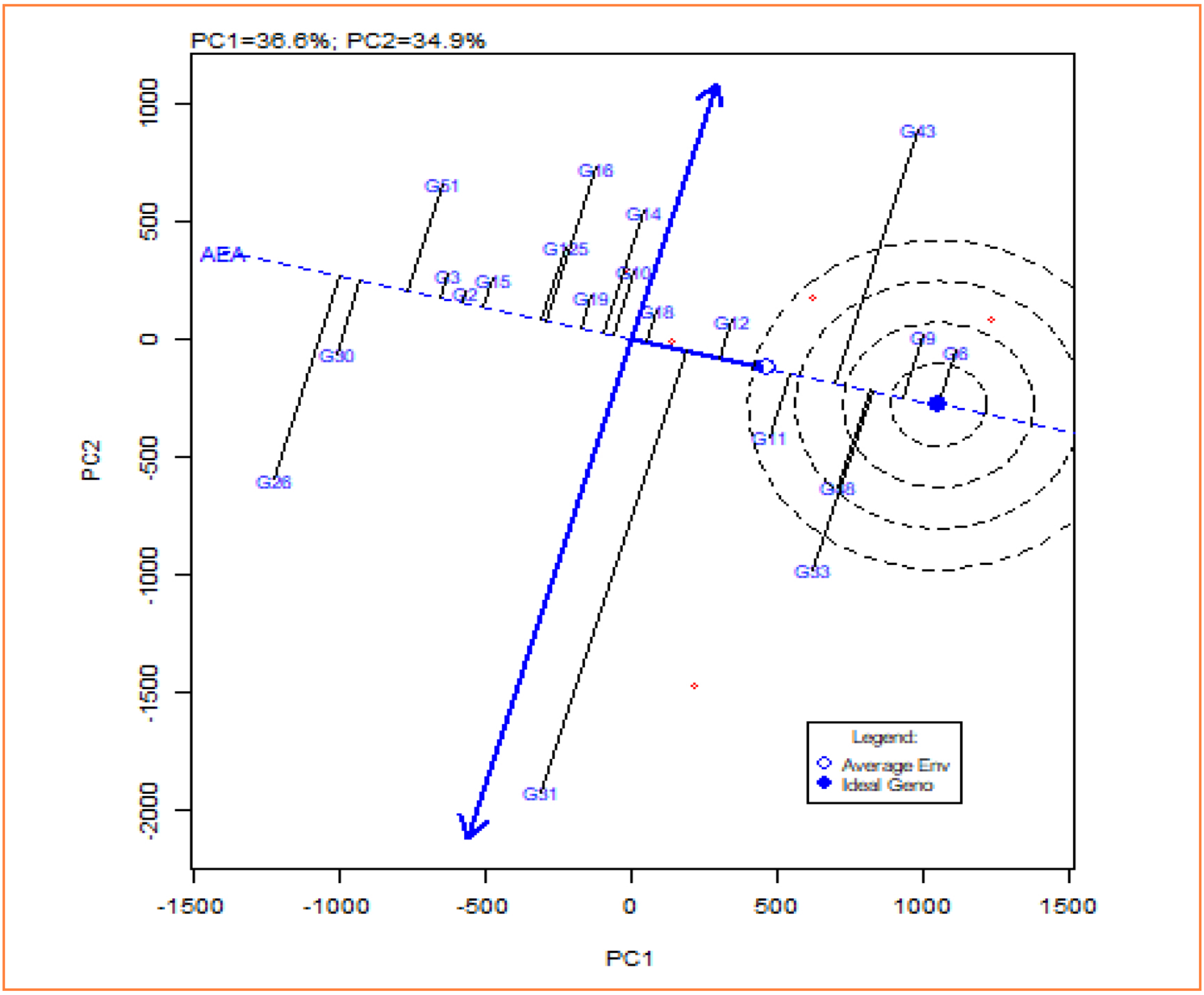

Figure 3 The "mean vs. stability" analysis of the twenty winged bean genotypes for the yield in six environments, in humid agro-environments of Nigeria (seed·kg·ha^{-1})
G2:Tpt-2; G3: Tpt-3; G6: Tpt-6; G9: Tpt-9; G10: Tpt-10; G11: Tpt-11; G12: Tpt-12; G14: Tpt-14; G15: Tpt-15; G16: Tpt-16; G18: Tpt-18; G19: Tpt-19; G26: Tpt-26; G30: Tpt-30; G31: Tpt-31; G33: Tpt-33; G43: Tpt-43; G48: Tpt-48; G51: Tpt-51; G125: Tpt-125. IF19, 20: Ile-Ife 2019, Ile-Ife 2020; IB19, 20: Ibadan 2019, Ibadan 2020; KI19, 20: Kishi 2019, Kishi 2020

whereas genotypes Tpt-26, Tpt-30, Tpt-51, Tpt-3, Tpt-2, Tpt-15, Tpt-16, Tpt-125, Tpt-19, Tpt-14, and Tpt-10 were the poorest performers in the seed yield as they were found grouped below the average. The farther a genotype's projectile line or vector deviates from the average environment axis (AEA), the more unstable the genotype is. On the other hand, the closer a genotype's vector lies to the AEA, the more stable the genotype is (Yan 2001; Yan et al., 2007). The genotypes Tpt-18, Tpt-12, Tpt-6, and Tpt-9 were among the most stable genotypes that were high-yielding, as they were found the closest to the AEA, whereas the genotypes Tpt-2, Tpt-3, Tpt-15, and Tpt-19 were considered stable but had low seed yield. In addition, the genotype Tpt-12 was identified as the ideal genotype because of the high seed yield, and the most stable among the high-yielding genotypes (Fig. 3). Therefore, Tpt-12, Tpt-6, Tpt-18, and Tpt-9 were identified as stable and high-yielding genotypes, while Tpt-2, Tpt-3, Tpt-15, and Tpt-19 were stable but low-yielding. The genotype Tpt-12 was chosen as the best genotype because it lies the closest to the small circle on single arrow head. It was thought that an ideal genotype would have high yield potential and consistent performance across environments (Kaya et al., 2006; Yan & Tinker, 2006). The two environments IB20 and IF20 were located at the centre of the concentric circle, indicating that they were thought to be the best environments for assessing the stability of the genotypes, and the most representative of all the environments. Thus, it means that in these settings, the identification and selection of durable genotypes can be conducted with reliability. The ability of the genotypes to withstand the harsh weather conditions encountered in these environments may have made such environments the best ones for the selection. This result supports the findings of Akinyosoye (2022), Tiwari et al. (2022), and Yan et al. (2000), who all agreed that the environment closest to the concentric point is ideal for the selection of stable genotypes. On the average environment axis, environments IB19 and IF19 had the longest projectiles. This implies that they are the best environments for selecting high-yielding genotypes, but it does not imply that the genotypes chosen in these environments are stable. Genotypes selected for the yield advantage in these environments, on the other hand, can be kept as cultivars for seed improvement. Oyekunle et al. (2017) reported that testing discriminant conditions in the early stage would save costs by reducing the number of genotypes for selection, as well as the number of locations/seasons.

4 Conclusions

The results obtained in this study revealed that the seed yield of the winged bean was significantly influenced by the interaction (GEI), followed by environment (E), and genotype (G), accounted for 37.1%, 28.1%, and 13.5% of the total variation, respectively. The GGE biplot made it easier to identify genotypes with stable performance, discriminate between different environments, and specifically identify how well the genotypes adapted to different conditions in the environments. Thus, the environments IB20 and IF20 were adjudged the most ideal environments to discriminate between genotypes, due to the minimum effect of the environment on the performance of the genotypes. The genotype Tpt-12 was identified as high-yielding and stable. Thus, Tpt-12 would be recommended for commercial cultivation in southwestern Nigeria. Moreover, the selected high-yielding winged bean genotypes are hereby recommended as promising parental lines for grain yield improvement in the winged bean improvement programmes.

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