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RELATIVE DISCRIMINATING POWERS OF GGE AND AMMI MODELS IN THE SELECTION OF TROPICAL SOYBEAN GENOTYPES

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ABSTRACT

Selection of crops is preceded by multi-locational testing in plant breeding; however, it becomes difficult for breeders to determine which genotypes should be selected in the presence of genotype by environment (GEI). Six genotypes of soybean (*Glycine max* (L.) Merr.) were evaluated at ten locations in Nigeria for grain yield and stability. The analysis of variance revealed significant ($P \leq 0.05$) GEI effect. Mean grain yield of the soybean genotypes ranged from 1148 kg ha^{-1} for genotype M351 to 1584 kg ha^{-1} for TGx 1448-2E. Ilorin in the southern guinea savanna of Nigeria was the most variable with high interaction principal component axes (IPCA); while Bauch in the northern guinea savanna was identified as more stable location in evaluating the soybean genotype. Mega-environments and the best yielding soybean genotypes in each mega-environment were revealed by the GGE biplot analysis. Furthermore, TGx 1448-2E and TGx 1440-1E, were established as the most promising, and stable genotypes across the test locations. Stability model of GGE biplot was superior, effective and informative in mega-environment analysis compared to AMMI analysis.

Key Words: *Glycine max*, principal component analysis

RÉSUMÉ

La sélection des cultures est précédée de tests multilocaux en amélioration des plantes; cependant, il apparaît difficile pour les améliorateurs de déterminer quels types de génotypes sélectionner en présence du génotype x environnement (GEI). Six génotypes du Soja (*Glycine max* (L.) Merr.) étaient évalués dans dix milieux au Nigeria pour le rendement en grains et la stabilité. L'analyse de la variance a révélé un effet significatif ($P \leq 0.05$) du GEI. Le rendement moyen en grains des génotypes du soja variait de 1148 kg ha^{-1} pour le génotype M351 à 1584 kg ha^{-1} pour TGx 1448-2E. Ilorin au sud de la savanne guinéenne au Nigeria était le plus variable avec une interaction élevée des axes de la composante principale (IPCA); pendant que Bauch dans le nord de la savanne guinnéenne était identifié comme milieu le plus stable dans l'évaluation du génotype du soja. Les Mega-environments et le meilleur génotype du soja du point de vue rendement dans chaque mega-environment étaient révélés par l'analyse du biplot. En plus, TGx 1448-2E et TGx 1440-1E, étaient jugés les plus promettants et génotypes stables à travers le test de milieu. Le modèle de stabilité du biplot GGE était supérieur, effective et informative dans l'analyse méga-environmentale en comparaison avec l'analyse du AMMI.

Mots Clés: *Glycine max,* analyse de la composante principale

INTRODUCTION

Soybean (*Glycine max* (L) Merr.) is a legume that grows in tropical, subtropical, and temperate climates. It is a crop with essential amino acids pattern that come close to satisfying the needs of the human diet (Osho *et al.*, 1995). In Africa, the high cost of protein–rich food stuffs (meat, fish, eggs and milk) has resulted in increased soybean utilisation as an alternative source of inexpensive protein (Ogundipe and Weingartner, 1992).

Traditionally, evaluation of genetic diversity in soybean has been based on the differences in morphological and agronomic characters (Bernard *et al*., 1998). However, individual genotypes of soybean are only well adapted to certain regions, and the phenotypes are highly influenced by many environmental factors. This phenomenon is referred to as genotype by environment interactions (GEI), which is a routine occurrence in plant breeding programmes. Both the genotype and environment determine the phenotype of an individual. The effects of these two factors, however, are not always additive because of the interaction between them. The presence of significant GE interaction makes it necessary to partition a cultivar development programme with different objectives for different regions and for different weather conditions (Busey, 1983).

The Additive Main Effects and Multiplicative Interaction (AMMI) analysis has been reliably used for better decision making with regards to selection of genotypes (Crossa *et al.*, 1991; Gauch, 1992). However, there is need to perfectly incorporate genotype (G) and genotype by environment (GEI) in cultivar evaluation and plant breeding programme in multi-environment trials (MET). The objective of this research was to examine the relative discriminatory abilities of AMMI and GGE stability models in selection for grain yield and stability among tropical soybean genotypes.

MATERIALS AND METHODS

A multi-environment trial study was carried out for three years at ten different locations in Nigeria. The locations cut across three ecological zones of Nigeria and included Abeokuta (7°11'N, 3°18'E) in the derived savanna region with transitional forest savanna vegetation, Ikenne (6°52'N, 3°41'E) and Ile-Ife (7°49'N, 4°07'E) in rain forest zone, Ilorin (8°30'N, 4°.32'E), Mokwa (9°18'N, 5°04'E) Bida (9°05'N, 6°00'E) and Yandev (7°23'N, 9°05'E) in Southern Guinea savanna, Samaru (11°17'N, 4°18'E), Zaria (11°02'N, 7°43'E) and Bauchi (10°21'N, 9°52'E) in Northern Guinea savanna vegetation.

Six soybean cultivars TGx 1440-1E, TGx 1448-1E, TGx1 448-2E, TGx 1455-1D, Samsoy 2 and M 351 that were released for cultivation in Nigeria and other tropical countries (Ojo, 2003) were obtained from genetic resource unit of International Institute for Tropical Agriculture (IITA), Nigeria for the study. The experimental design was a randomised complete block design with three replicates at each site under rain-fed conditions. Each plot consisted of 480 plants in four plant rows. Each row was 6 m long with 75 cm inter-row spacing. Spacing between plants was 5 cm. At maturity, data on grain yield was collected from the inner rows leaving 1 m on either sides as borders.

The data were subjected to combined analyses of variance using the GLM procedure of Statistical Analysis System (SAS, 1999). The GGE Biplot methodology, which is composed of two concepts, the genotype (G) concept (Gabriel, 1971) and the genotype plus genotype by environment interaction (GGE) concept (Yan *et al*., 2000), was applied for visual examination of the genotype by environment interaction (GEI) (GGE-biplot software). The GGE biplot was constructed using first two principal components (PC1 and PC2) derived from subjecting environment centered yield data. The Additive Main Effect and Multiplicative Interaction (AMMI) analysis using MATMODEL (version 2.0) was also utilised to analyse the data.
The AMMI model is stated below:

$$Yge = \mu + \alpha g + \beta e + \Sigma\lambda nYgn\ \pi en + \theta ge$$

Where

Yge = the yield of genotype;
g, in environment e;
μ = the grand mean;
αg = the genotype mean deviation;

βe = the environment mean deviation;
λn = the eigen value of the PCA axis n;
Ygn and πen = the genotype and environment PCA scores for the PCA axis n;
N = the number of PCA axes retained in the model; and
θge = the residual error.

RESULTS

The combined analysis of variance for grain yield of six soybean genotypes evaluated at thirty environments (ten locations within three years) in Nigeria is shown in Table 1. The result revealed that genotypes, environments and genotype by environment interaction (GEI) effects were significant ($P \leq 0.01$). The genotype effect accounted for about 3.7% of the total variation while the environmental effect contributed about 61.8%. This indicated that environment effect was the predominant source of variation, followed by GEI which accounted for 14.9%. The importance of GEI component over genotype gives opportunity for specific breeding (adaptation).

Data for grain yield, averaged over three years, of the six soybean genotypes grown at ten locations is presented in Table 2. Genotype TGx 1448-2E recorded the highest grain yield (1593.19 kg ha^{-1}), while genotype M351 had the lowest yield (1141.96 kg ha^{-1}). The mean grain yield of the soybean varieties in each environment is presented in Table 3. The environmental effect showed a wide range of grain yield. It varied from 88.89 kg ha^{-1} (Ilorin/2005) to 2,041.72 kg ha^{-1} (Zaria/2005).

AMMI analysis of variance for grain yield of the six soybean genotypes showed significant differences ($P \leq 0.01$) for all the sources of variation (Table 4). Over 50% of the total sum of square was attributed to environmental effect, 11% to genotypic effects; while 18% to GEI effects. The GEI was partitioned into two interaction principal components analysis axes (IPCA). IPCA1 and IPCA2 of the AMMI model captured 45 and 33% of the GEI sum of squares (SS), respectively.

Table 5 shows the mean yield of six soybean genotypes and the value of the first IPCA scores. TGx 1448-1E had the highest IPCA score (46.37); while the smallest value (26.58) was recorded for M351. This showed the stability of M351 across the test locations. Also, IPCA value of 1.33 was recorded for Bauchi; while the highest IPCA value was observed for Ilorin. This indicated low interaction of the climatic conditions in Bauchi and high interaction in Ilorin. Bauchi is, therefore, more stable in evaluating the performance of the soybean genotypes.

The GGE biplots of the first two interaction principal component (PC1 and PC2) accounted for 86.6% of the total variation with PC1 and PC2; explaining 67.5 and 19.1%, respectively (Fig. 1).

TABLE 2. Grain yield of six soybean genotypes evaluated at ten locations in Nigeria

Genotypes	Mean yield (kg ha^{-1})
TGx 1440-1E	1,537.66
TGx 1448-1E	1,424.24
TGx 1448-2E	1,593.19
TGx 1455- 1D	1,271.97
Samsoy 2	1,405.97
M351	1,141.96
LSD	172.32

TABLE 1. Combined analysis of variance for grain yield of six soybean genotypes evaluated at thirty environments in Nigeria

Source of variation	Degree of freedom	Sum of squares	Mean squares	Percentage total variation
Replication (within environment)	60	1,589.16	264,860.8**	
Genotype (G)	5	1,204.03	2,408,058.4**	3.70
Environment (E)	29	20,129.85	6,934,430.9**	61.80
G x E	145	4,850.96	336,872.3**	14.89
Error	293	4,817.53		

** significant at $P \leq 0.01$ probability level

TABLE 3. Mean grain yield (kg ha^{-1}) of the soybean varieties in thirty environments in Nigeria

Location	Year		
	2005	2006	2007
Ikenne	1,083.33	1,398.17	1,975.00
Abeokuta	119.06	1,095.6	1,790.61
Ife	1,456.44	1,097.94	1,218.22
Ilorin	88.89	1,515.28	3516.67
Mokwa	1,610.06	1,695.83	1,024.33
Bida	1,559.72	1,166.72	495.56
Samaru	723.11	1,791.56	1,207.28
Yandev	1,061.56	1,886.56	1,819.44
Bauchi	1,755.67	609.55	1,536.78
Zaria	2,041.72	1,624.94	1,109.28
LSD (0.05)			236.33

TABLE 4. Additive main effects and multiplicative interaction (AMMI) analysis of variance for grain yield of six soybean genotypes evaluated in ten locations across three years in Nigeria

Source	Degree of freedom	Sum of squares	Mean squares	Percentage of total variation	Percentage of G x E
Environment	9	60,678,514.71	6,742,057.19**	53.50	
Block	20	6,092,115.60	304,605.78**		
Genotype	5	12,579,255.97	2,515,851.19**	11.09	
G x E	50	20,494,849.00	409,896.98**	18.07	
IPCA 1	12	9,239,434.44	769,952.87**		45.08
IPCA 2	10	6,695,125.40	669,512.54**		32.67
Residual	28	4,587,757.72	163,848.49		22.38
Error	95	17,646,598.65	185,753.67		
Total	179	113,423,042.12	633,648.28		

** significant at $P \leq 0.01$ probability level

The polygon view was drawn to join TGx 1448-1E, TGx 1448-2E, Samsoy 2 and M 351, which were the genotypes located farthest from the biplot origin such that the other genotypes, TGx 1455-1D and TGx 1440-1E were within this polygon. Figure 1 also shows that the test locations used in the study can be grouped into three mega-locations. Ilorin in one sector and Ikenne, Bida, Mokwa, Samaru, Bauchi, Zaria and Yandev in another sector. Abeokuta and Ife were also group together in another sector.

Figure 2 shows the mean grain yield and stability performance of the soybean genotypes. The genotypes were ranked along the average-environment co-ordinate (AEC x-axis) with an arrow pointing to a greater value based on their mean performance across all locations. The double-arrowed line separates entries with below-average means. Genotypes TGx 1448-2E, TGx 1440-1E, Samsoy 2 and TGx 1448-1E were placed above the double-arrowed line; while the remaining genotypes were located below the double-arrowed line. Genotype TGx 1448-2E was the leading genotype on the AEC (x-axis). Genotypes TGx 1448-1E and Samsory 2 had longer projections on the ATC (y-axis); while

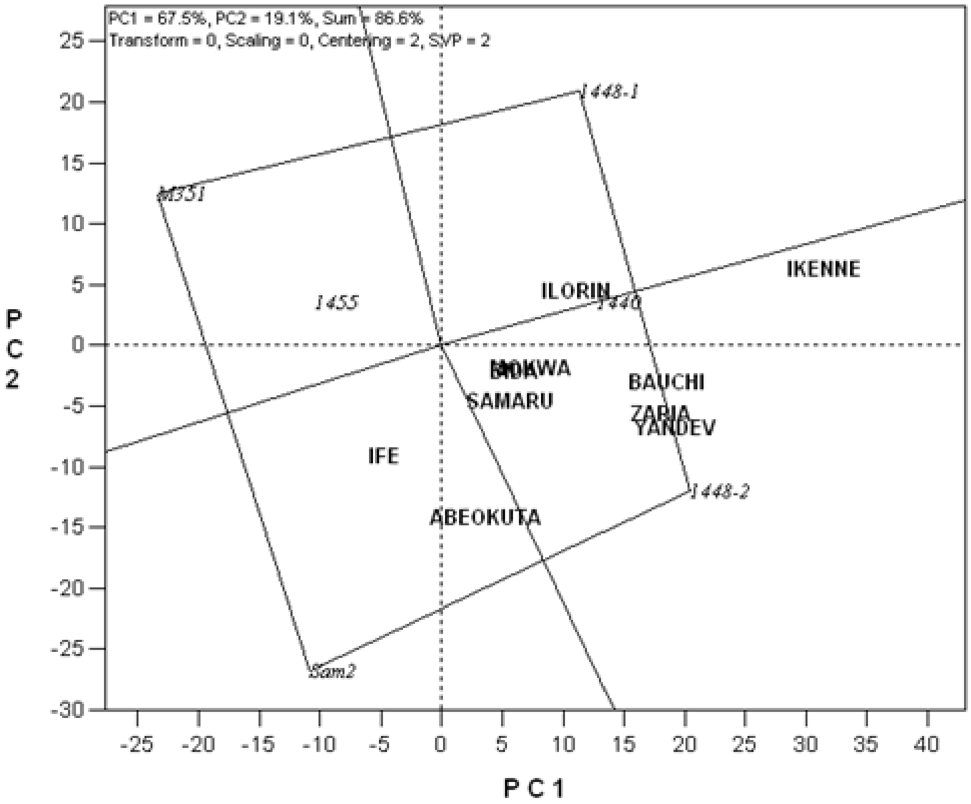

Figure 1. The "which-won-where" view of the GGE biplot showing which soybean genotypes best in which location in Nigeria.

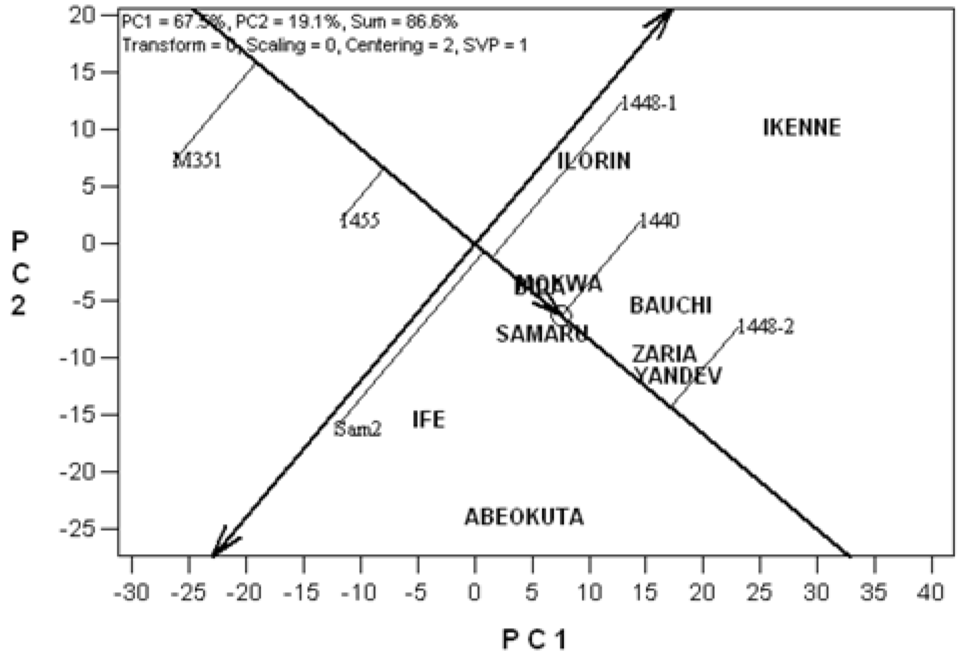

Figure 2. Mean yield and stability of soybean genotypes across ten locations in Nigeria.

genotypes TGx 1448-2E and TGx 1440-1E had shorter projections on the AEC (y-axis).

DISCUSSION

The mean yield of soybean genotypes used in this experiment across thirty environments differed substantially. This is indicative of the wide genetic background of the genotypes. The AMMI analysis provided a clear picture of the G x E interaction. As a result of its low interaction, TGx 1455- 1D could be considered stable in any environment. Genotype TGx 1448-2E, TGx 1440-1E and Samsoy 2, with above average grain yield, can only be recommended for all the test locations provided that improved management practices and optimum climatic factors are in place. The three genotypes were responsive to changes in the environments and thus, not stable.

GGE biplot was also used to compare the performance of the soybean genotypes at the test locations. In the “which-won-where” polygon view, the vertex cultivar in each sector represents the highest yielding cultivar in the location that falls within that particular sector (Yan *et al.*, 2007). A line drawn from the origin of the biplot and perpendicular to the side of the polygon effectively divided the test locations into three sectors. This indicates that a single genotype had the highest yield in each mega-location; and each mega-location provided similar information about the genotypes. TGx 1448-1E performed best in Ilorin, while TGx 1448-2E can be selected for grain yield production in Ikenne, Mokwa, Bida, Samaru, Bauchi, Zaria and Yandev. In Ife and Abeokuta, Samsoy 2 had the best performance while genotypes M351 did not perform well in any of the locations.

According to Yan *et al.* (2000), the average yield of the cultivars is approximated by the projections of their markers on the AEC x-axis while the stability of the cultivars is measured by their projection onto the double-arrow line (AEC y-axis). TGx 1448-2E and TGx 1440-1E, were identified as high yielding and more stable genotype which was in disagreement with the result of AMMI analysis.

TABLE 5. Means and first principal component analysis (PCA) scores form AMMI analysis of grain yield for six soybean genotypes evaluated at ten locations in Nigeria

Genotypes	Ikenne	Abeokuta	Ife	Ilorin	Mokwa	Bida	Samaru	Yandez	Bauch	Zaria	Mean	IPCA1
TGx 1440-1E	1916.67	1025.11	1279.34	2163.89	1668.22	1063.45	1181.78	1695.89	1490.56	1889.78	1537.47	43.31
TGx 1448-1E	1940.78	802.67	902.89	2072.22	1361.22	1199.56	1142.11	1848.89	1437.67	1523.22	1423.12	46.37
TGx 1448-2E	1879.66	1063.56	1204.22	2086.11	1580.67	1097.33	1437.33	1960.67	1545.56	2050.89	1590.60	40.62
TGx 1455	1106.44	838.44	1372.33	1983.33	1500.11	1033.89	1173.56	1555.33	1429.33	1245.33	1323.81	31.33
Samsoy 2	1037.00	1376.22	1533.33	1717.67	1439.00	1182.89	1303.33	2076.89	1233.55	1523.11	1442.30	29.32
M351	939.89	934.22	1252.89	1819.43	1200.11	866.89	1204.33	1249.33	688.56	1319.56	1147.52	26.58
Mean	1470.07	1006.70	1257.50	1973.78	1458.22	1074.00	1240.41	1731.17	1304.20	1591.98	1410.80	
IPCA1	4.80	-10.73	-4.40	16.02	1.69	-8.18	-4.13	6.32	-1.33	6.19		

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