

GENOTYPE BY ENVIRONMENT INTERACTION OF EARLY AND INTERMEDIATE MATURING MAIZE VARIETIES IN THE SOUTHERN GUINEA SAVANNA OF NIGERIA

Gbadamosi¹A., Olaoye²G., Akinwale³R. A., Bankole²F.A. and Takim^{2*}F.O.

¹Teaching and Research Farm, Landmark University Omu-Aran, Nigeria

²Department of Agronomy, University of Ilorin, P. M. B. 1515, Ilorin, Nigeria

³Department of Crop Production and Protection, Obafemi Awolowo University, Ile-Ife, Nigeria

*Corresponding author's e-mail: felixtakim@yahoo.co.uk

ABSTRACT

Multi-location data collected from evaluation of 24 early and 18 late/intermediate drought-tolerant (DT) open pollinated varieties (OPVs) of maize in the southern Guinea savannah (SGS) of Nigeria, were subjected to genotype (G) and genotype x environment (GGE) analyses with the objectives to i) assess their yield potential and stability and ii) determine the discriminating ability and representativeness of the test locations with a view to identifying core testing sites for evaluating maize genotypes of different maturity groups in the southern Guinea savannah ecologies of Nigeria. Results showed significant ($P < 0.01$) genotype (G), environment (E) as well as genotype x environment interaction (GEI) effect for grain yield, suggesting that the locations at which the genotypes were tested comprised of a number of unique environments. The greatest proportion of total variation to grain yield was contributed by the environments (42.1% for the early maturity and 52.4% for the intermediate/late maturity), compared to the negligible genotypic contribution which ranged from 2.3 % (early maturity) and 0.3 % (intermediate/late maturity), depending on the period of evaluation. However, the early maturing variety, TZE-W DT STR C4 and intermediate/late maturity variety, TZL COMPI-W C6 F2 consistently demonstrated superiority for grain yield potential regardless of the environment where they were evaluated. They were the closest to the ideal genotype and may be considered as superior varieties for further testing in farmers' fields for the purpose of release. Ilorin appears to be a good test location for selecting superior genotypes due to its high discriminating ability and representativeness.

Key words: *Zea mays* L; maturity groups; genotype x environment interaction; grain yield

INTRODUCTION

The selection of suitable breeding and testing locations is crucial to the success of a maize breeding programme because genotype by environment interaction (GEI) effect is one of the main complications in the selection of broad adaptation in most breeding programmes. This is because multilocal evaluation of the varieties is costly and time-consuming. Thus, plant breeders/agronomists focus on how available resources can be optimally allocated over years, seasons, locations, and replications, to provide as much information as possible, in a most cost-effective manner without sacrificing precision. Therefore, GEI can be defined as the differential expression of genotypes when evaluated in a given set of environmental conditions. It constitutes a vital area in plant breeding because its understanding among others, helps to determine optimum allocation of resources for testing genotypes across locations and/or years, provide information on the understanding of stability of performance of varieties and assist in the

subdivision of a particular area to mini-environments for testing new varieties.

Analysis of variance (ANOVA) is useful for estimating the existence and magnitude of GEI but fails to explore any underlying structure within the observed GEI and also fails to determine the pattern of response of genotypes and environments. Among the powerful statistical tools which have been increasingly utilized for the analysis of multi-environment trial (MET) data is the genotype main effect plus genotype by environment interaction (GGE) biplot. This model was developed to identify the winning cultivar in a given environment and the most suitable environment for each cultivar, compare any pair of cultivars in individual environments, and for mega-environment differentiation, and determination of the discriminating ability and representativeness of the environments (Yan 2001). It is based on environment-centered data, which integrates the genotypic (G) main effect with the genotype-by-environment (GGE) interaction effect of a genotype-by-environment dataset (Yan *et al.*,

2000). It has been widely used for evaluating genotypes for their yield potential and stability across environments (Badu-Apraku *et al.*, 2008; Badu-Apraku and Lum, 2010), as well as for evaluating environments with a view of classifying them into mega-environments (Badu-Apraku *et al.*, 2011b). Furthermore, it provides information on i) the cultivars that will be suitable for the different environments, ii) stability of cultivars in the various environments and iii) identification of the mega-environments. Apart from being widely used in the analysis of genotype by environment data, GGE biplot software has also been described as an effective statistical tool for identifying genotypes with superior multiple traits that could be useful as parents in a breeding programme (Yan and Rajcan, 2002). Two separate studies in Nigeria (Badu-Apraku *et al.*, 2008; Badu-Apraku and Lum, 2010) have used the GGE biplot analysis to decompose the GEI components to obtain information on the performances of early maturing maize cultivars that were suitable for *Striga*-infested and *Striga*-free environments and to investigate stability of cultivars in the various environments. The southern Guinea savannah (SGS) of Nigeria is drought-prone due to the irregular rainfall pattern which necessitated the development and testing of drought tolerant (DT) maize open pollinated (OPVs) and hybrids for cultivation in the ecologies. Drought Tolerant Maize for Africa (DTMA) project evaluated several maize genotypes of different genetic constitution and maturity groups in multilocal trials, which was facilitated by the international Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. However, apart from subjecting the data to the general ANOVA, information is lacking on the representativeness, discriminating ability and repeatability of the testing sites, which could reduce the costs associated with varietal testing in the ecologies. Therefore, the objectives of this study were to 1) determine the performance and stability of early and intermediate/late maturing DT maize varieties across selected locations in SGS of Nigeria and 2) determine the discriminating power and representativeness of the locations used for evaluating maize varieties in SGS of Nigeria with the view to identify core testing sites and ideal location for evaluating maize varieties of different maturity groups

MATERIALS AND METHODS

Description of experimental materials

The materials used comprised twenty-four (24) early maturing and eighteen (18) intermediate/late maturing DT open pollinated varieties (OPVs) of maize (Table 1) which were developed by maize scientists at the IITA, Ibadan, Nigeria. The experimental materials formed part of

the series of genotypes evaluated in several locations in the SGS ecologies of Nigeria.

Description of experimental site

The genetic materials were evaluated at seven (7) locations in the SGS ecologies of Nigeria between 2007 and 2010. The test locations were Ilorin (2007 - 2010), Oke-Oyi (2007 and 2008), Ejiba (2007 and 2008), Mokwa (2009 and 2010), Kisi (2007 and 2008), Ballah (2007 and 2008) and Badeggi (2009 and 2010). Table 2 shows the coordinates of the testing sites.

Experimental layout and cultural practices

The trials were conducted under rain-fed condition using a randomized complete block design with three replications each year. Each plot consisted of four rows, 5m long spaced 0.75 m apart with 0.25 m spacing between plants within the row. Three seeds were sown per hill and later thinned to two plants per stand to obtain a final population density of 66,000 plants/ha for the early maturing group and 53000 plants/ha for the late/intermediate maturity group. In order to optimize crop performance at each site, fertilizer application was as split-dosage at the rate of 80kgN/ha, 60K₂O/ha and 60P₂O₅ at three weeks after planting (3WAP) using compound fertilizer (NPK 20:10:10) and at 6-7 WAP using urea fertilizer. Weed control was done using pre-emergence application of Premextra at 2.5kg ai/ha and a supplemented hoe weeding at 4 weeks after planting (WAP).

Data collection and Statistical analysis

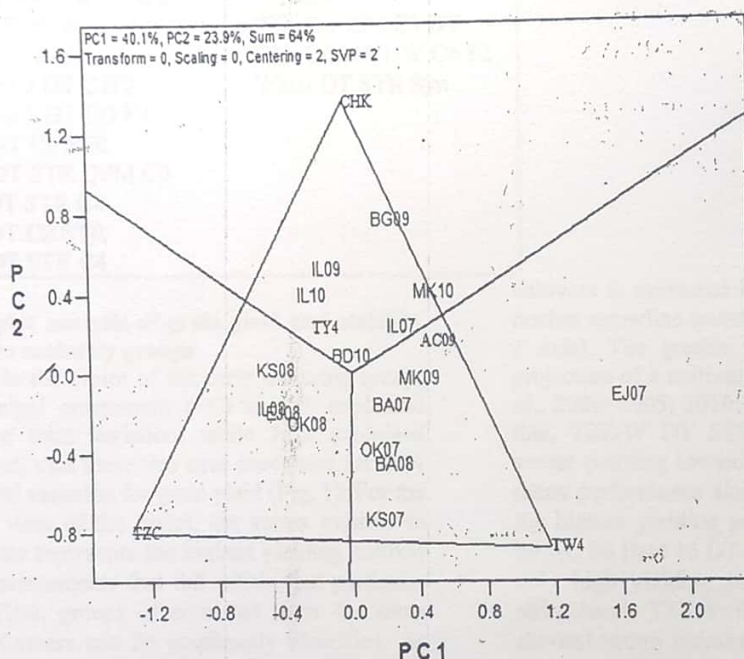
Although data were collected on several agronomic and yield traits, data on grain yield, anthesis-silking-interval (ASI) and ears per plant (EPP) were presented since these three give an indication of genotypic performance under moisture deficit condition. Separate analyses of variance (ANOVA) was performed on grain yield, ASI and EPP for each location to test for the homogeneity of errors, followed by combined ANOVA across environments for 2007/2008 and 2009/2010 with PROC MIXED procedures of SAS software (SAS Institute, Inc. 2002). Pertinent means were there after separated using the least significant difference (LSD) $P < 0.05$, according to Steel and Torrie (1980). Subsequently, means of grain yield were subjected to genotype main effect plus genotype by environment interaction (GGE) biplots analysis to decompose the GEI into principal component axes.

RESULTS

Results of the combined ANOVA for the early maturing varieties revealed that environment effect (E) was highly significant ($P < 0.01$) for grain yield, ASI and EPP. The varieties (G) differed significantly ($P < 0.01$) only for grain yield while

GEI effect was significant ($P < 0.01$) for grain yield and ASI (Table 3). The proportion of the total sum of squares contributed by environments was the highest for all traits measured, ranging from 42.1% for grain yield, 54.9% to 57% for ASI, while the percentage contribution of the total sum of squares due to the varieties was the lowest for all traits measured, ranging from 0.5% (EPP) to 2.3% for grain yield. The contribution of GEI on the other hand ranged from 7.6% (EPP) to 42.1% (grain yield), which suggests the need for extensive testing of cultivars in multiple environments over years before cultivars are recommended for cultivation.

Among the intermediate/late maturing varieties, E was highly significant ($P < 0.01$) for all the traits. Although G was not significant for any of the three traits, the GEI effect was significant ($P < 0.01$) for ASI (Table 4). The proportion of the total variation contributed by environment was the highest for all the traits, ranging from 52.4% (grain yield) to 64.3% (EPP). In contrast, the percentage contribution due to genotypes in this group was the lowest for all traits and it ranged from 0.3% for grain yield to 1.0% for EPP. The contribution of GEI to total variation ranged from 7.9% (EPP) to 13.5% (ASI).



CODE	PREDIGREE
TW4	TZE-W DT STR C4
CHK	Local check
TZE	TZE Comp 3 DT C0F2
TY4	TZE-Y DT STR C4
AC09	AC 90 Pool 16 DT STR

CODES	SITES
EJ	Ejiba
IL	Ilorin
OK	Oke-Oyi
BD	Badeggi
KS	Kisi
BA	Ballah
MK	Mokwa

Fig 1: Polygon view of the genotype main-effect plus genotype by environment interaction (GGE) biplot of 5 early maturing DT maize varieties evaluated at 16 environments in southern Guinea savanna of Nigeria, between 2007 and 2010.

Table 1: Drought tolerant maize progenies evaluated between and 2010 in the SGS, Nigeria

Early maturing OPVs	Intermediate/late maturing OPVs
2008 DTMA-Y STR	DT SYN2-W
2008 A-W STR	DT SYN3-W
2008 A-Y STR	DT SYN4-W
2009 DTE-W STR Syn	DT SYN7-W
2009 DTE-Y STR Syn	DT SYN8-W
2009 TZE-W DT STR	DT SYN9-W
2009 TZE-Y DT STR	DT-SR-W CO F2
AC 90 Pool 16 DT STR	DT-STR-W C2
DTE-W STR Syn C1	DT STR-W SYN2
DTE-Y STR Syn C1	DT STR-Y SYN2
DT-W STR Synthetic	DT-SYN-1-W
DT-Y STR Synthetic	DT-SYN2-W
EV DT 97 STR C1	IWD C3 SYN F2
EV DT-W 99 STR C0	SUWAN-1-SR-SYN
EV DT-W 99 STR QPM C0	TZB-SR
Syn DTE STR-W	TZL COMP4 C3 DT
Syn DTE STR-Y	TZL COMP 1-W C6 F2
TZE Comp 3 DT C1F2	White DT STR Syn
TZE Comp 3 DT CO F2	
TZE-W DT C2 STR	
TZE-W DT STR QPM C0	
TZE-WDT STR C4	
TZE-Y DT C2 STR	
TZE-Y DT STR C4	

GGE biplot analysis of grain yield and stability in the two maturity groups

In the biplot of the early maturing group, the principal component (PC) axis 1 explained 40.1% of total variation; while PC2 explained 23.9% and, thus these two axes accounted for 64% of the total variation for grain yield (Fig. 1). For the polygon view of the biplot, the vertex cultivar in each sector represents the highest yielding cultivar in the environments that fall within that particular sector. Thus, groups of sites that share the same best performers can be graphically identified. As observed in Figure 1, TZE-W DT STR C4 (TW4) was the vertex cultivar in Ejiba (07), Mokwa (09), Oke-Oyi (07), Ballah (07) & (08), and Kisi (07). TZE Comp 3 DT C0F2 (TZC) was the vertex cultivar in Kisi (08), Ilorin (08), Oke-Oyi (08), and Ejiba (08). Local check (CHK) was the vertex cultivar in Badeggi (09), Mokwa (10), Badeggi (10), Ilorin (07), (09) & (10) while TZE-Y DT STR C4 (TY4) was less responsive than the vertex cultivars.

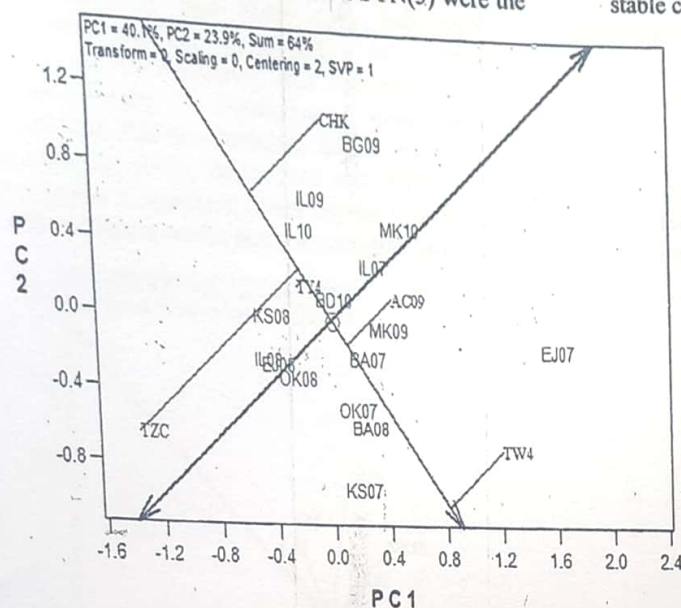
In the mean vs. stability view of the GGE biplot, the genotypes were ranked along the average-environment axis (AEC abscissa), with an arrow pointing to a greater value based on their mean performance across all environments. The double-arrowed line separates entries with below-average means from those with above-average means. The average yield of the cultivars is approximated by the projections of their markers on the average-tester axis. The stability of the

cultivars is measured by their projection onto the double arrowline (average-tester coordinate [ATC] y axis). The greater the absolute length of the projection of a cultivar, the less stable it is (Yan *et al.*, 2000; 2005; 2010; Yan, 2001). On the basis of this, TZE-W DT STR C4 (TW4) with a short vector pointing toward greater value based on the mean performance along the ATC was stable and the highest yielding genotype. This was followed by AC 90 Pool 16 DT STR (AC09) which was not only high yielding but stable genotype. On the other hand, TZE-Y DT STR C4 (TY4) with a shortest vector pointing toward lesser value based on the mean performance along the ATC was the most stable low yielding cultivar while TZE Comp 3 DT C0F2 (TZC) and local check (CHK) were not only low yielding but the least stable cultivars.

For the intermediate/late maturing group, the principal component (PC) axis 1 explained 54% of total variation; while PC2 explained 30.6% and, thus these two axes accounted for 84.6% of the total variation for grain yield (Fig. 2). In the polygon view of the biplot, TZLCOMP1-W C6 F2 (4) was the best (vertex cultivar) for Badeggi (09), Mokwa (09), Ballah (08), Ilorin (07), Kisi (07), Ilorin (09). TZB-SR (3) was the vertex cultivar for Oke-Oyi (07 and 08), Badeggi (10), Ballah (07), Mokwa (10), Kisi (08), White DT STR SYN (5) was the best for Ejiba (08) and Local Check (2) was the best for Ejiba (07), Ilorin (08) and (10). The trend for the mean vs. stability view of the GGE biplot was different as TZLCOMP1-W C6 F2 (4) was stable and the highest yielding

cultivar while Local check (2) was not only high yielding but the least stable cultivar. Both DT-SYN-1-W(1) and White DT STR SYN(5) were the

lowest yielding and the most stable cultivars while TZB-BR (3) was not only low yielding but the least stable cultivar.



CODE	PREDEGREE
TW4	TZE-W DT STR C4
CHK	Local check
TZC	TZE Comp 3 DT C0F2
TY4	TZE-Y DT STR C4
AC09	AC 90 Pool 16 DT STR

CODES	SITES
EJ	Ejiba
IL	Ilorin
OK	Oke-Oyi
BD	Badeggi
KS	Kisi
BA	Ballah
MK	Mokwa

Figure 2: Mean versus stability view of GGE biplot based on genotype x environment yield data of 5 early maturing DT maize varieties evaluated at 16 environments in southern Guinea savanna of Nigeria, in 2007 and 2010.

Table 2. Description of the test locations used in the study

Location	State	Latitude	Longitude	Altitude (m)	Rainfall (mm)
Ilorin	Kwara	8°30'0N	4°32'60E	289	1318
Oke-Oyi	Kwara	8°15'0N	4°58'60E	455	1250
Ejiba	Kogi	8°18'0N	5°37'60E	235	1168
Mokwa	Niger	9°16'60N	5°26'0E	87	1250
Kisi	Oyo	9°46'0N	3°51'0E	372	2000
Ballah	Kwara	13°22'0N	5°34'60E	249	1150
Badeggi	Niger	9°3'0N	6°9'0E	117	1300

Table 3: Sum of squares from combined (ANOVA) for grain yield (ton/ha) and other agronomic traits in 5 early maturing DT maize varieties evaluated in 16 environments in the southern Guinea savanna of Nigeria between 2007 and 2010.

Source	Df	Grain yield		Anthesis-silking-interval		Ears per plant	
			%SS		%SS		%SS
Rep	3	1.13	0.2	1.50	0.2	0.04	0.3
Environment (E)	15	200.02**	42.1	368.67**	57	6.44**	54.9
Genotype (G)	4	10.70**	2.3	7.09	1.1	0.06	0.5
G x E	60	119.69**	25.2	88.19**	13.6	0.88	7.6
Pooled Error	231	144.08	30.3	181.25	28	4.30	36.6
Corrected Total	311	475.11		646.59		11.72	
R-Square (%)		0.696		0.72		0.63	
CV (%)		27.07		31.44		15.44	

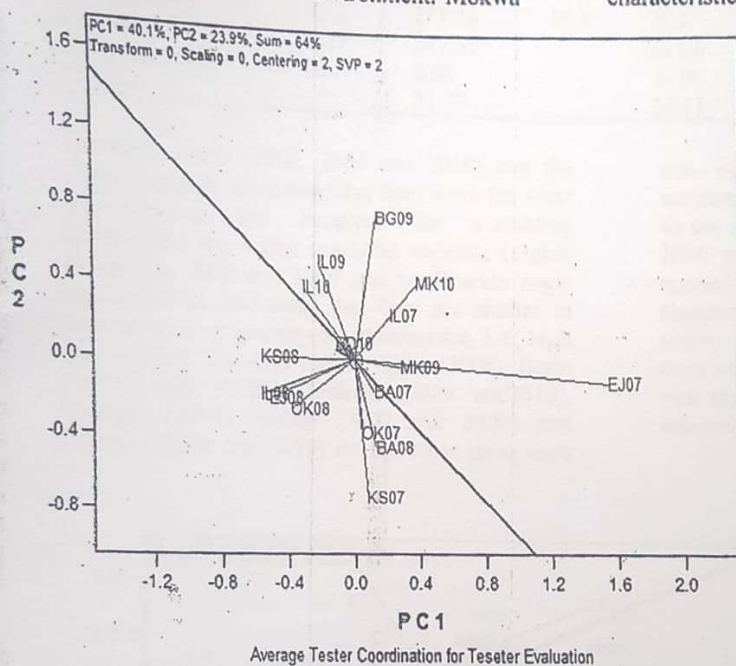
Discriminating power and representativeness of the test environments

The discriminating power versus representativeness view of GGE biplot analysis of the results of the test sites for the two maturity groups are presented in Figures 3 and 4. In the biplots, the vector length approximates the standard deviation in the environment. The longer the

vector, the more discriminating the environment. In addition, angle between vectors approximates the correlation coefficient between them. Therefore, two vectors with an acute angle between them showed positive correlation, vectors with angle 90° showed no relationship while vectors with angle greater than 90° indicate a negative correlation. The angle between an environment vector and the

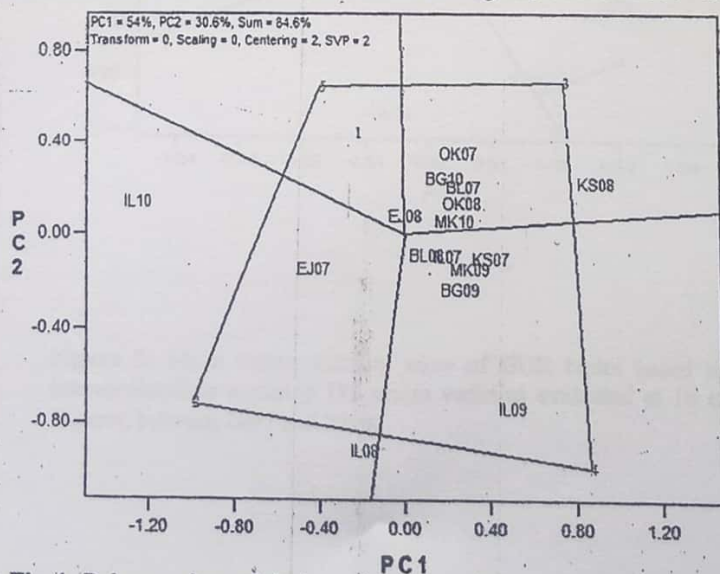
average environment axis (AEA) measures the representativeness of the environment. In the light of these, Ilorin (2007, 2009 and 2010) and Oke-Oyi (2007 and 2008) had small acute angles among them, suggesting that these sites had high repeatability and are representative of all test environments for evaluating early maturing maize varieties (Figure 1). Furthermore, results also showed that the two locations had a moderate discriminating ability. Ilorin (2007 and 2008) were also negatively correlated which implies that Ilorin (2008) was not a useful test environment. Mokwa

(2009), Ballah (2007) and Badeggi (2010) were not correlated with any of the other test environments as indicated by the shortest vector, which is an indication that they may not be useful test environments. Ejiba and Kisi with the least discriminating ability also had the least repeatability while Ballah (2007) with the shortest vector was the closest to the average environment axis (AEA) and was the most representative of all test environments. The ability to discriminate cultivars and represent the target region is the main characteristic of an ideal environment.



CODES	SITES
EJ	Ejiba
IL	Ilorin
OK	Oke-Oyi
BD	Badeggi
KS	Kisi
BA	Ballah
MK	Mokwa

Figure 3: Vector view of genotype main effect plus genotype by environment interaction (GGE) biplots showing the Discriminativeness and representativeness of 5 early maturing DT maize varieties evaluated at 16 environments in southern Guinea savanna of Nigeria, between 2007 - 2010



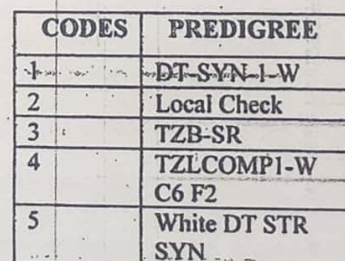
CODES	PREDIGREE
1	DT-SYN-I-W
2	Local Check
3	TZB-SR
4	TZLCOMP1-W C6 F2
5	White DT STR SYN

CODES	SITES
EJ	Ejiba
IL	Ilorin
OK	Oke-Oyi
BG	Badeggi
KS	Kisi
BL	Ballah
MK	Mokwa

Fig 4: Polygon view of the genotype main effect plus genotype by environment interaction (GGE) biplot of combined 5 intermediate/late maturing DT maize varieties evaluated at 16 environments in southern Guinea savanna of Nigeria, between 2007 and 2010.

Source	Df	Grain yield		Anthesis-silking-interval		Ears per plant	
		%SS	%SS	%SS	%SS	%SS	%SS
Rep	3	1.66	0.3	2.5	0.3	0.02	0.2
Environment (E)	15	302.66**	52.4	523.4**	60	6.69**	64.3
Genotype (G)	4	1.63	0.3	4.83	0.6	0.12	1.0
G x E	60	59.13	10.2	118.07**	13.5	0.83	7.6
Pooled Error						7.9	
Corrected Total	231	212.44	36.8	224	25.7	2.77	26.6
R-Square (%)	311	577.52		872.8		10.41	
CV (%)		0.63		0.74		0.73	
		31.27		34.11		11.44	

not correlated with any of the other test environments as shown by the shortest vector and so are not useful environment. However, Horn in 2009 was the closest to AEA and was the most representative of all the test environments, suggesting that it had the most discriminating ability along with high repeatability and was the most representative of all the test environments. It was also the closest to the ideal environment for this maturity group.



CODES	SITES
EJ	Ejiba
IL	Ilorin
OK	Oke-Oyi
BG	Badeggi
KS	Kisi
BL	Ballah
MK	Mokwa

Figure 5: Mean versus stability view of GGE biplot based on genotype x environment yield data of 5 intermediate/late maturing DT maize varieties evaluated at 16 environments in southern Guinea savanna of Nigeria, between 2007 and 2010.

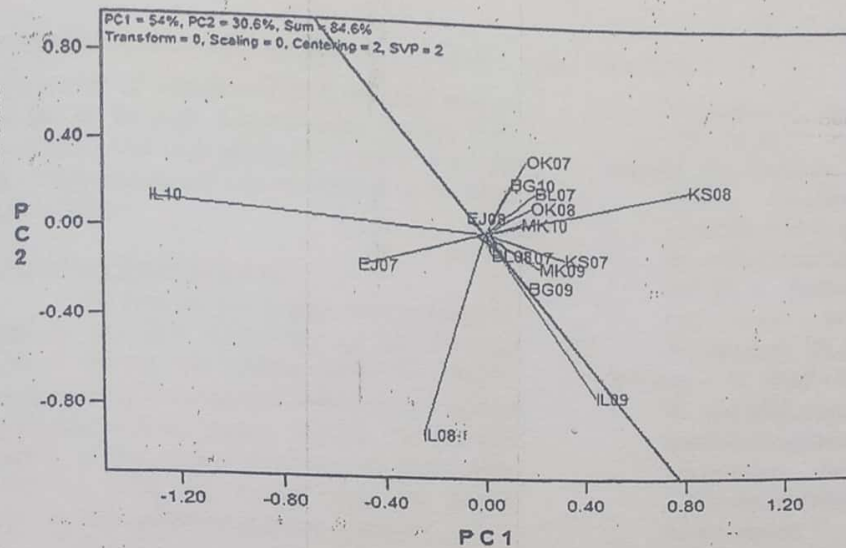


Figure 6: Vector view of genotype main effect plus genotype by environment interaction (GGE) biplots showing the Discriminativeness and representativeness of 5 intermediate/late maturing DT maize varieties evaluated at 16 environments in southern Guinea savanna of Nigeria, in 2007 and 2010.

DISCUSSION

There was a much wider range of environment (E) main effects over genotypic (G) main effects for both the early and the intermediate/late maturing group in this study, which shows the degree of the variability in the environmental factors of the testing sites. Apart from soil characteristics of different testing sites, other weather related parameters such as temperature and relative humidity as well as the amount and distribution of rainfall have been known to result in differential performance of test varieties (Olaoye and Omuoti, 2006). This finding is also in agreement with the reports from many multi-environment trials, (DeLacy *et al.*, 1996; Cooper *et al.*, 1996; Haussmann *et al.*, 2001; Badu-Apraku *et al.*, 2011a and b).

The low proportion explained by the biplots of early maturing varieties relative to that of the intermediate/late maturing is an indication of greater complexity among the genotypes and genotype $\times$ environment interaction (GEI). For example, any test environment with shorter vector is less informative compared to the one with longer vector and thus provide little or no information about the genotypes being tested. Consequently, such environment could be excluded when choosing test environments without losing any vital information. Furthermore, test environments with small angles relative to direction of AEA are more representative of the test environments than those that have large angles with it (Yan and Tinker, 2005), implying that the cosine of the angle between any environment vector and the AEA approximates the correlation coefficient between the genotype values in that environment and the genotype means across the environments (Yan *et al.*, 2007).

For selection for broad adaptation in maize production, an ideal genotype should have both high mean performance and high stability within a mega-environment (Badu-Apraku *et al.*, 2011a). Thus, for early maturing group TZE-W DT STR C4 (TW4) and TZLCOMP1-W C6 F2 (4) for intermediate/late maturing group were the highest yielding and most stable open pollinated cultivars (OPV). This implies that were highly consistent across the environment. They were closest to the ideal genotype and may be considered as best varieties. They are suitable for production in all the locations,

In multi-environment trials, the usefulness of the repeatability is in assessing the representativeness of the test locations over years and representativeness of a test site is a key factor for determining how it should be used in cultivar evaluation; assuming adequate discriminating ability (Yan *et al.* 2007). This suggests that Ilorin is a good testing site for intermediate/late maturing group, which is in agreement with the report of Bello *et al.*, (2012), which reported superiority in yield performance of intermediate/late maturing group compared to the early maturing group in Ilorin. In conclusion, the results of the present study indicated that for the early maturing group, TZE-W DT STR C4 and TZL COMP1-W C6 F2 for the intermediate/late maturing group, consistently demonstrated superiority for grain yield potential regardless of the environment where they were evaluated. Most of the locations used for evaluating early and intermediate/late maize maturing varieties were not very representative or discriminating. No core testing site was identified for any maturity group. However, Ilorin proved the most efficient location for evaluating the

performance of varieties of both maturity groups because of its high discriminating ability, high repeatability and high representativeness of all the test environments and was the closest to the ideal environment.

ACKNOWLEDGMENTS

The fund for this project was provided by Mellinda and Bill Gates through the Drought Tolerant Maize for Africa (DTMA) Project coordinated by International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. We are also grateful to the maize improvement programme (MIP) of IITA for backstopping the project activities with sufficient quantity of seeds.

REFERENCES

- Badu-Apraku, B and A.F. Lum (2010). The pattern of grain yield response of normal and quality protein maize cultivars in stressed and non-stressed environments. *Agronomy Journal* 102:381-394.
- Badu-Apraku, B, J.M. Fajemisin and A.O. Diallo. (1995). The performance of early and extra-early varieties across environments in West and Central Africa. In: Contributing to food self-sufficiency: Maize research and development in west and central Africa. B. Badu-Apraku, M.O. Akoroda, M. Ouderaogo and F.M. Quin (eds.). *Proceedings of a Regional Maize Workshop*, 29 May- 2 June 1995. Cotonou, Benin Republic: IITA. Pp. 149-159.
- Badu-Apraku, B., R.O. Akinwale, A. Menkir, K. Obeng-Antwi, A.S. Osuman, N. Coulibaly, J.E. Onyibe, G. C. Yallou, M.S. Abdullahi And A. Didjera (2011a). Use of GGE Biplot for Targeting Early Maturing Maize Cultivars to Mega-Environments in West Africa. *African Crop Science Journal*, 19 (2): 79 – 96.
- Badu-Apraku, B., M. Oyekunle, K. Obeng-Antwi, A. S. Osuman, S.G. Ado, N. Coulibay, C.G. Yallou, M. Abdullahi, G. A. Boakyewaa and A. Didjeira (2011b). Performance of extra-early maize cultivars based on GGE biplot and AMMI analysis. *Journal of Agricultural Science*, doi: 10.1017/S0021859611000761.
- Badu-Apraku, B, A.F. Lum, M.A.B. Fakorede, A. Menkir, Y. Chabi, C.The, M. Abdullahi, S. Jacob and S. Agbaje. (2008). Performance of early maize cultivars derived from recurrent selection for grain yield and *Striga* resistance. *Crop Science* 48:381-394.
- Bello O. B., Abdulmalik S. Y., Ige S. A., Mahamood J., Oluleye F., Azeez M. A., Afolabi M. S (2012). Evaluation of Early and Late/Intermediate Maize Varieties for Grain Yield Potential and Adaptation to a Southern Guinea Savanna Agro-ecology of Nigeria. *International Journal of Plant Research*, 2(2): 14-21
- Cooper, M., DeLacy, I. H. and Basford, K. E. (1996). Relationships among analytical methods used to analyze genotypic adaptation in multi-environment trials. In: M. Cooper and G. L. Hammer, (eds). *Plant adaptation and crop improvement*. CAB Int., Wallingford, UK. Pp 193-224.
- DeLacy, I. H., Basford, K. E., Cooper, M., Bull, J. K. and McLaren, C. G. (1996). Analysis of multi-environment trials- A historical perspective. In: M. Cooper and G. L.Hammer, (eds). *Plant adaptation and crop improvement*. CAB International, Wallingford, UK. Pp 39-124.
- Fakorede, M.A.B. and Adeyemo, M.O. (1986). Genotype $\times$ environment components of variance for three types of maize varieties in the rainforest zone of S.W. Nigeria. *Nigerian Journal of Agronomy* 1, 43-46.
- Haussmann, B.I.G, D.E. Hess, B.V.S. Reddy, S.Z. Mukuru, M. Kayento, H.G. Welzand H.H. Geiger (2001). Pattern analysis of genotype $\times$ environment interaction for *Striga* resistance and grain yield in African sorghum trials. *Euphytica* 122:297-308.
- Olaoye, G. and H. E. Omueti (2006). Evaluation of Short duration maize (*Zea mays* L.) varieties for adaptation to a typical Southern Guinea Savanna Ecology of Nigeria. *Journal of Agricultural Research and Development* 5(2): 97-111.
- Yan, W. and J.B. Holland (2010). A heritability-adjusted GGE biplot for test environment evaluation. *Euphytica* 171:355-369.
- Yan W, Kang, M.S., Ma. B., Woods. S. (2007). GGE biplot vs. AMMI analysis of genotype-by-environment data. *Crop Science* 47: 643-653.
- Yan, W. and Rajcan, I. (2002). Biplot evaluation of test locations and trait relations for breeding - superior soybean cultivars in Ontario. *Crop Science* 42:11-20.
- Yan, W., Hunt, L. A., Sheng, Q. and Szlavnic, Z. (2000). Cultivar evaluation and mega-environment investigation based on GGE biplot. *Crop Science* 40: 597-605.
- Yan, W. and Holland, J. B. (2010). A heritability-adjusted GGE biplot for test environment evaluation. *Euphytica* 171:355-369.