UNDER PEER REVIEW

Original research paper

AN ASSESSMENT OF TARO YIELD AND STABILITY USING AMMI AND GGE BIPLOT MODELS

ABSTRACT

The yield of eight taro (*Colocasia esculenta* (L) Schott) genotypes across two locations in two years was assessed using the Additive Main Effect and Multiplicative Interaction (AMMI) and Genotype and Genotype-by-Environment (GGE) biplot models. The results of combined analysis of variance for yield of the taro genotypes grown in 4 environments showed that yield was significantly affected by environments (E), genotypes (G) and genotype by environment interactions (GEI). Differences between genotypes and environments accounted for 24.13% and 56.41% of the total variation respectively while genotype x environment interaction accounted for 9.03% of the total variation. The first interaction principal component axis (IPCA) from the AMMI analysis accounted for 71.10% of variation due to GEI. The biplot accounted for 97.09% of the treatment sum of squares. Both AMMI and GGE models identified NCe 005, NCe 011 and NCe 010 as most stable, but NCe 010 with the highest yield was rated the best genotype across the environments. Igbariam 2013 was selected as favourable test environment for the taro yield multi-environment trial. The result showed that application of AMMI and GGE biplots facilitate visual comparison and identification of superior genotype for each target environment.

Keywords: Taro; genotype x environment interaction; selection and variation.

INTRODUCTION

Taro is an important traditional staple crop in rural African countries, but its contribution to food security is limited by lack of research on its agronomy and commercialization (Mare, 2009). It is a starchy tuber crop that has been widely cultivated and consumed in the south eastern zone of Nigeria for decades (Ndon *et al*., 2003). Nigeria is the world's largest producer of taro, ranking third among the nation's root and tuber crops after yam and cassava (FAO, 2007). Taro is an excellent multipurpose food crop for subsistence agriculture and

UNDER PEER REVIEW

home gardens but in recent years (2008 – 2012), yield has declined drastically due to the incidence of taro leaf blight (TLB) in the country (FAO, 2013). As such, it merits more attention in research focusing on yield as Ivancic and lebot (2000) earlier reported that taro yield is the most important goal in taro improvement.

Plant breeders carry out performance tests at different locations in different years in target areas in order to determine genotype stability, and data obtained from these tests are further used to determine the magnitude of G x E interactions. Some of the different methods that have been used in performing GEI analyses include additive main effects and multiplicative interaction model (AMMI), principal component analysis and linear regression analysis, analysis of variance (ANOVA) and Genotype and Genotype-by-Environment (GGE) biplot analysis (Abay *et al*., 2009; Miranda *et al*., 2009; Akcura *et al*., 2011; Mitrovic *et al.*, 2012). The ANOVA explains only main effects and gives no information on individual genotypes and localities, which are components of the interaction (Mitrovic *et al*., 2012) while AMMI analysis combines additive components in a single model for the main effects of genotype and environment as well as multiplicative components for the interaction effect. The graphic analyses bring out phenotypic stability, genotypic behaviour of the cultivars and environments that optimize performance (Miranda *et al*., 2009). It is useful in summarizing and approximating patterns of response which exist in the original data (Akcura *et al*., 2011). The GGE biplot analysis is another method which integrates the genotype and genotype by environment effects in the evaluation of cultivars. The GGE uses graphic axes to identify superior cultivars in the mega environments (Akcura *et al*., 2011). Mega environments comprise groups of environments which consistently share the same test cultivars (Abay *et al.*, 2009). GGE model also combines ANOVA and PCA by partitioning together sum of squares of genotypes and sum of squares of genotype by environment interaction using the PCA method. It is also used for the presentation and estimation of genotypes in different

UNDER PEER REVIEW

environments (Miranda *et al*., 2009). These two statistical tools (AMMI and GGE) have broader relevance for agricultural researchers because they pertain to any two-way data matrices, and such data emerge from many kinds of experiments (Narouirad *et al*., 2013).

Breeding for wide adaptation and for yield stability have sometimes been considered one and the same, insofar as the later term indicates a consistently good yield response across environments. It has also been widely acknowledged that only genotype × location (G x L) interaction, rather than all kinds of G x E interaction, is useful for depicting adaptation patterns, as only this interaction can be exploited by selecting for specific adaptation or by growing specifically adapted genotypes (Ghaderi *et al.*, 1980; Lin and Binns, 1994; Bowman, 1989; Annicchiarico, 1992, 1997; Romagosa and Fox, 1993; Piepho *et al.*, 1998). In particular, the analysis of multi-environment yield trials should focus primarily on G x L interaction with climatic, soil, biotic (pests and diseases) and crop management factors as characterizing features of the locations.

The objective of this study was therefore, to elucidate the yield stability of eight taro genotypes in four contrasting environments in Nigeria.

MATERIALS AND METHODS

The experiments were conducted at the National Root Crops Research Institute's farm at Igbariam (Latitude 06°15'N; Longitude 06°52'E; Alt. 81 m) and Michael Okpara University of Agriculture teaching and research farm, Umudike (Latitude 05º29'N; Longitude 07º33'E; Alt. 122 m) in 2013 and 2014 cropping seasons. Umudike is in the humid tropics and has a total rainfall of about 2177 mm per annum, annual average temperature of about 26^0C. The predominant vegetative type is rain forest (NEST, 1991), while the soil is a sandy loam ultisol (Agboola, 1979). The rainfall pattern is bimodal. A long wet season from April to October/early November is interrupted by a short “August break”. Dry season stretches from early November to March. Igbariam has no distinct temperature seasons; the temperature is

UNDER PEER REVIEW

relatively constant during the year. The vegetation is classified as a derived savanna, with a tropical moist forest biozone. The soil in the area is high in acrisols, alisols, plinthosols (ac), acid soil with clay-enriched lower horizon and low base saturation (FDALR, 1985).

Eight (8) genotypes of taro (*Colocasia esculenta* L. Schott) obtained from National Root Crops Research Institute, Umudike were used (Table 1).

Table 1: The genotypes and their common/local names

S/N	Genotype	Common/local name
1	NCe 001	Cocoindia
2	NCe 002	Ede ofe green
3	NCe 003	Ede ofe purple
4	NCe 005	Ukpong
5	NCe 010	Akiri
6	NCe 011	Akpahiri
7	NCe 012	Akiri mgbawa
8	Local variety	Ede Orba

The experiment was laid out in a randomized complete block design with three replications in each location. Each observation plot measured 4m by 4m, with plant spacing of 50cm x 100cm (intra and inter spacing; 20,000 plants/ha). Weed control was carried out manually while basal fertilizer application was done at 6 weeks after planting (WAP) using NPK 15:15:15 at rate of 450kg/ha.

Data were obtained on taro yield and subjected to analysis of variance using the GenStat Discovery 12th edition (GenStat, 2009). The AMMI model was analyzed using the same statistical package. The GGE Biplot was analysed with R statistical package (R Core Team, 2013). In the analyses, each combination between the two locations and the two years was considered as an environment giving rise to four environments, thus; Umudike, 2013 (E1), Umudike, 2014 (E2), Igbariam, 2013 (E3) and Igbariam, 2014 (E4).

UNDER PEER REVIEW

RESULTS

AMMI Analysis

Effects of genotype, environment and genotype by environment interaction (GEI) on the taro tuber yield were highly significant (P<0.01) (Table 2). Genotype and environment captured about 24.13% and 56.41% of the variation respectively, while the GEI accounted for 9.0% of the variation and this partitioned between the first two interaction principal component axes (IPCAs). High effective partitioning of the interaction sum of squares by AMMI was observed as the mean square for the first IPC axis was more than 10 times the mean square for the residual. The IPCA1 was highly significant and accounted for 71.10% of the total variation in the GEI sum of squares (SS). The IPCA2 was significant (P<0.05) and captured 25.74% of the total variation in the GxE interaction SS. Therefore, the two PCA axes jointly accounted for 96.84% of the interaction SS, leaving 3.16% of the variation in the GEI to the residuals.

Table 3 revealed differential yield ranking of the genotypes across the four environments. Mean tuber yield ranged from 4.24 t/ha for NCe 005 to 9.67 t/ha for NCe 010 with an overall mean yield of 7.33 t/ha. NCe 010 had the highest tuber yield in three out of the four environments while NCe 002 gave the highest yield in the remaining environment. Four of the genotypes (50%) yielded above the overall genotype average, out of which NCe 010, NCe 012 and NCe 003 yielded consistently above the environment averages. NCe 005 yielded consistently below average in all the environments. The highest yield was obtained from Umudlike 2014, though with a negative interaction effect. The remaining environments had below average yield performances. Across the environments, NCe 010 had the highest yield of 9.67t/ha with IPCA1 score of 0.21. “Ede Orba” had the largest positive interaction of 1.30 while NCe 001 recorded the highest negative interaction of -1.22. Umudike 2014 had the

UNDER PEER REVIEW

highest negative IPCA1 score of -1.88 while Igbariam 2014 had the highest positive IPCA1 score of 0.76.

From the AMMI biplot, even though NCe 005, NCe 011 and NCe 010 differed in yield, they appeared to have similar magnitude of positive specific interactions with all the environments except Umudike 2014 (Figure 1). NCe 001 had a positive interaction with Umudike 2014 and a below average mean yield. The biplot showed that NCe 002, NCe 012, NCe 003, and NCe 010 were above average for taro yield. The IPCA1 score of NCe 010 is closest to zero and thus was the most stable taro genotype. This was followed by NCe 005, though with a relatively low yield.

Table 2: AMMI Analysis of variance for taro yield (tha^{-1}) of 8 taro genotypes grown at 4 environments (combination of 2 locations and two years)

Source	DF	SS	MS	%Total SS	% Interaction
Treatments	31	940.3	30.33**	89.57	
Genotypes	7	253.3	36.19**	24.13	
Environments	3	592.2	197.40**	56.41	
Block	8	27.1	3.39*		
Interactions	21	94.8	4.51**	9.03	
IPCA	9	67.4	7.49**		71.10
IPCA	7	24.4	3.48*		25.74
Residuals	5	3.0	0.61		3.16
Error	56	82.4	1.47		
Total	95	1049.8	11.05		

UNDER PEER REVIEW

Table 3: AMMI Analysis showing mean yield of eight taro genotypes across four environments with their IPCA1 scores

Environment	NCe 001	NCe 002	NCe 005	NCe 010	NCe 011	NCe 012	NCe 003	EdeOrba	Means	IPCAe1
Umudike2013	4.81	9.12	3.54	9.06	5.46	6.58	7.45	5.71	6.47	0.64
Umudike2014	12.73	10.81	7.96	13.53	10.48	13.36	15.01	8.33	11.52	-1.88
Igbariam2013	3.6	4.96	2.17	6.91	5.43	5.43	6.59	5.31	5.05	0.47
Igbariam2014	3.92	5.8	3.29	9.19	6.21	6.97	7.75	6.96	6.26	0.76
Means	6.26	7.67	4.24	9.67	6.89	8.08	9.20	6.58	**7.325**	
IPCAg1	-1.22	0.56	0.25	0.21	0.31	-0.56	-0.85	1.30		

Note: IPCAg1 = IPCA1 scores for the genotypes; IPCAe1 = IPCA1 scores for the environments.

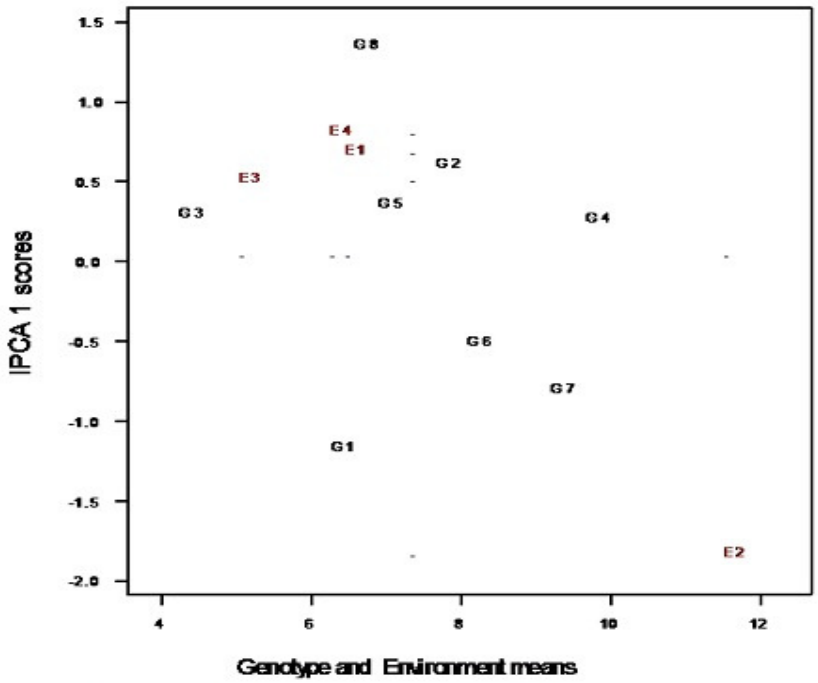
GGE biplot analysis

Principal Component 1 and Principal Component 2 jointly accounted for 92.55% (PC1=74.06%, PC2=18.49%) of the total variation relative to the genotypes and their interactions with the environments (i.e G + GE). Figure 2 displays a polygon view of eight taro genotypes evaluated at four environments. Igbariam 2013 was closest to the biplot origin while Umudike 2014 was farthest. Three of the sectors (sector 3, 4 and 5) in the pentagon had no test environment. Sectors 1 and 2 had NCe 010 and NCe 003 as their vertex genotypes respectively. Nce 010 won in three environments (Igbariam 2013, Umudike 2013 and Igbariam 2014) while Nce 003 won in Umudike 2014. The ranking of taro genotypes for both mean yield and stability performance across the four environments is shown in Figure 3. NCe 010, with the highest mean yield, was the most stable and ranked closest to the "ideal genotype". In terms of closeness to the "ideal genotype", NCe 010 was followed by Nce 003. NCe 005 closely followed NCe 010 in terms of stability but ranked farthest away from the "ideal genotype". For the environments, the biplot showed that Igbariam 2013 is the "ideal environment" while Umudike 2014 ranked farthest away from the "ideal environment".

An important aspect of test environment evaluation is its representativeness of the mega-environment. The smaller the angle with the abscissa of the average environment, the more

UNDER PEER REVIEW

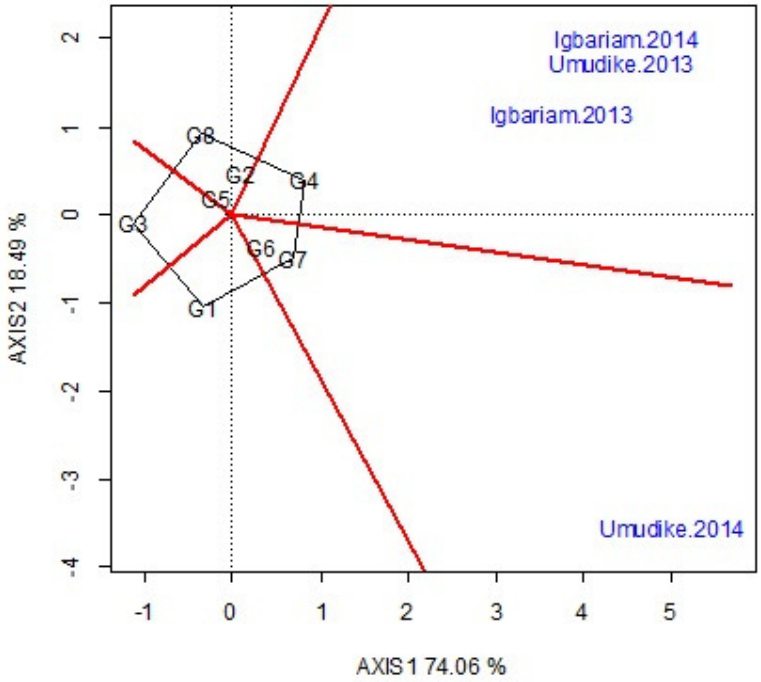
representative the test environment would be. Igbariam 2013 had the smallest angle with the abscissa of the average environment and it was considered the most representative for taro yield (Figure 4).



E1 = Umudike 2013, E2 = Umudike 2014, E3 = Igbariam 2013, E4 = Igbariam 2014; G1 = NCe 001, G2 = NCe 002, G3 = NCe 005, G4 = NCe 010, G5 = NCe 011, G6 = NCe 012, G7 = NCe 003, G8 = 'Ede Orba".

Figure 1: The AMMI biplot (IPCA1 vs mean) for taro yield (t/ha) of 8 genotypes across 4 environments

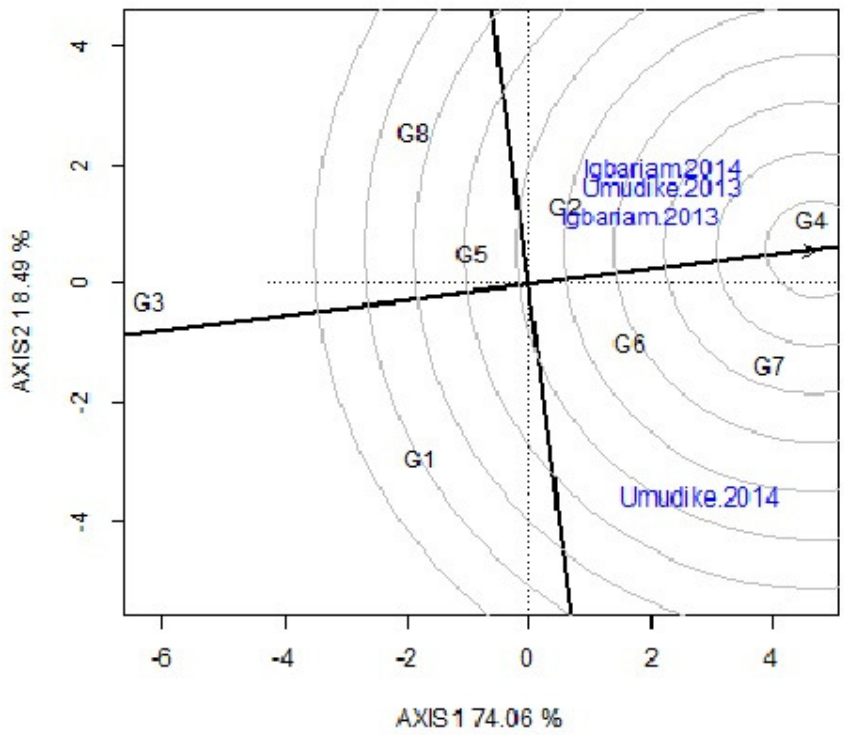
UNDER PEER REVIEW



E1 = Umudike 2013, E2 = Umudike 2014, E3 = Igbariam 2013, E4 = Igbariam 2014; G1 = NCe 001, G2 = NCe 002, G3 = NCe 005, G4 = NCe 010, G5 = NCe 011, G6 = NCe 012, G7 = NCe 003, G8 = "Eda Orba".

Figure 2: Polygon view of the GGE biplot showing which taro genotype won in which environment

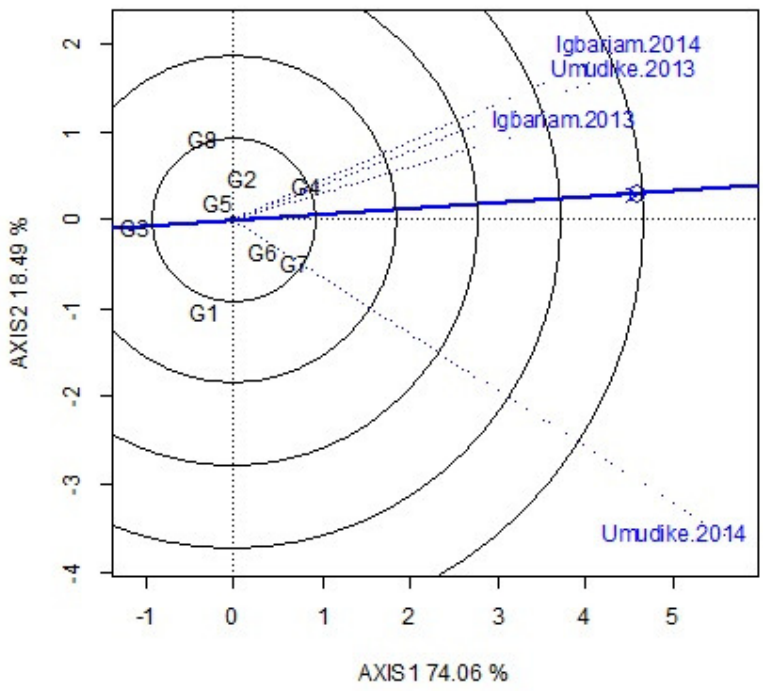
UNDER PEER REVIEW



G1 = NCe 001, G2 = NCe 002, G3 = NCe 005, G4 = NCe 010, G5 = NCe 011, G6 = NCe 012, G7 = NCe 003, G8 = "Edeoorba".

Figure 3: Ranking genotypes and environments based on both mean and stability relative to an ideal genotype and ideal environment respectively

UNDER PEER REVIEW



G1 = NCe 001, G2 = NCe 002, G3 = NCe 005, G4 = NCe 010, G5 = NCe 011, G6 = NCe 012, G7 = NCe 003, G8 = "Ede Orba".

Figure 4: The discrimination and representativeness view of the GGE biplot to show the discriminating ability and representativeness of the test environments

DISCUSSION

Farmers are interested in cultivars that produce consistent yields under their growing conditions and this is one of the major goals of plant breeders (Adugna and Labuschagne, 2002). Hence, the information on GxE interaction and stability will be of paramount importance for taro breeders and farmers under a set of environments. The presence of GEI makes it difficult for breeders to decide which genotypes should be selected. There is need to select for stability whenever such interactions assume a practical importance in a testing programme (Makinde *et al*., 2013). High significant year x location x genotype interaction observed for yield clearly demonstrates that genotype by environment interaction across the environments clearly plays a significant role in this crop. This is in line with the work

UNDER PEER REVIEW

performed by Anley *et al.* (2013). Tripathi *et al*. (1987) reported that the significant GxE interaction indicates that genotypes (G) responded differently to a change in the environment. Genotype main effect and genotype by environment interaction (GEI) are the two sources of variation that are relevant to genotype evaluation and should be considered simultaneously for appropriate genotype evaluation (Yan and Tinker, 2006; Sabaghnia *et al*., 2008).

To understand GEI, two types of biplots, the AMMI biplot (Crossa, 1990; Gauch, 1992) and the GGE biplot (Yan *et al*., 2000; Yan and Kang, 2003) are the most commonly used. The two biplots were used in this study to determine the GEI of the genotypes across environments. The taro genotypes exhibited different level of stability for yield. In terms of stability, the estimations of both AMMI and GGE biplot models were similar. They showed that NCe 010 was the most stable genotype across the test environments followed by NCe 005. NCe 001 and "Ede Orba" were the most unstable genotyes across the environments. GGE biplot and AMMI biplot models indicated NCe 010 and Umudike 2014 as the highest yielding genotype and environment respectively. NCe 010 was very close to the "ideal genotype" which might have resulted from its relative high stability and yield of the genotype. Yan and Kang (2003) defined "ideal genotype" as one that is the highest yielding across the test environments. In terms of closeness to the "ideal environment" as indicated by the GGE biplot, Igbariam 2013 ranked closest. GGE and AMMI methods were adequate to explain the GEI in taro. However, the GGE biplot provides more useful information than AMMI through its discriminating power, representativeness view (as shown in Figure 4) and mega-environment analysis in evaluation of test environments. Superiority of GGE biplot over AMMI model has been reported (Yan *et al*., 2007; Alake and Ariyo, 2012).

CONCLUSION

Farmers in developing countries such as Nigeria who use limited inputs for growing taro under harsh and unpredictable environments will need stable varieties. As a result, genotype

UNDER PEER REVIEW

with good yield performance and stability should be recommended. This study showed that both GGE and AMMI methods were adequate to explain the GEI in taro. Both methods indicated NCe 010 as the preferred genotype as it was the best both in yield performance and yield stability. In the GGE biplot ranking, it ranked closest to the ideal genotype. Therefore, this genotype is suitable for cultivation in these agro-ecological zones and could be utilized as a good breeding material in developing taro varieties with high adaptation.

REFERENCES

Abay F., Bjornstad A. (2009): Specific adaptation of barley varieties in different locations in Ethiopia. Euphytica 167, 181-195.

Adugna W., Labuschagne M. T. (2002): Genotype-environment interactions and phenotypic stability analyses of linseed in Ethiopia. Plant Breeding 121, 66-71.

Agboola S. A. (1979): An agricultural atlas of Nigeria, Oxford University Press.

Akcura M., Taner S., Kaya Y. (2011): Evaluation of bread wheat genotypes under irrigated multi-environment conditions using GGE biplot analyses. Agriculture 98 (1): 35-40.

Alake C. O, Ariyo O. J. (2012): Comparative Analysis of Genotype × Environment Interaction Techniques in West African Okra, (*Abelmoschuss caillei,* A. Chev Stevels). Journal of Agricultural Science 4 (4): 135-150.

Anley W., Zeleke H., Dessalegn Y. (2013): Genotype x environment interaction of maize (*Zea mays* L.) across North Western Ethiopia. Journal of Plant Breeding and Crop Science 5 (9): 171-181.

Annicchiarico P. (1992): Cultivar adaptation and recommendation from alfalfa trials in northern Italy. Journal of Genetics and Breeding 46, 269-278.

Annicchiarico P. (1997): Additive main effects and multiplicative interaction (AMMI) of genotype-location interaction in variety trials repeated over years. Theoretical and Applied Genetics 94, 1072-1077.

Bowman D. T. (1989): Statistical procedures to measure population variation. In: Stalker H. T., Chapman C. (eds.) Scientific management of germplasm: characterization, evaluation and enhancement, p. 65-73. Rome, International Board for plant Genetic Resources.

Crossa J. (1990): Statistical analyses of multilocation trials. Advances in Agronomy 44, 55-85.

UNDER PEER REVIEW

FDALR (1985): The reconnaissance soil survey of Sokoto state, Nigeria. Soil report. Federal Department of Agriculture Land Resources, Kaduna.

Food and Agricultural Organization (2007): FAOSTAT statistics division of the Food and Agriculture Organization, http://faostat.fao.org.

Gauch H. G. (1992): AMMI analysis of yield trials. In: Kang M. S., Gauch H. G. (eds.) Genotype-by- environment interaction. CRC Press, Boca Raton, p. 1–40.

GenStat (2009): GenStat 12th Edition. VSN International bioscience software and consultancy. Hemel Hempstead, HP2 4TP UK.

Ghaderi A., Everson E. H., Cress C. E. (1980): Classification of environments and genotypes in wheat. Crop Science 20, 707-710.

Ivancic A., Lebot V. (2000): The genetics and breeding of taro. Séries Repères, CIRAD, Montpellier, 194p.

Lin C. S., Binns M. R. (1994): Concepts and methods for analysis of regional trial data for cultivar and location selection, Planting Breeding Reviews 12, 271–297.

Makinde S.C.O., Ariyo, O. J., Akinbowale R. I. (2013): Assessment of groundnut performance in different environments using Additive Main effects and Multiplicative Interaction (AMMI) model. Canadian Journal of Plant Breeding 1 (2): 60-66.

Mare R. M. (2006): Phytotron and field performance of taro [*Colocasia esculenta* (L.) Schott] landraces from Umbumbulu. M.Sc. Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Miranda G. V., Souza L. V., Guimarães L. J. M., Namorato H. L., Oliveira R., Soares M. O. (2009): Multivariate analyses of genotype × environment interaction of popcorn. Pesquisa Agropecuaria Brasileira 44 (1): 45-50.

Mitrovic B., Stanisavljevic D., Treski S., Stojakovic M., Ivanovic M., Bekavac G., Rajkovic M. (2012): Evaluation of experimental Maize hybrids tested in Multi-location trials using AMMI and GGE biplot analysis. Turkish Journal of Field Crops 17 (1): 35-40.

Naroui Rad M.R., Abdu Kadir M., Rafii M.Y., Jaafar H.Z.E., Naghavi M.R., Ahmadi F. (2013): Genotype × environment interaction by AMMI and GGE biplot analysis in three consecutive generations of wheat (*Triticum aestivum*) under normal and drought stress conditions. Australian Journal of Crop Science 7 (7): 956-961.

NEST (Nigeria Environmental Study Action /Team). (1991). Nigeria's Threatened Environment: A National Profile. Nigeria: NEST.

Ndon B. A., Ndulaka N. H., Ndaeyo N. U. (2003): Stabilization of yield parameters and some nutrient components in cocoyam cultivars with time in Uyo, southern Nigeria. Global Journal of Agricultural Sciences 2, 74-78.

UNDER PEER REVIEW

Okpul T. (2005): Effect of variety × site on corm yield, leaf blight resistance and culinary quality of seven taro, *Colocasia esculenta* (L.) Schott, varieties in Papua New Guinea. Master of Science Thesis, University of Technology, Lae, Papua New Guinea.

Piepho H. P., Denis J. B., van Eeuwijk F. A. (1998): Predicting cultivar differences using covariates. Journal of Agricultural, Biological, and Environmental Statistics 3, 151-162.

R Core Team (2013): R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URLhttp://www.R-project.org/.

Romagosa I., Fox P. N. (1993): Genotype x environment interaction and adaptation. In Hayward M. D., Bosemark N. O., Romagosa I. eds. Plant breeding, principles and prospects. p. 374-390. Chapman and Hall, London, UK.

Sabaghnia N., Dehghani H., Sabaghpour S. H. (2008): Graphic analysis of genotype by environment interaction for lentil yield in Iran. Agronomy Journal 100, 760–764.

Tripathi B. K., Gill S. S., Misra G. P. (1987): Genotype x environment interaction and stability analysis in sugarcane *(Saccharum* spp. Hybrids). Indian Journal of Genetics 47 (3): 271-274.

Yan W., Kang M. S. (2003): GGE biplot analysis: a graphical tool for breeders, geneticists, and agronomists. CRC Press, Boca Raton.

Yan W., Tinker N. A. (2006): Biplot analysis of multi-environment trial data: principles and applications. Canadian Journal of Plant Science 86, 623–645.

Yan W., Hunt L.A., Sheng Q., Szlavnics Z. (2000): Cultivar evaluation and mega-environment investigations based on the GGE biplot. Crop Science 40: 597-605.

Yan W., Kang M. S, Ma B., Woods S., Cornelius P. L. (2007): GGE biplot*vs*.AMMI analysis of genotype-by-environment data. Crop Science 47: 643-655.